

Japanese Steel Industry's Challenge toward Carbon Neutral Steelmaking



Hydrogen Utilization in Iron and Steelmaking Processes Project
by Green Innovation Fund called GREINS project



JFE Steel Corporation

March 10, 2026

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GREINS Project

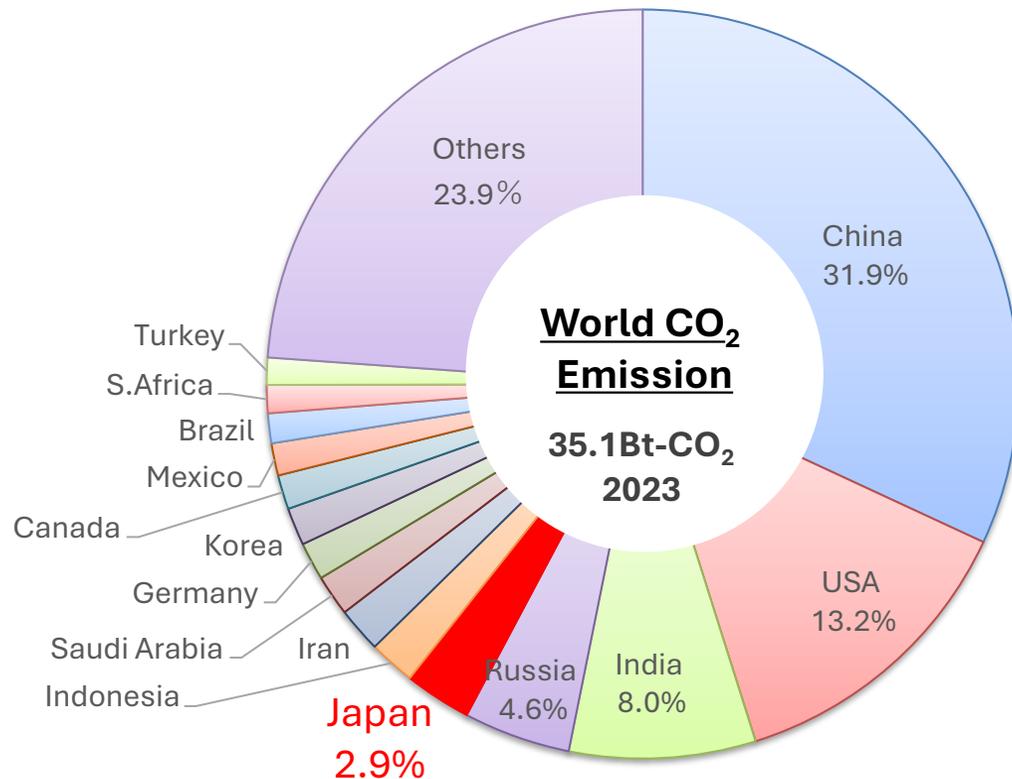
*: JFE Steel Corporation

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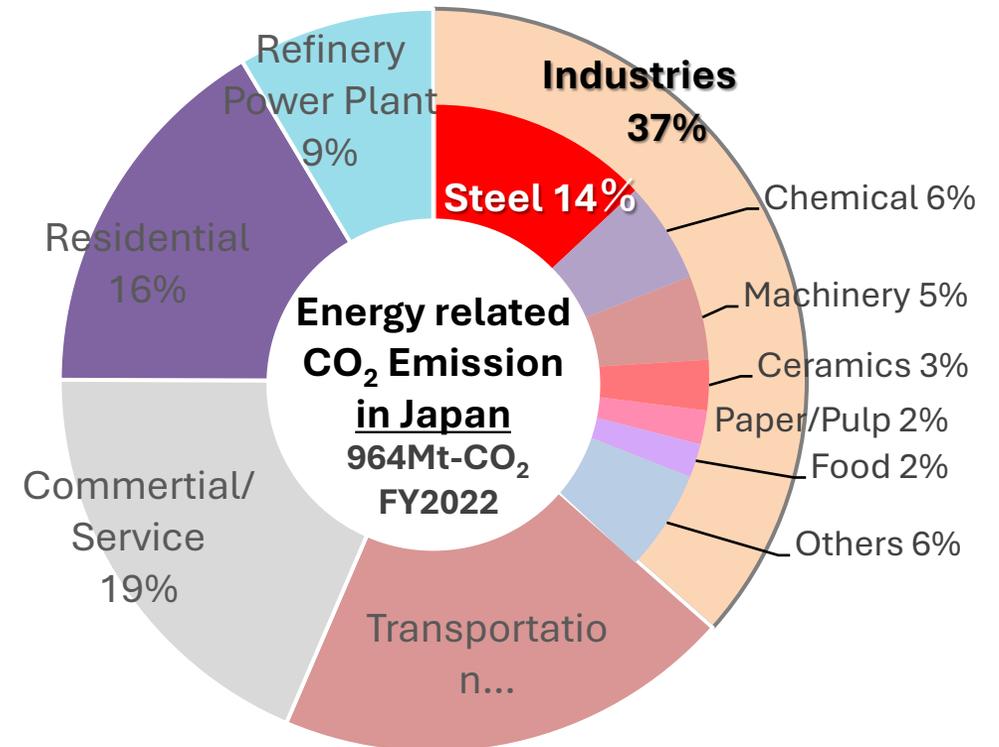
- ✓ **Overview of development of hydrogen reduction steelmaking aimed at reducing CO₂ emissions in Japan**
- ✓ Significance of multi-pathway process development
- ✓ Developing technologies towards carbon neutrality

Global and Japanese CO₂ Emissions

- ✓ Japan is the fifth largest CO₂ emitter in the world, and **almost 3%**.
- ✓ **14%** of whole domestic CO₂ emission is discharged **from steel industry in Japan**.
- ✓ **Since 2008**, the **Japanese steel industry** has been **working on technology development aimed at reducing CO₂ emissions** from steelworks.



After GLOBAL NOTE® HP; original source: IEA
<https://www.globalnote.jp/post-3235.html>



Based on data from *National Greenhouse Gas Inventory Document of JAPAN(2024)*.
<https://www.nies.go.jp/gio/aboutghg/index.html>

Development of Hydrogen Reduction Steelmaking Aimed at reducing CO₂ emissions in Japan

COURSE 50

2008: A project called **COURSE50** started development of **blast furnace hydrogen reduction technology**.

COURSE50 means CO₂ Ultimate Reduction System for Cool Earth 50 .

2017: It was confirmed for the first time in the world that it is possible to reduce CO₂ by more than 10% in blast furnaces through hydrogen reduction technology using an experimental blast furnace.

GREINS
Green Innovation in Steelmaking

2021: **Hydrogen Utilization in Iron and Steelmaking Processes project started.**

This is a **Multi-pathway process development project** called **GREINS** (Green Innovation in Steelmaking).

- Blast furnace process
- Direct reduction process
- Electric arc furnace process
- Electric smelting furnace process (started in 2024)

Both **COURSE50** and **GREINS** are **funded by** the New Energy and Industrial Technology Development Organization (**NEDO**).

<https://www.greins.jp/en/message/message01/>

Organization

✓ This project is carried out by **the Hydrogen Steelmaking Consortium.**

Four partners

Hydrogen Steelmaking Consortium



Nippon Steel Corporation, JFE Steel Corporation, Kobe Steel and JRCM
(The Japan Research and Development Center for Metals)

The consortium conducts **joint research with 14 research institutes.**

Joint research institutes

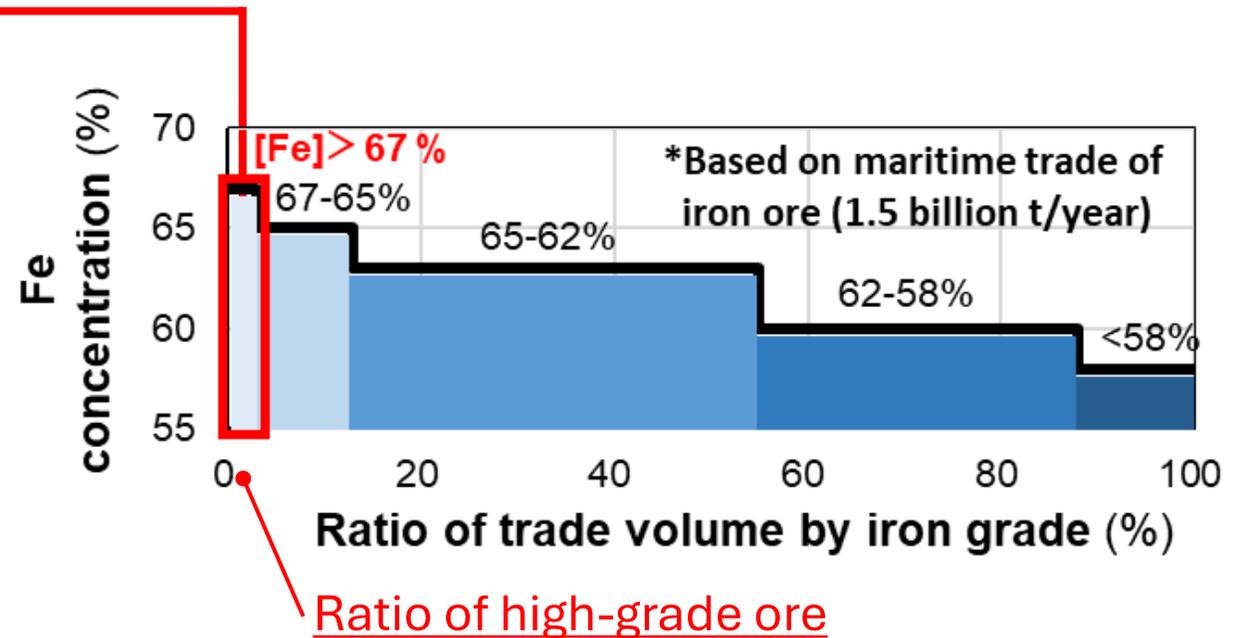
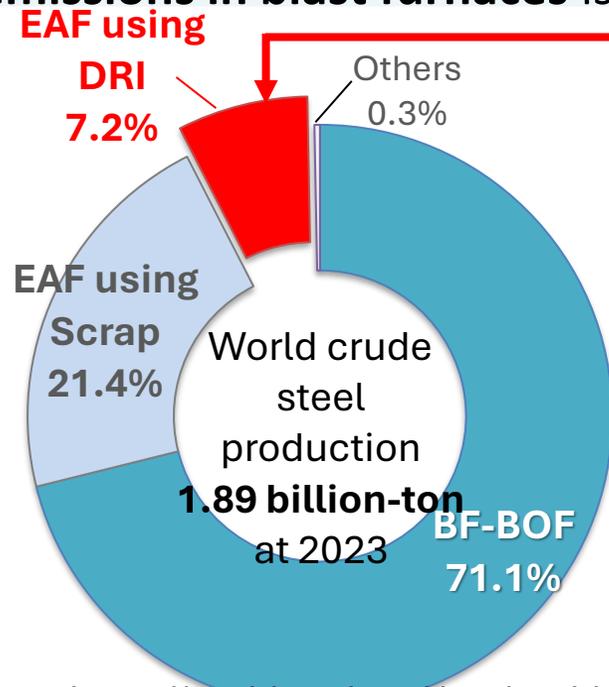
- HOKKAIDO University
- Central Research Institute of Electric Power Industry (CRIEPI)
- WASEDA University
- University of TOYAMA
- College of Industrial Technology
- OSAKA University
- NIPPON Institute of Technology
- TOHOKU University
- The University of TOKYO
- Institute of Science Tokyo
- KYOTO University
- Research Institute of Innovative Technology for the Earth (RITE)
- KYUSHU University
- National Institute of Technology (KOSEN), Suzuka College

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- ✓ Overview of development of hydrogen reduction steelmaking aimed at reducing CO₂ emissions in Japan
- ✓ **Significance of multi-pathway process development**
- ✓ Developing technologies towards carbon neutrality

What kind of steelmaking process in the near future ?

- ✓ Although **direct reduced iron using natural gas** is commonly produced , it **requires** the use of **high-grade ore**.
- ✓ Since the **amount of high-grade ore** for direct reduced iron is **limited**, the **use of low-grade ore** will be **essential in the future**.
- ✓ It is **currently difficult** to produce **high-grade steel** by electric arc furnace, therefore **steel production using blast furnaces** will continue in the future.
- ✓ In Asia, the **BF-BOF** route relying on **low-grade ore** is **predominant**, thus development of a **massive reduction of CO₂ emissions in blast furnaces** is necessary.



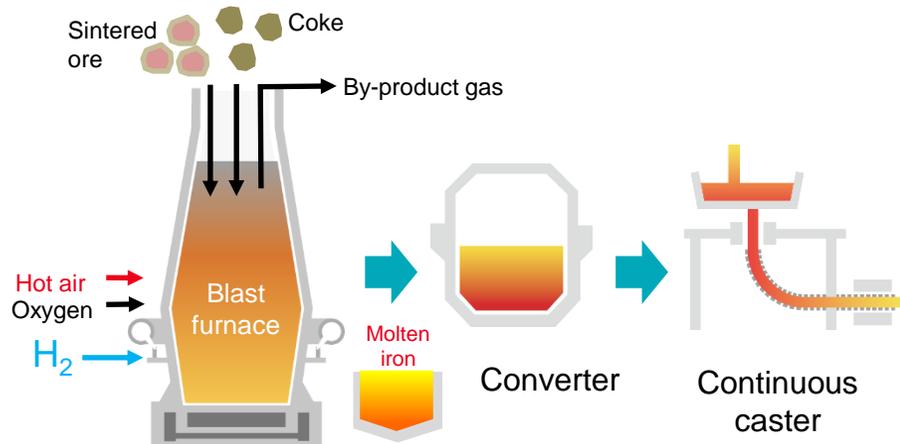
Based on data from <https://worldsteel.org/data/world-steel-in-figures-2024/>

Source : G.Wimmer et.al.: Feramu (in Japanese), 27(2022),p.19

Significance of Multi-pathway process development

- ✓ **High-grade steel production by a carbon-neutral** steelmaking process has **not yet** been established.
- ✓ In the project, we are **pursuing** development of the **blast furnace-converter** process and the **direct reduction-electric arc furnace & electric smelting furnace** process.

Hydrogen reduction technology using blast furnace



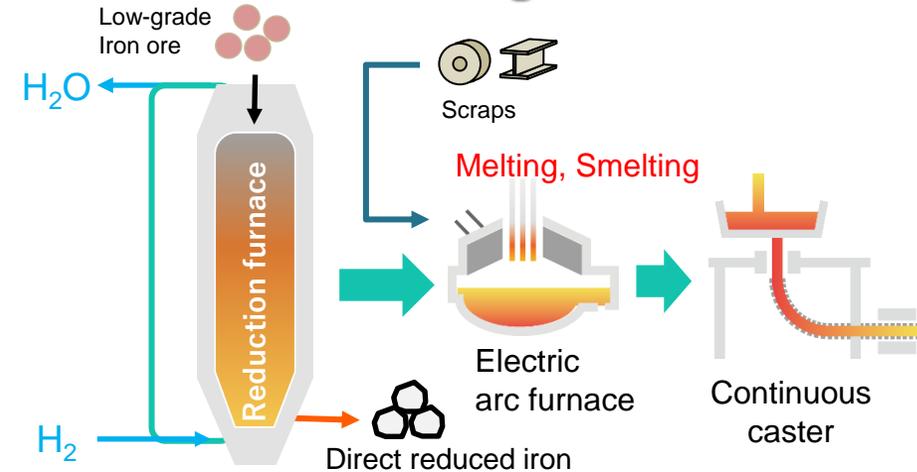
Merits

- Usage of low-grade iron ore
- Production of high-grade steel

Subjects

- CCUS is indispensable for carbon neutrality

Hydrogen direct reduction technology to use low-grade iron ore



Merits

- Carbon-neutral steelmaking process with sufficient supply of green hydrogen and green power

Subjects

- Usage of low-grade iron ore
- Production of high-grade steel

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- ✓ Overview of development of hydrogen reduction steelmaking aimed at reducing CO₂ emissions in Japan
- ✓ Significance of multi-pathway process development
- ✓ **Developing technologies towards carbon neutrality**

Research and development items of the project

1. Development of hydrogen reduction technology using blast furnaces

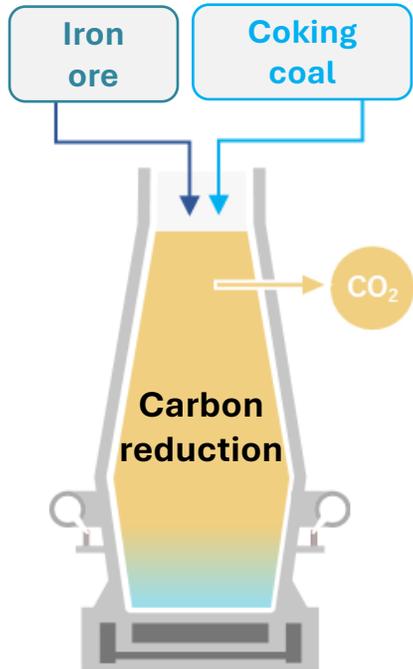
- ① **Development of hydrogen reduction technology using hydrogen from within steelworks**
 - Direct use of Hydrogen : **COURSE50 BF**
- ② **Development of low-carbon technologies using external hydrogen and CO₂ from BF gas**
 - Direct use of Hydrogen : **Super COURSE50 BF**
 - Indirect use of Hydrogen: **Carbon Recycling BF**

2. Development of hydrogen direct reduction technology to reduce low-grade iron ore

- ① **Development of hydrogen direct reduction technology**
 - Direct use of Hydrogen : **Hydrogen direct injection shaft furnace**
 - Indirect use of Hydrogen: **Carbon recycling shaft furnace**
- ② **Development of **electric arc furnace for high-grade steel** production**
- ③ **Development of **electric smelting furnace for hot metal** production**

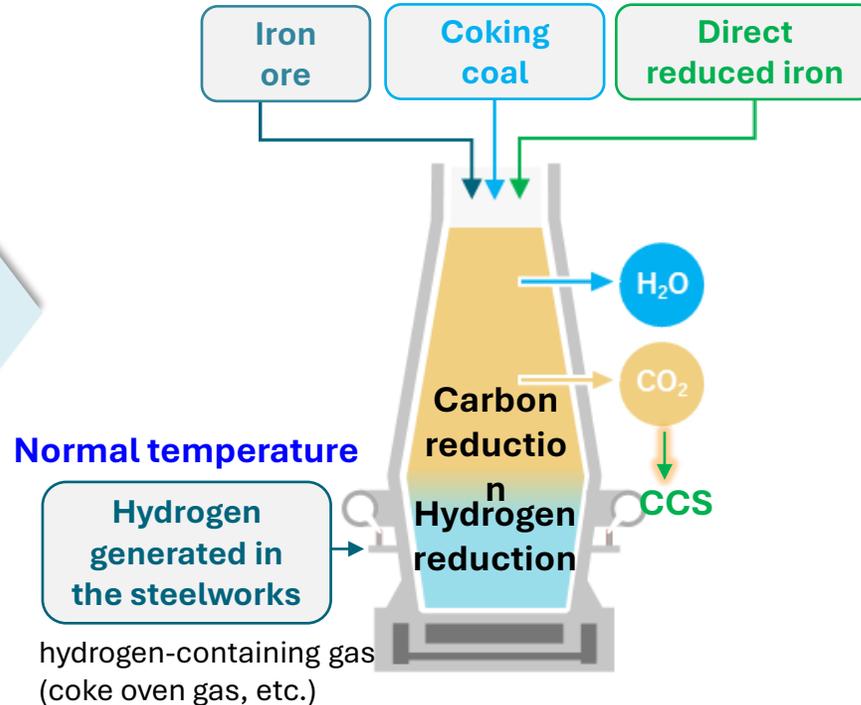
Hydrogen reduction technology using blast furnaces: Direct use of hydrogen

Conventional blast furnace



COURSE50 blast furnace

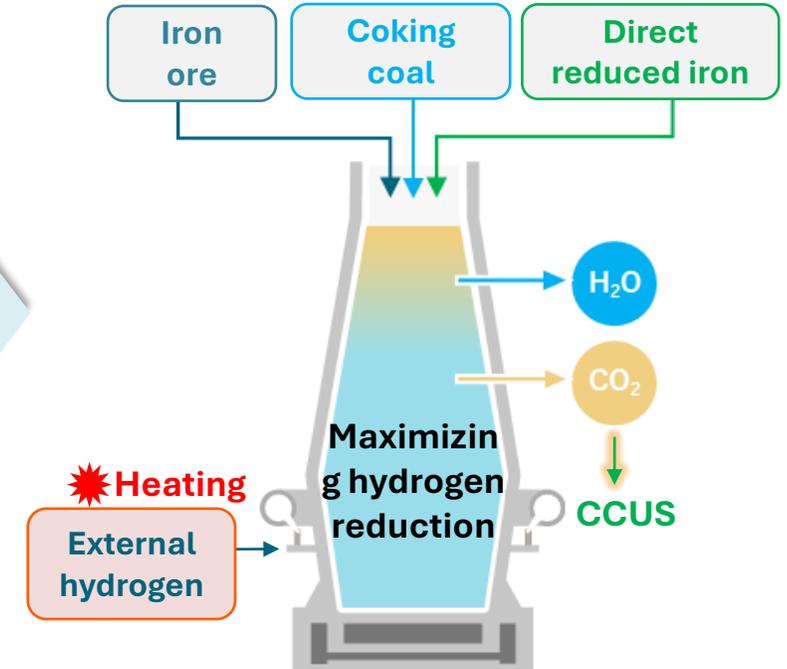
Injecting hydrogen generated in the works



CO₂ reduction target: 10% + CCS: 20% = 30% reduction

Super COURSE50 blast furnace

Injecting external hydrogen



Maximum CO₂ reduction & Maximum use of CCU/CCS: Carbon neutrality

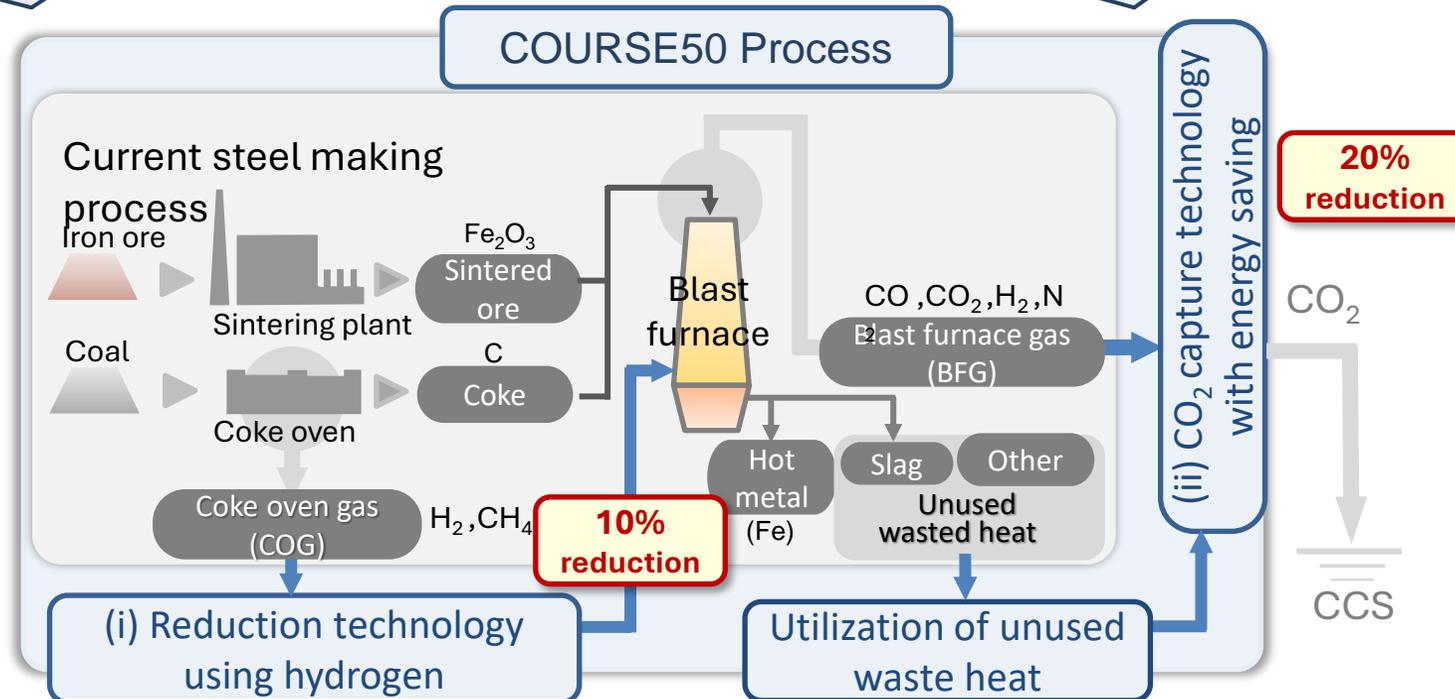
Outline of COURSE50 Project

(1) Reduction of CO₂ emissions

Reducing CO₂ emissions by 10%,
partially replacing coke with hydrogen in BF

(2) CO₂ capture

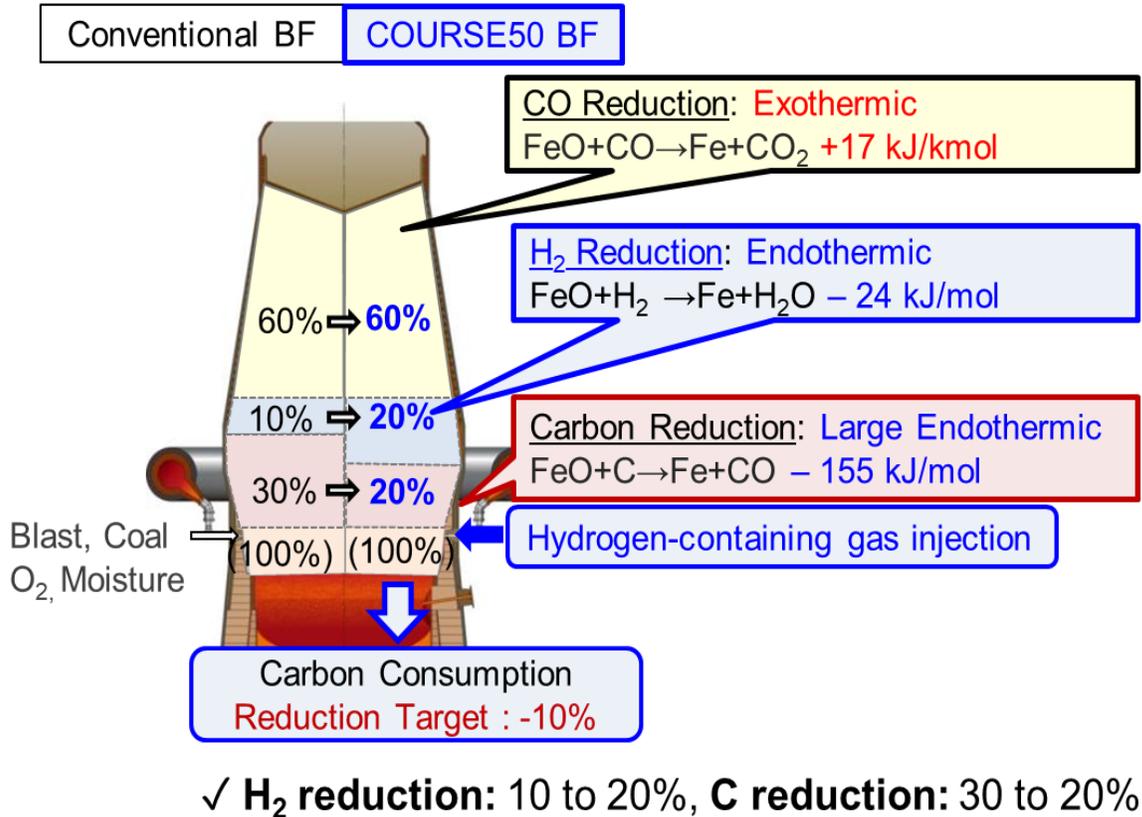
Reducing CO₂ emissions by 20%,
capturing CO₂ from BF gas



100% sponsored research by NEDO (The New Energy and Industrial Technology Development Organization) operated by Nippon Steel, JFE Steel, Kobe Steel and Nippon Steel Engineering.

How to operate Experimental Blast Furnace (EBF)

Concept of COURSE50 Blast Furnace



Pre-prediction of operation by a mathematical model

Solid temp. H₂ concentration

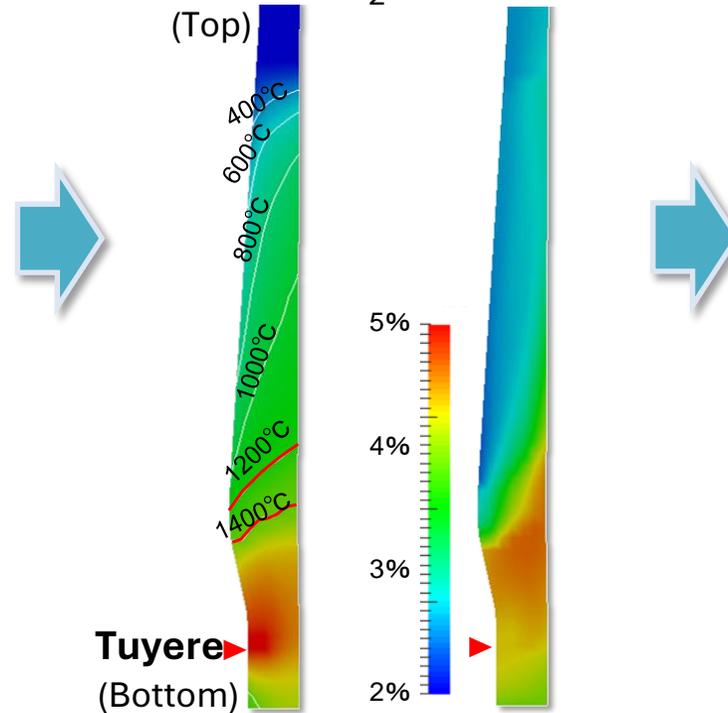


Fig. Example of calculated results.

Operation using EBF



Fig. Discharge of Hot Metal.

✂ The basic concept of Super COURSE50 is the same as that of COURSE50, aiming to minimize carbon reduction (maximize CO₂ reduction) by expanding hydrogen reduction to the limit by injecting a large amount of heated hydrogen.

Results of Hydrogen Injection into COURSE50 EBF

- ✓ In 2020, a test of **injection of room temperature hydrogen** was conducted and a **16% reduction in CO₂ emissions** was achieved at the 12m³ COURSE50 experimental blast furnace.

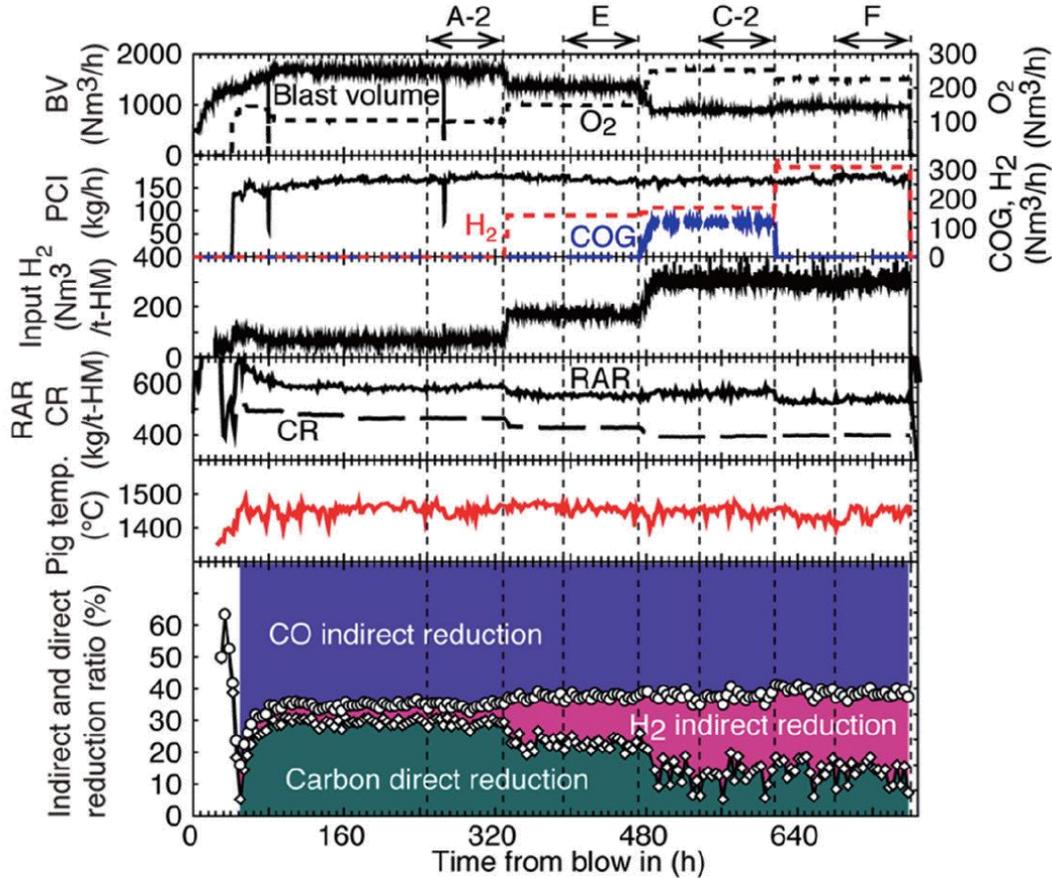


Fig. Example of operation trend of experimental blast furnace.

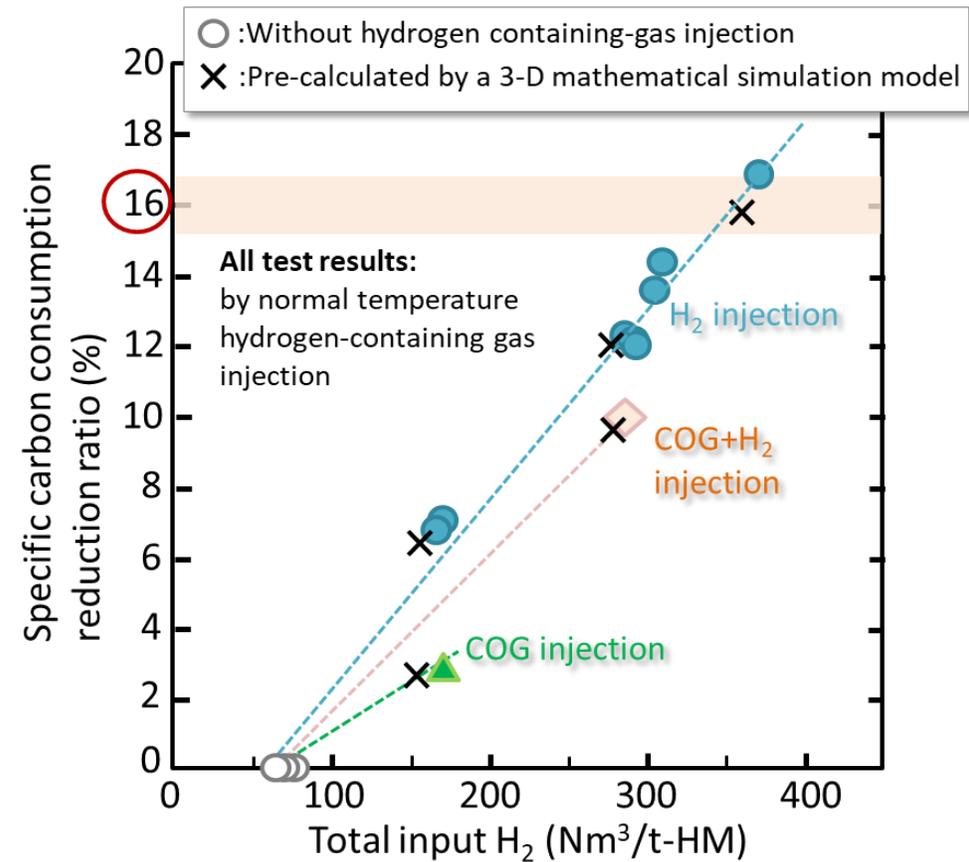


Fig. Relationship between total H₂ input and carbon consumption (=CO₂) reduction ratio.

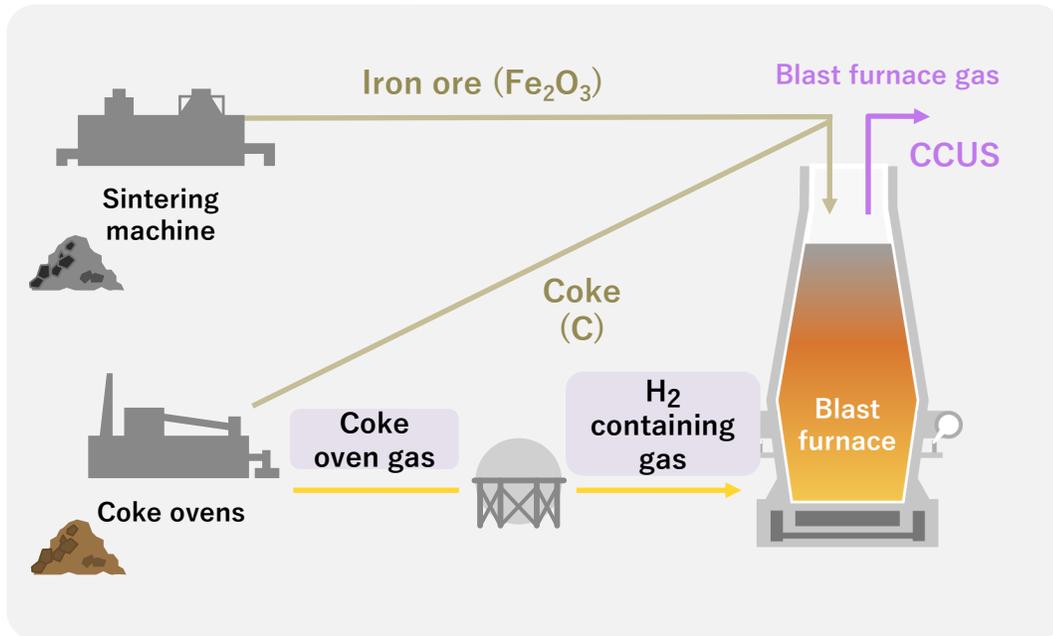
Revised from Kamijo et. al., ISIJ International, Vol. 62 (2022), No. 12, pp. 2433–2441

[Next step] Demonstration of COURSE50 BF

Mass hydrogen-containing gas injection into large sized actual blast furnace

- ✓ **Hydrogen-containing gas injection facility will be introduced at the Kimitsu No.2 Blast Furnace of Nippon Steel Corporation, and a demonstration test is scheduled to begin in FY2026.**

Blast furnace hydrogen reduction technology
(CO₂ reduction by 10%)



Demonstration test using actual blast furnace



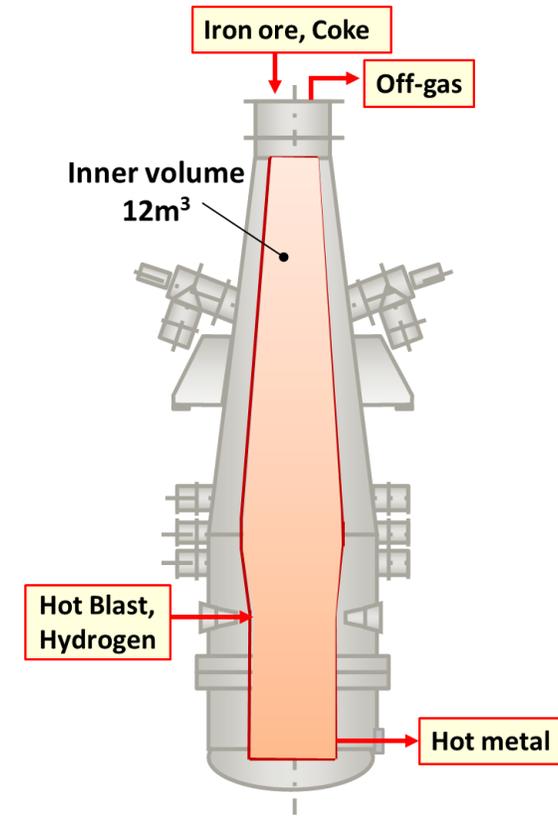
Super COURSE50 Experimental Blast Furnace

- ✓ The COURSE50 EBF at East Japan Works Kimitsu Area of Nippon Steel was modified to develop **heated hydrogen injection technology**.

Experimental blast furnace (EBF) facilities

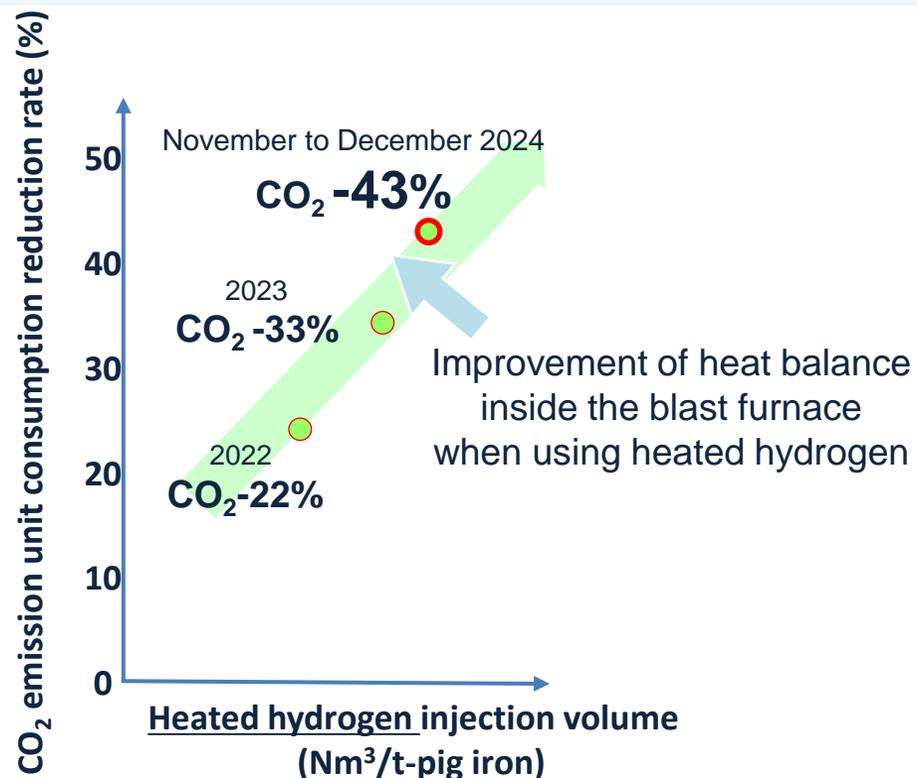


Vertical cross-section of EBF



Recent Progress of Super COURSE50 BF

- ✓ **First-in-world achievement of 43% CO₂ emissions reduction** successfully demonstrated in the Super COURSE50 experimental blast furnace.
- ✓ We will continue to **develop scale-up technologies** and **CO₂ reduction technologies reaching over 50%** to accelerate towards full-scale implementation in large-scale blast furnaces.

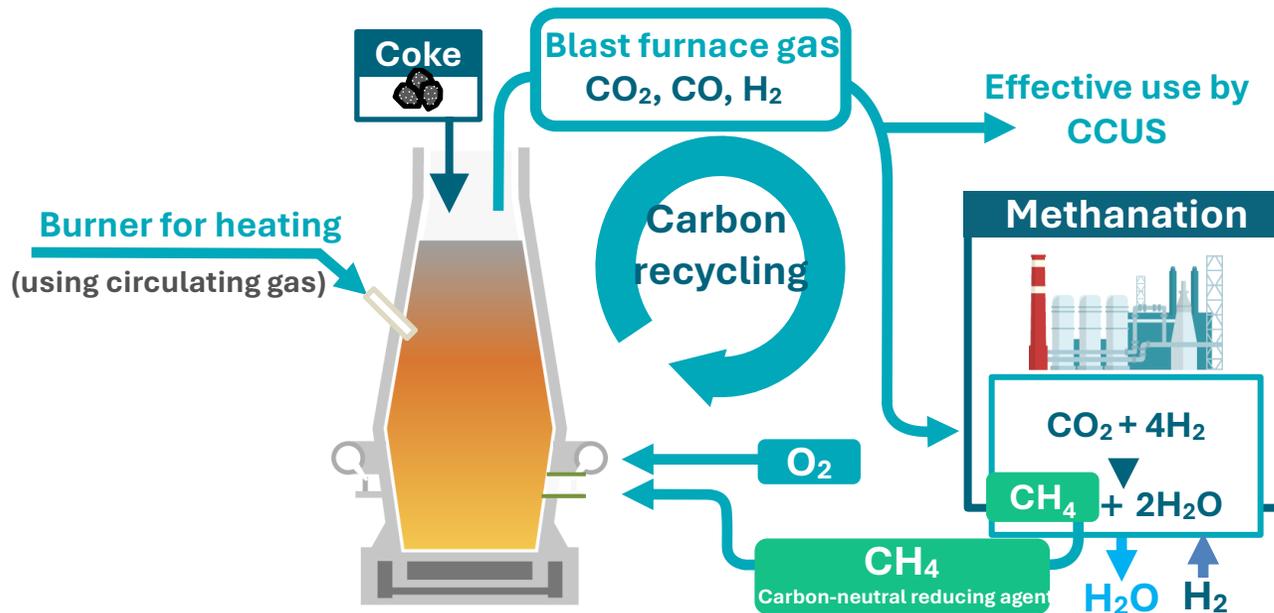


Hydrogen reduction technology using blast furnaces:

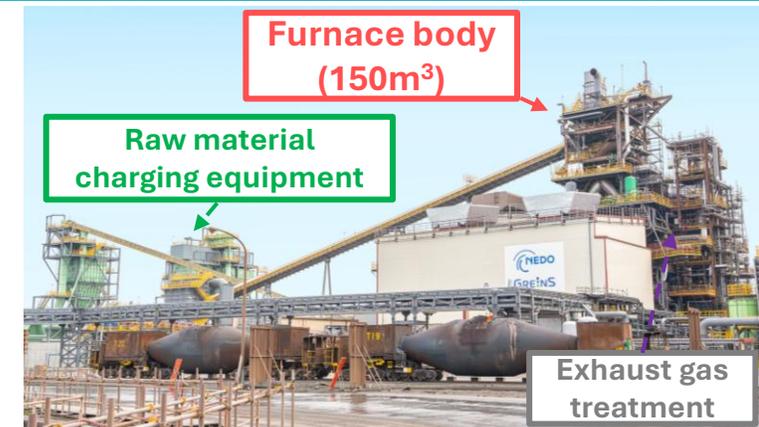
Indirect use of hydrogen by Carbon Recycling BF

- ✓ CO_2 from blast furnaces is converted into CH_4 using green H_2 and repeatedly reused as a reducing agent in blast furnaces.
- ✓ Replacing part of the reducing agent from coke to carbon-neutral CH_4 reduces CO_2 emissions from blast furnaces.

Concept of Carbon Recycling Blast Furnace



Carbon recycling test blast furnace



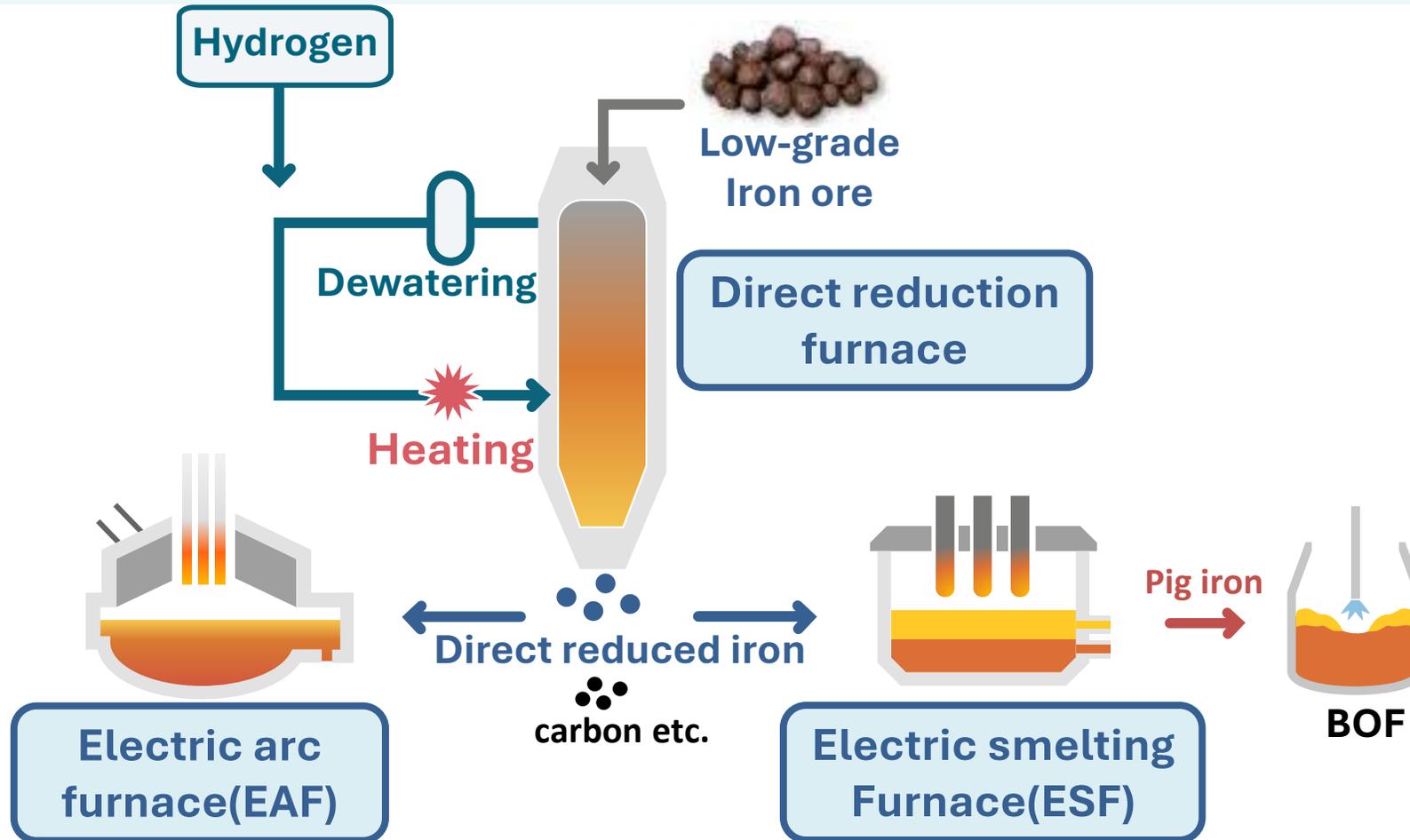
Construction Overview

1. **Construction Period:** March 2022 to April 2025
2. **Furnace Volume:** 150m³
3. **Construction Scope:** Furnace body, raw material charging, exhaust gas treatment and methanation equipment system, etc.
4. **Test Period:** 2025-26 fiscal year (continuous day and night operation)

- A 150m³ scale carbon recycling test blast furnace was constructed at JFE Steel's East Japan Steel Works (Chiba area), and Tests are scheduled to be conducted in fiscal 2025-2026.

Overview of hydrogen direct reduction technology to reduce and melt low-grade iron ore

- ✓ We will develop a process to produce high-grade steel using low-grade iron ore using hydrogen direct reduction furnace, electric arc furnace(EAF) and electric smelting furnace(ESF).

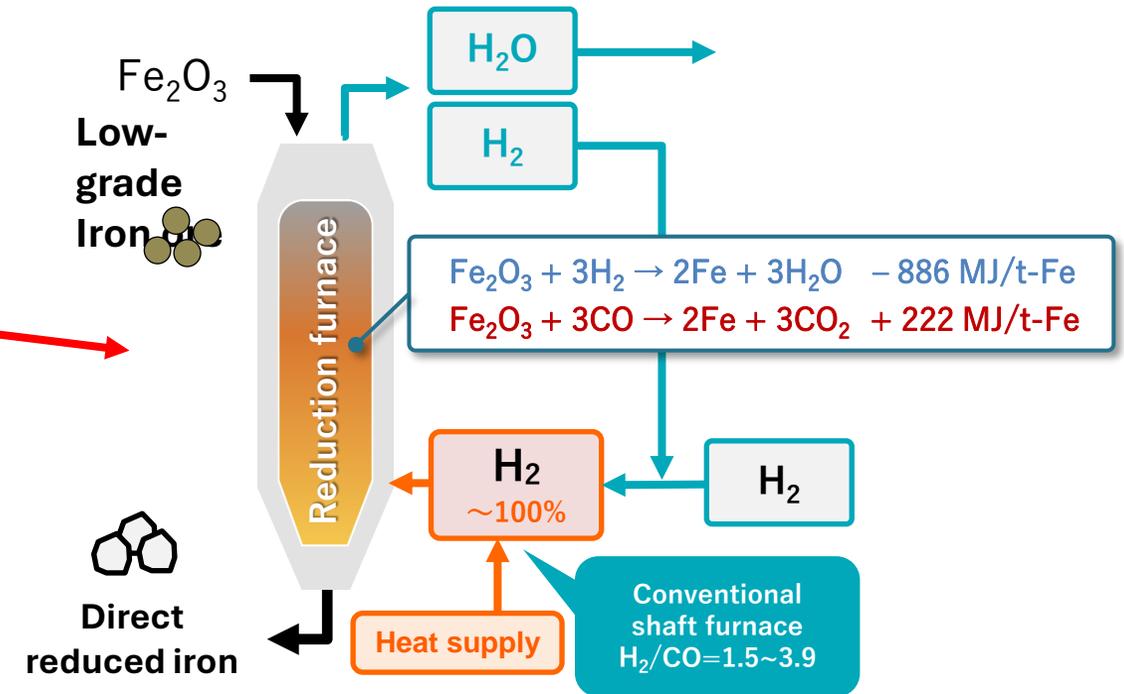


Hydrogen direct reduction technology by direct use of hydrogen

- ✓ Demonstrating technology that **reduces CO₂ emissions by 50% or more** relative to the existing blast furnace **through technology that directly reduces low-grade iron ore using hydrogen by 2030.**

Comparison with existing shaft furnace processes

	Existing shaft furnaces	Hydrogen-reducing shaft furnaces
Reduction materials	Natural gas	Hydrogen
H ₂ concentration	60~80%	~100%
Heat supply	natural gas/exhaust gas combustion	heating hydrogen, etc.
Raw materials	High-grade pellets	Lower-grade Pellets

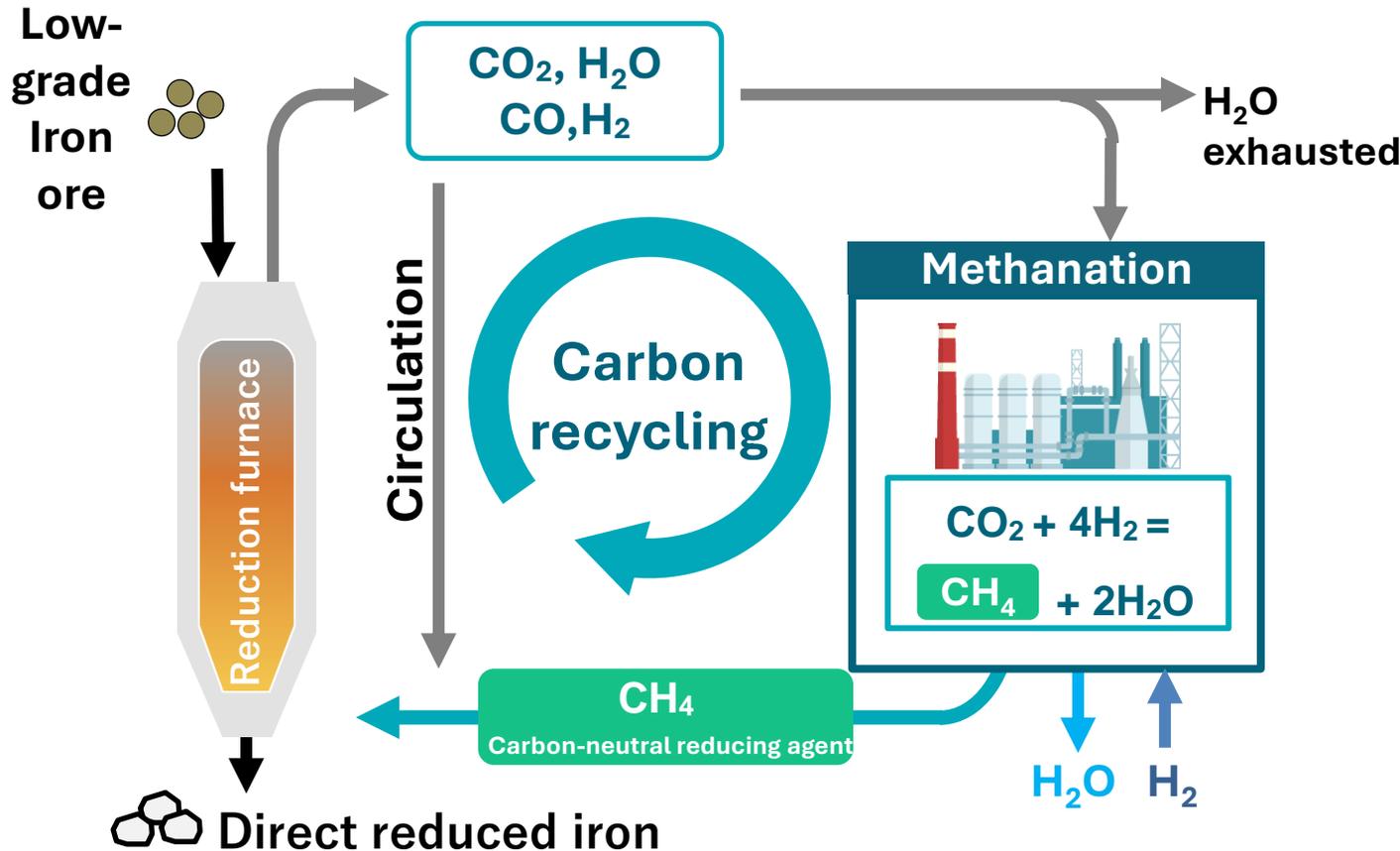


Business Strategy Vision : <https://green-innovation.nedo.go.jp/pdf/utilization-hydrogen-steelmaking/item-002/vision-direct-hydrogen-reduction-nipponsteel-002.pdf>

- **A 1t/hr scale experimental shaft furnace is under construction, and tests will be started within FY2025** at Hasaki R&D Center of Nippon Steel Corporation.

Carbon recycling direct reduction technology by indirect use of hydrogen

✓ CO₂ from reduction furnace is converted into CH₄ with H₂, and the CH₄ is used as reducing agent as well as the above-mentioned Carbon Recycling BF.



Direct Reduction bench furnace Overview

- Site: approx. 50 m × approx. 50 m
- Height: approx. 30 m
- Test volume: 15 kg/h

Reduction furnace (15kg/h)



Operating room, Electrical room

Reduction gas generator



Raw material pellets
Reduction rate: 0%
Brown color

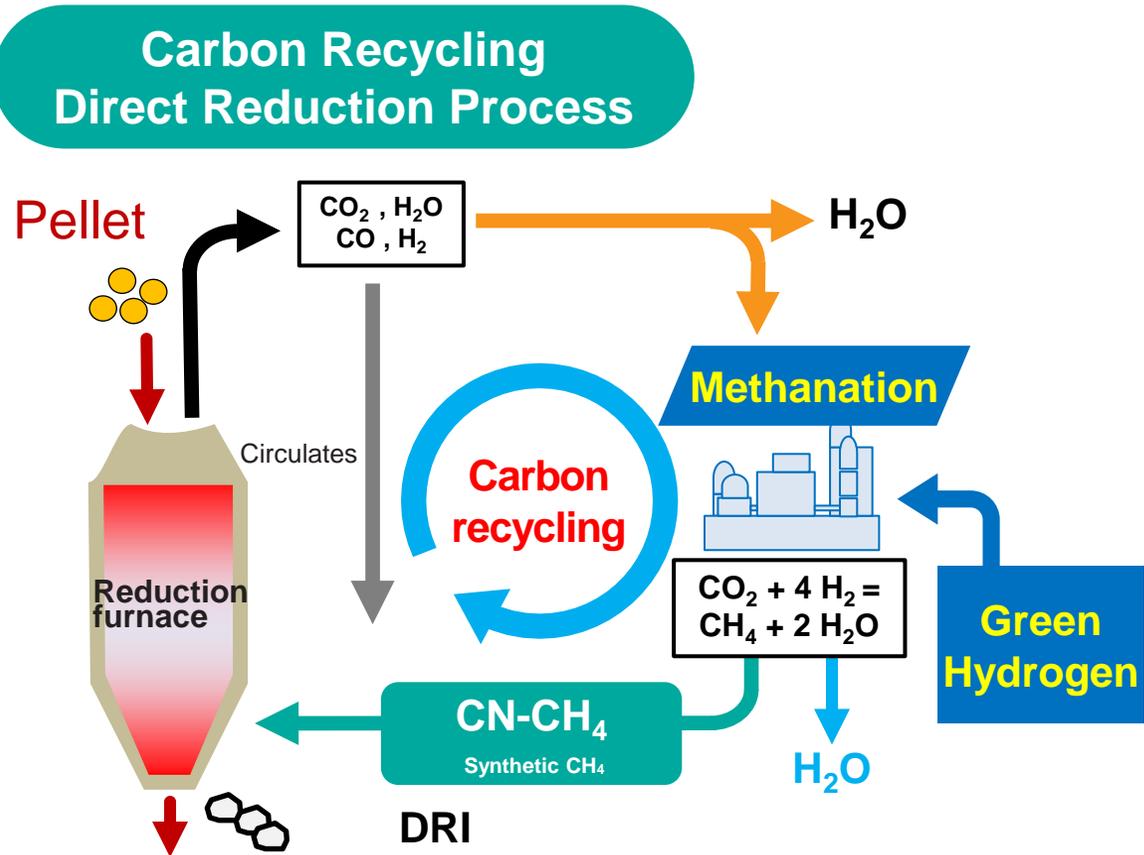


Reduced pellets
Reduction rate: >90%
Gray color with metallic luster

10mm

• A small-scale bench test furnace was constructed, and tests started in FY2024 at JFE Steel's East Japan Steel Works (Chiba area).

Technical development items related to CR shaft furnace

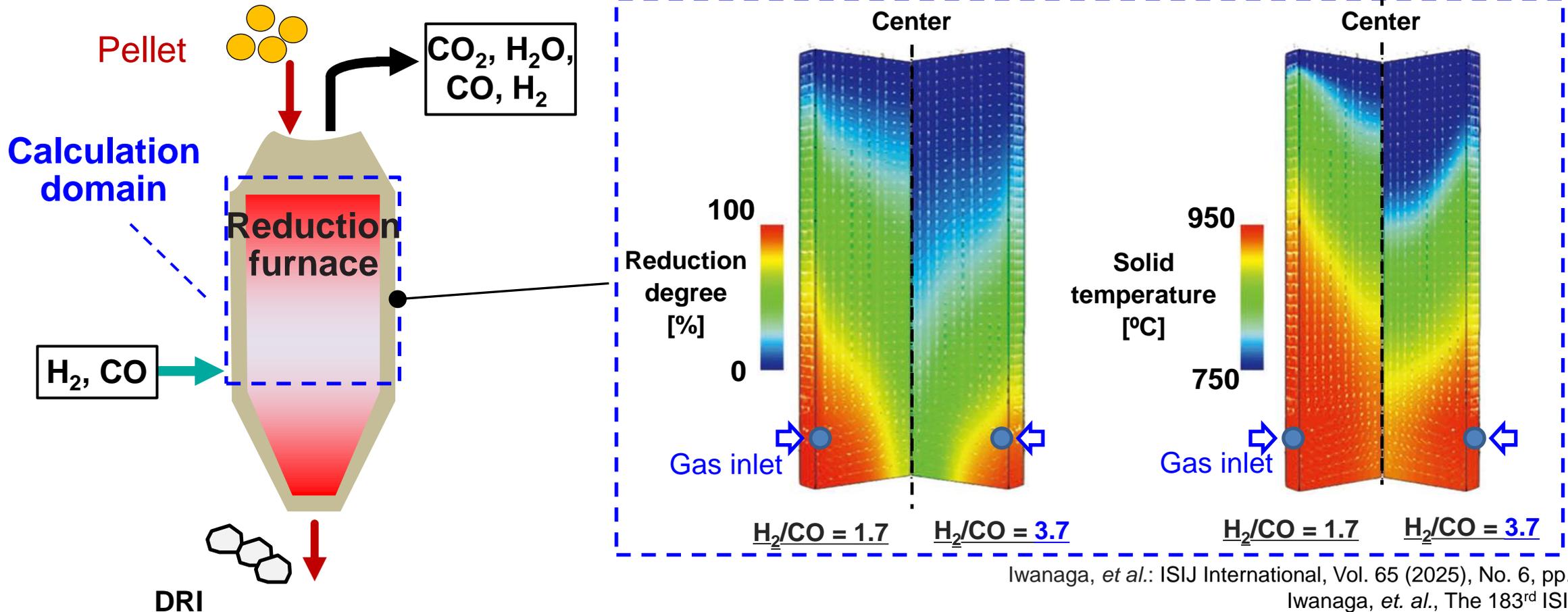


- Reduction with hydrogen is a highly endothermic reaction.
- By synthesizing methane from CO_2 through a methanation reaction, it is possible to avoid CO_2 emissions from the system and heat absorption in the shaft furnace.
- The mechanism of reduction degradation of pellets will also be examined.

Impact evaluation of large amount of hydrogen injection

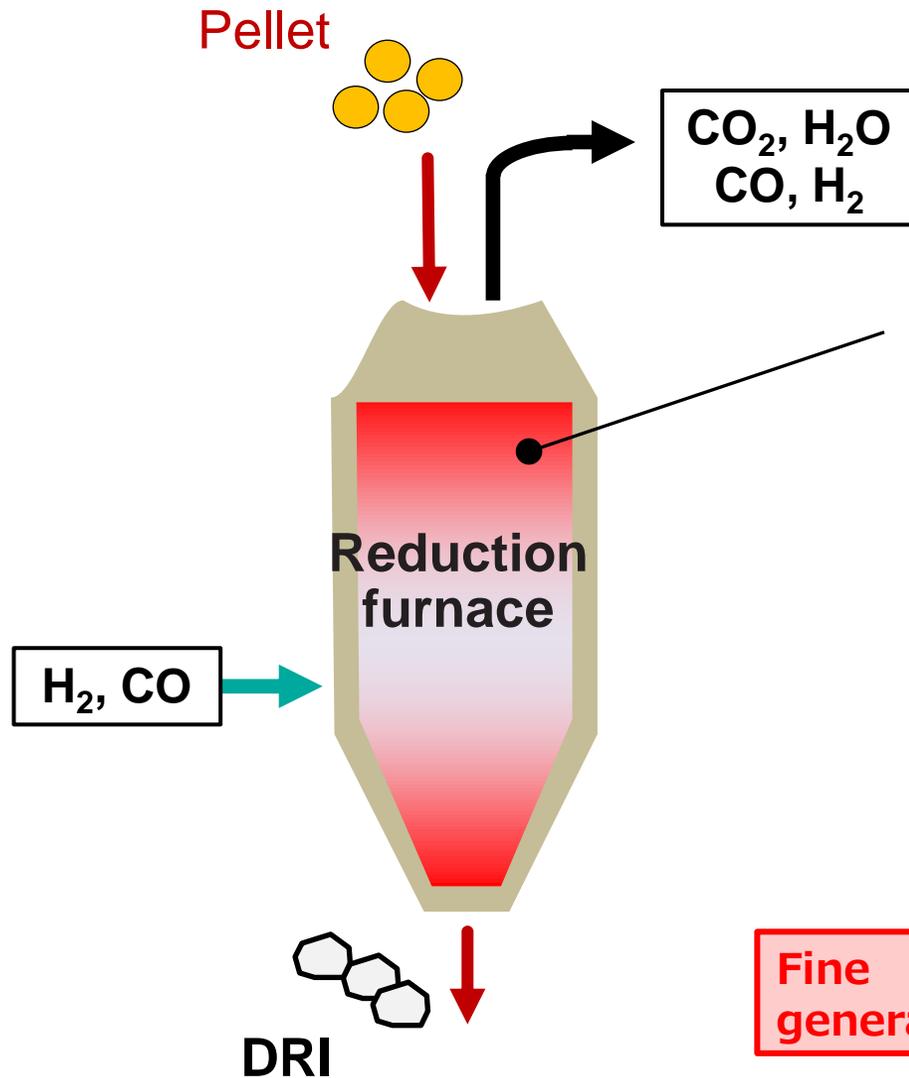
When the amount of hydrogen in the reducing gas increases, in the middle to upper part of the furnace:

- The furnace temperature decreases.
- The reduction rate decreases.



Iwanaga, et al.: ISIJ International, Vol. 65 (2025), No. 6, pp. 874–883
Iwanaga, et. al., The 183rd ISIJ Meeting

Issues with endothermic reaction



- The endothermic reaction may lead to a decrease in productivity due to a decrease in reaction rate.
- Lowering the reaction temperature may cause the reduction degradation of pellet.



General Exp. Condition

- Reduction temp.: 900°C
- After measuring tumbling strength
- H₂/CO = 4.0

Fine generation

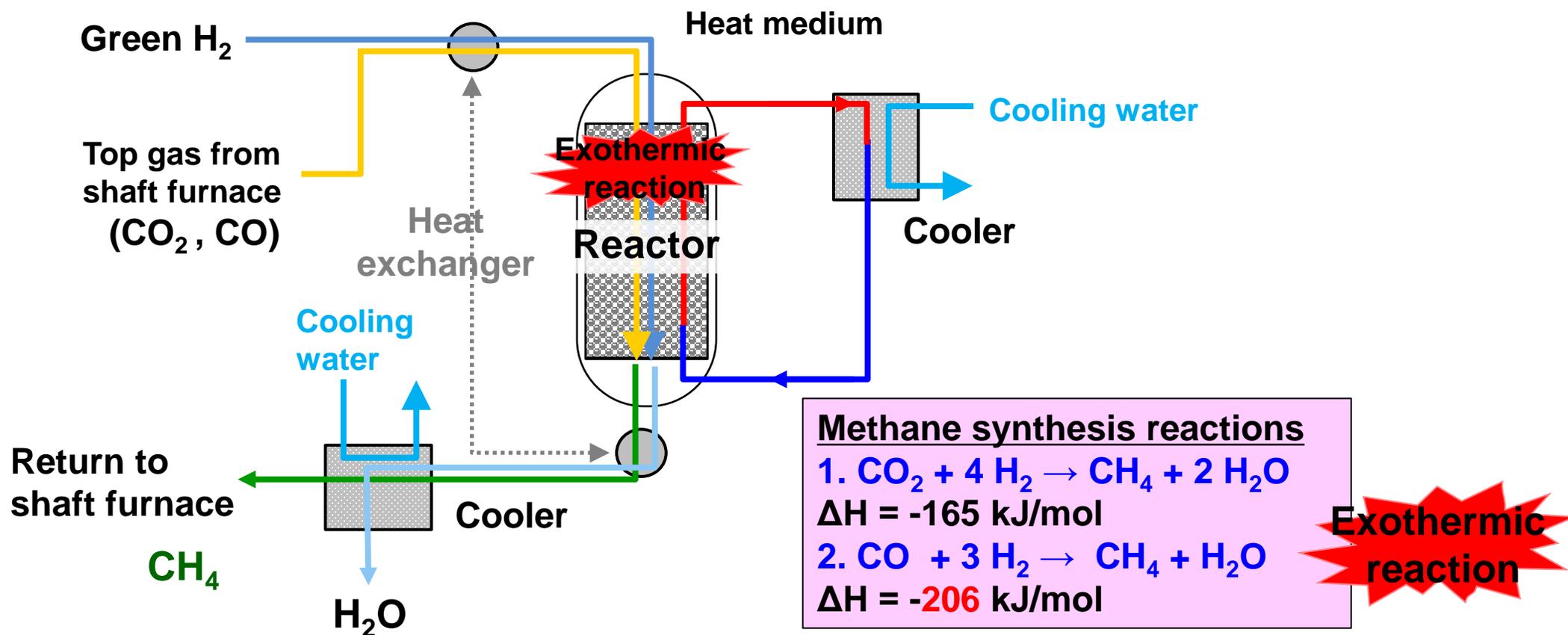
H
10 mm

Degradation behavior of pellet

Overview of methanation

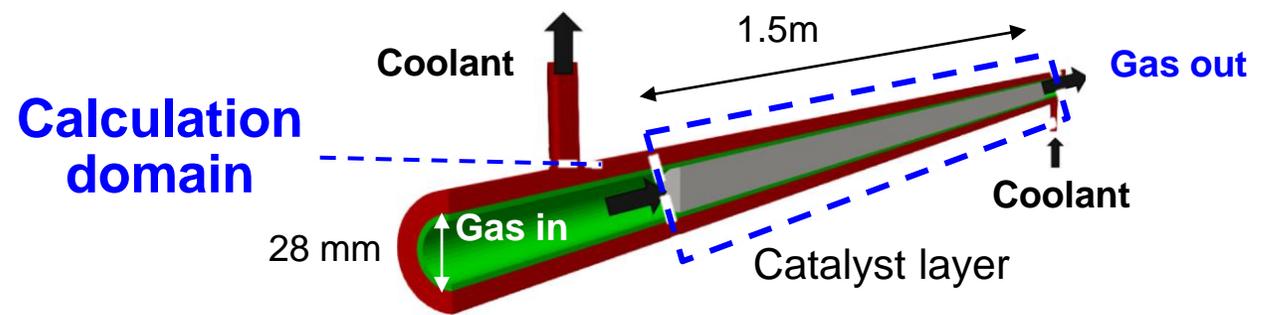
Methanation

- A process in which we can convert CO_2 and CO into CH_4 by using H_2 .
- One of the promising CCU processes needed to realize a carbon-neutral society.



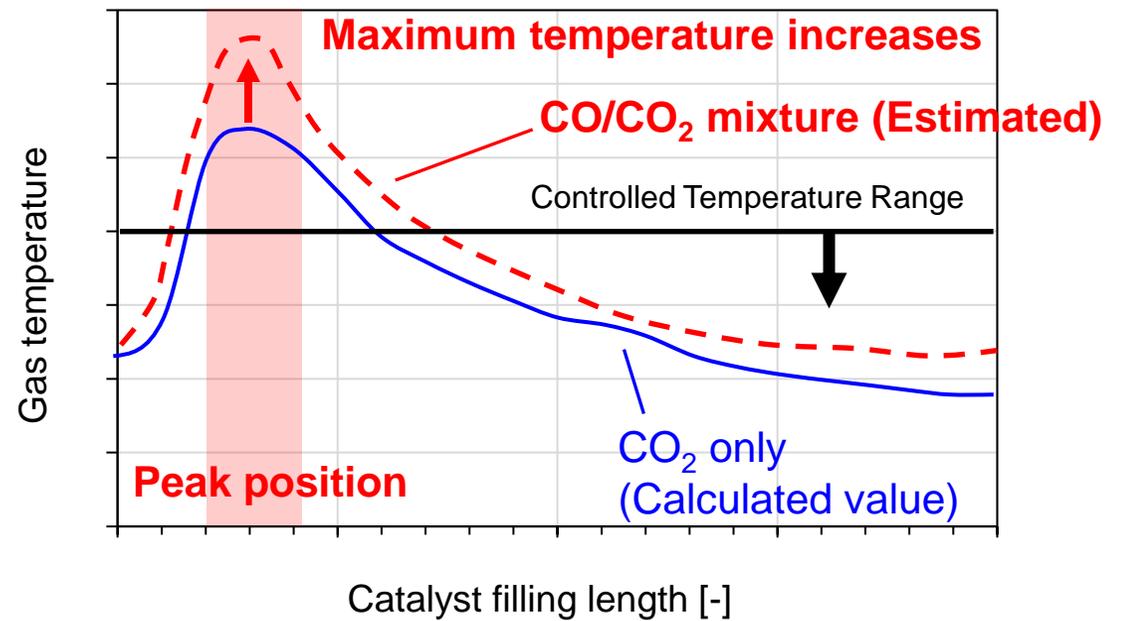
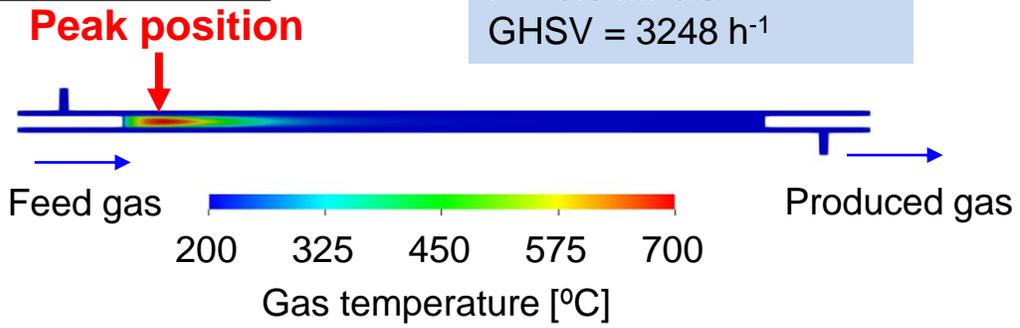
Investigation of methanation efficiency under various conditions

Concerns regarding methanation with a CO/CO₂ mixed gas:
 Methanation with CO alone generates more heat.
 Temperature control within the reactor may be difficult.
 → We are currently investigating the effects of CO through simulations.



Calculation assumptions
 $H_2/CO_2 = 4$
 $P = 0.5 \text{ MPaG}$
 $GHSV = 3248 \text{ h}^{-1}$

Calculation result

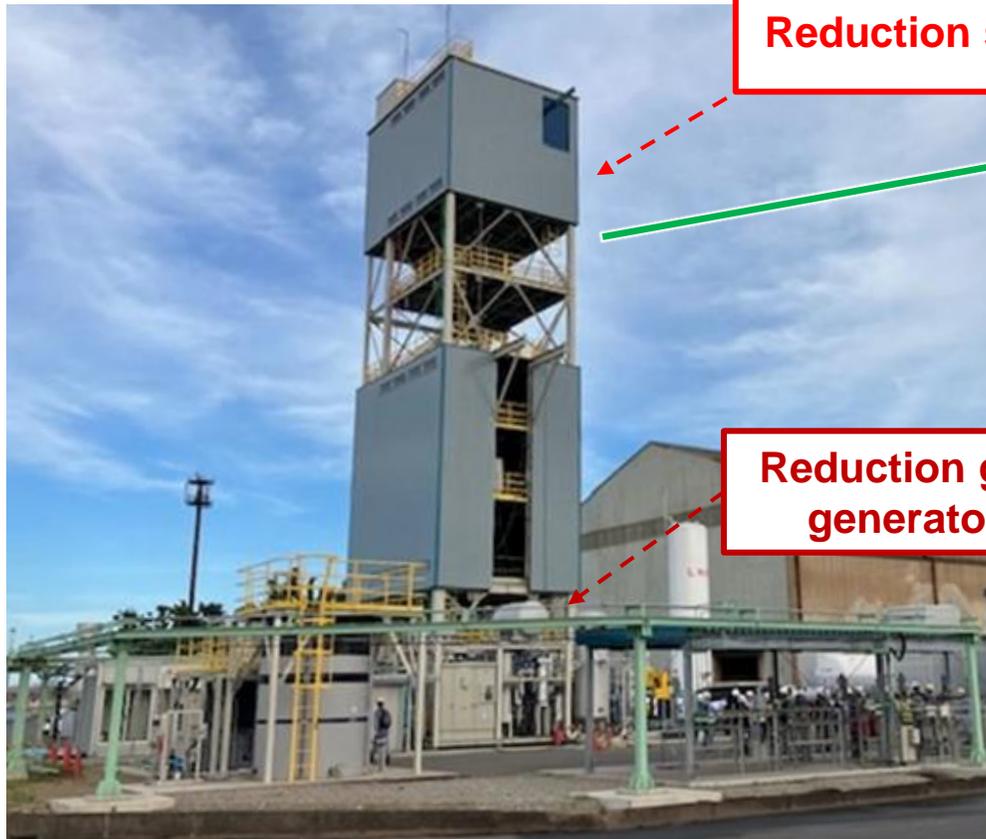


$GHSV = (\text{Catalyst bed volume [NL]}) / (\text{Gas flow rate [NL/h]})$
 Zhang, Norinaga : *Chemical Engineering Science*, **211** (2020), 115276.

Current status of reduction tests using shaft furnace

- Experimental operations have just begun at the end of 2024.
- Scheduled as 1-week operation in each month, through 2026.

★ External view (as of **March, 2025**)



Reduction shaft furnace

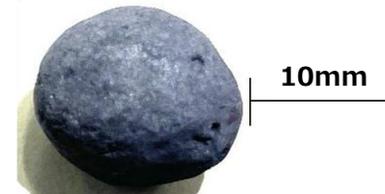
Reduction gas generator

Direct Reduction bench furnace Overview

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- **Height:** approx. 30 m
- **Test volume:** 15 kg/h

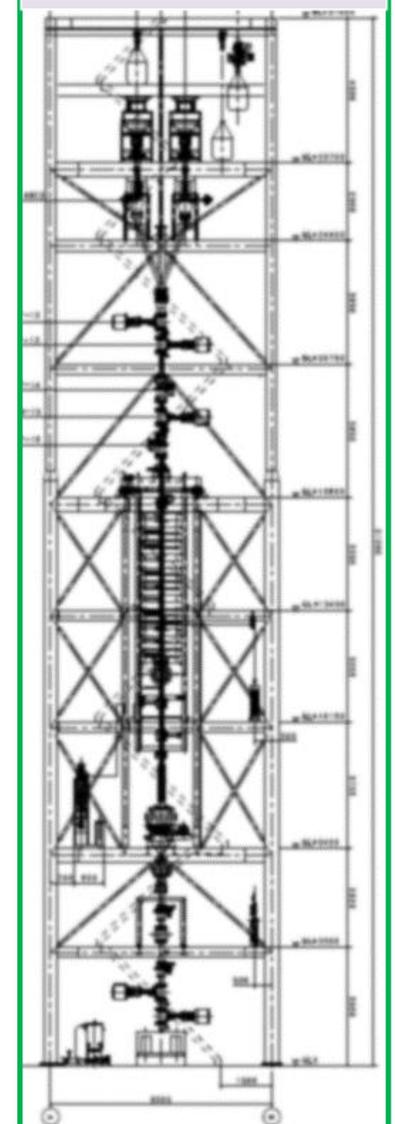


Raw material pellets
Reduction rate: 0%
Brown color



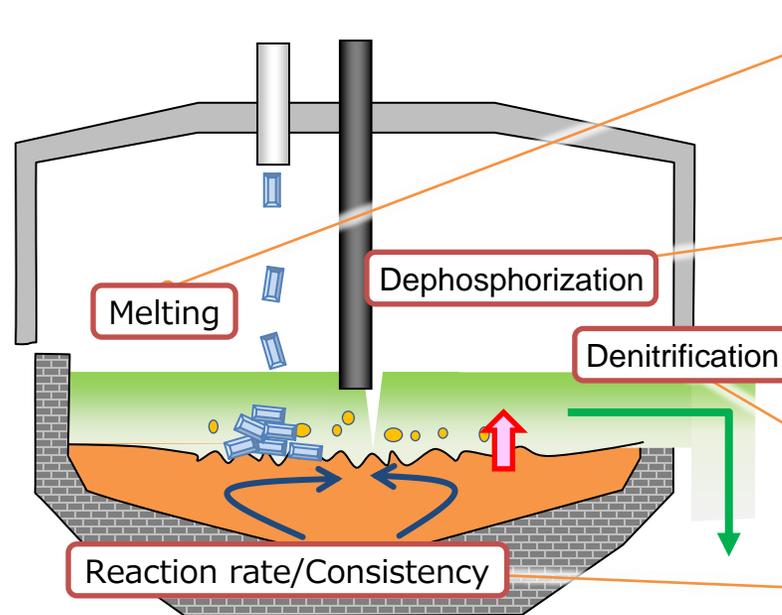
Reduced pellets
Reduction rate: >90%
Gray color with metallic luster

Exp. shaft furnace



Electric arc furnace(EAF) for high-grade steel production

- ✓ Demonstrating the technology to **refine impurities to the same level as the blast furnace process** (150 ppm or less of phosphorus and 40 ppm or less of nitrogen) **using hydrogen direct reduced iron from low-grade iron ore in the large-scale electric arc furnace process** (approx. 300 tons) **by 2030.**



Improvement of DRI melting rate

Optimization of DRI specifications, feeding position and rate, and improvement of stirring

Phosphorus reduction

Promotion of dephosphorization by improving stirring and controlling slag composition, reduction of slag generation

Nitrogen reduction

Accelerated denitrification by atmosphere control, carbon addition and decarburization

Optimal stirring technology

Optimization of stirring methods such as energizing type, furnace dimension, etc.

Technology for high-speed melting and refining of DRI in EAF

Tests begun in FY2024 using a 10t experimental electric furnace at Nippon Steel's Hasaki R&D Center.

Technology for preheating DRI and secondary refining

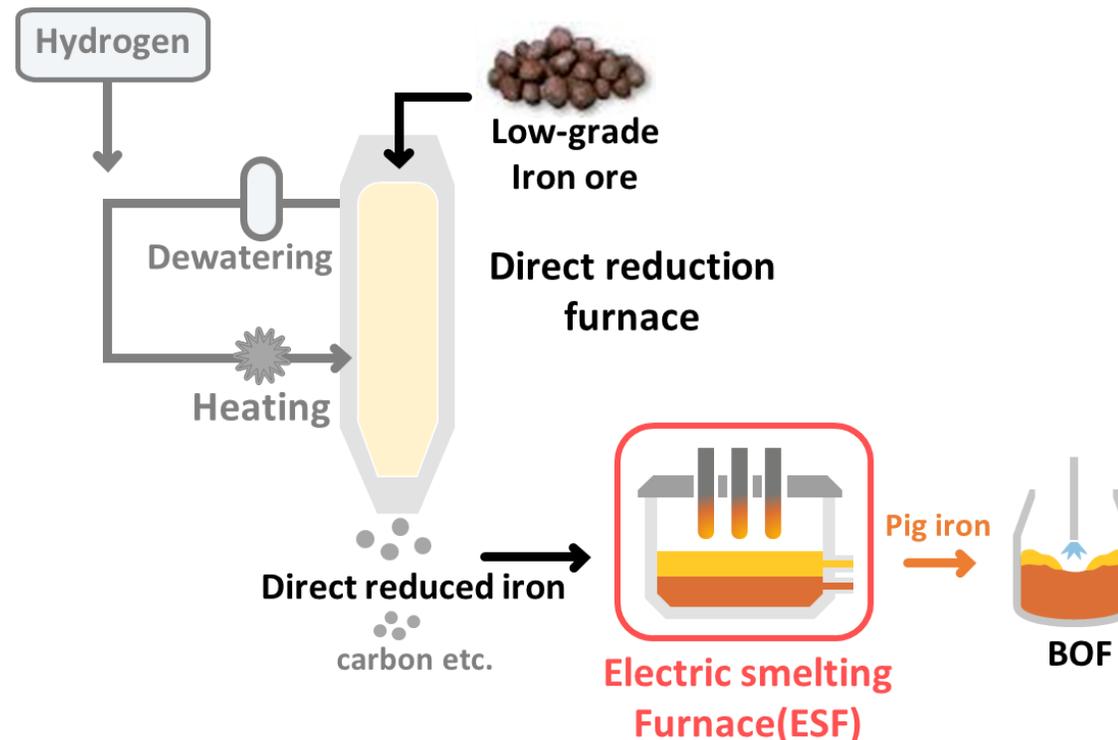
Tests begun in FY2024 using a 10t experimental electric furnace at JFE Steel's East Japan Steel Works (Chiba area).

Development of DRI melting technology

A 20t small commercial furnace was remodeled at Kobe Steel Takasago Works, and tests started in FY2022.

Electric smelting furnace(ESF) for hot metal production

- ✓ We are developing a technology to realize **efficient production** and control **impurities comparable to blast furnace process using low-grade iron ore**.
- ✓ Also, we are developing a technology for controlling electric smelting furnace (**ESF**) slag suitable for **domestic cement applications**.



- A **test electric smelting furnace (ESF)** will be **constructed**, and **test will be started in FY2026** at Nippon Steel Corporation.

SOURCE:

<https://www.greins.jp/en/technology/technology05/>

Development of energy-saving CO₂ Capture Technology

ESCAP®

The basic technology was established in COURSE50 project.

- **Chemical absorbent:** Nippon Steel & RITE*
- **Chemical process** : Nippon Steel Engineering

*Research Institute of Innovative Technology for the Earth

Commercialized 2 plants
(120t & 143t-CO₂/day)

ESCAP® (Energy Saving CO₂ Absorption Process): Registered trademark of Nippon Steel Engineering Co., Ltd.

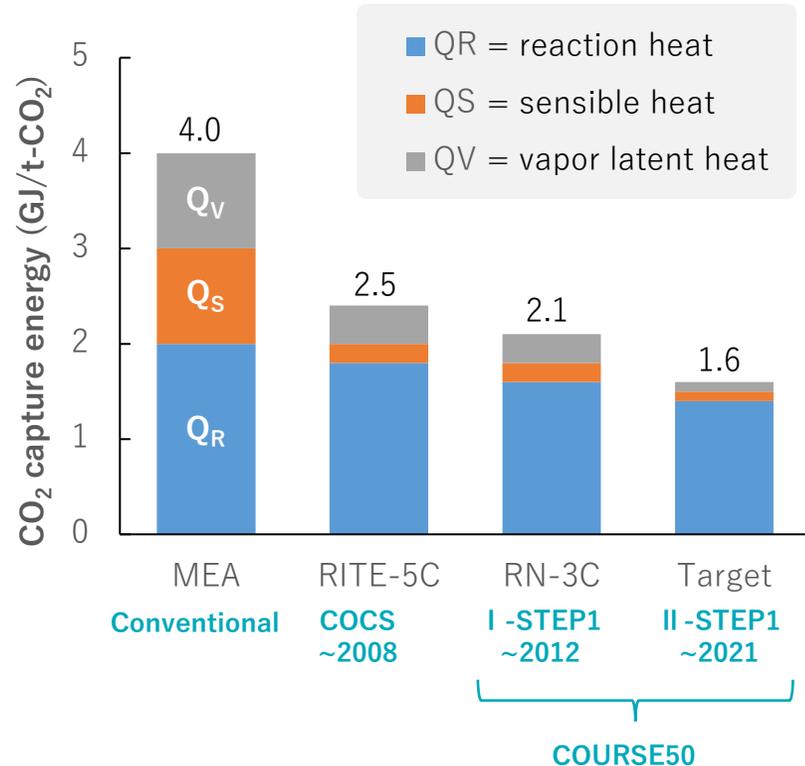


Fig. Development progress of new chemical absorbents

Source : Nippon Steel Technical Report No.127 (2022) p29.



Commercialized plant No.1
(AIR WATER Green Design)



Commercialized plant No.2
(Sumitomo Joint Electric Power Co., Ltd)

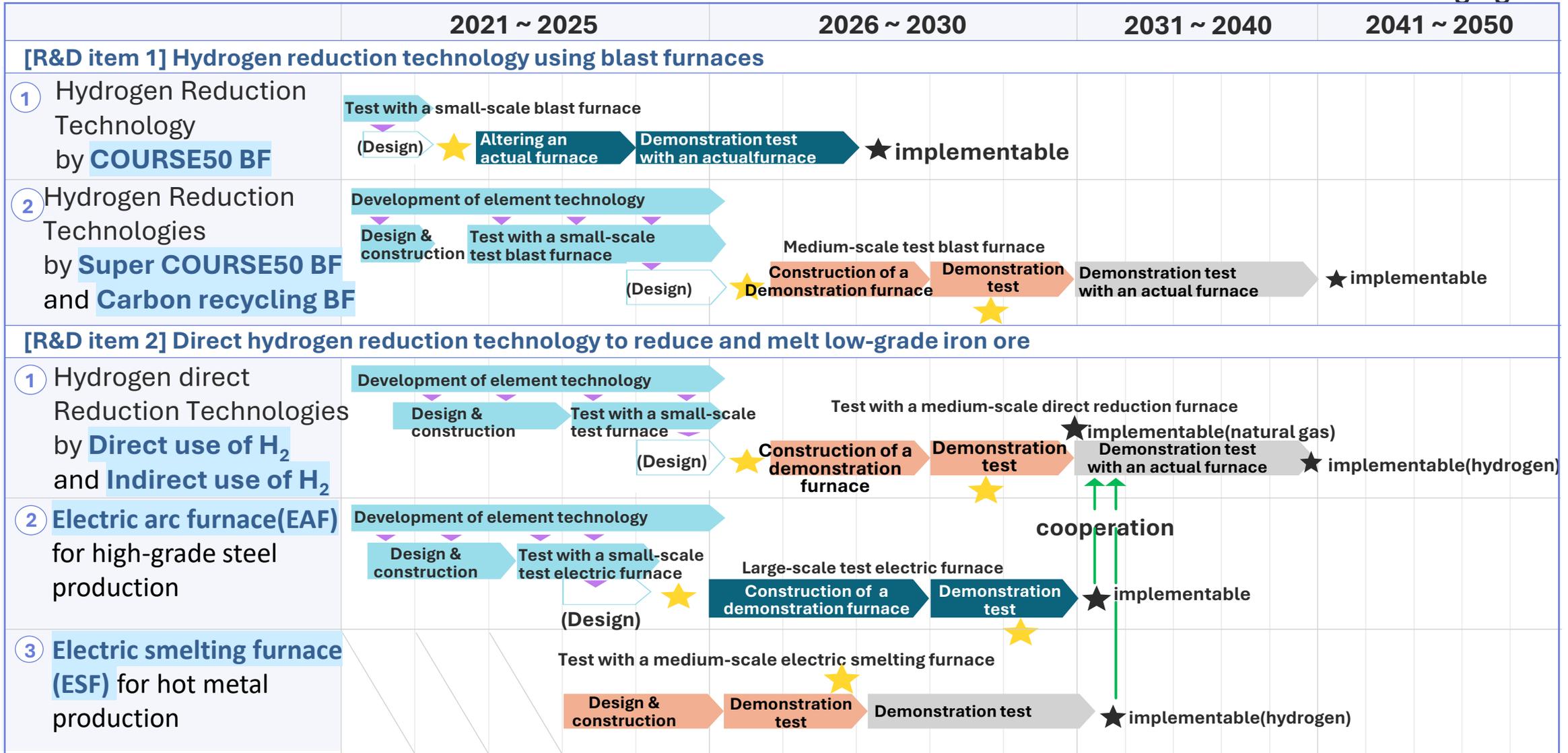
	Plant No.1 (from 2014)	Plant No.2 (from 2018)
Capacity	120 t/day	143 t/day
Emission sources	Ironmaking hot-stove exhaust gas	Coal-fired power plant exhaust gas
Application	Generates industrial CO ₂	Manufactures feed additives

Source of fig. & table: https://www.eng.nipponsteel.com/en/business/environment_and_energy_solution/escap/escap

Project Schedule

※METI's R&D and social implementation plan regarding the "Hydrogen Utilization in Iron and Steelmaking Processes" project, October 27, 2023. Provided schedule is an example of assumed schedule.

➡ Fundamental study & small-scale demo.
 ➡ Medium-scale
 ➡ Large-scale & actual
 ★ Stage-gate



Conclusions

- ✓ The Japanese steel industry was the first in the world to engage in **hydrogen reduction steelmaking**, through the **COURSE50** project supported by NEDO since 2008.
- ✓ Based on the technologies gained in COURSE50, we are working on a **multi-pathway process development project (GREINS project)** to realize carbon neutrality in steelmaking supported by NEDO since 2021.

For the carbon neutrality, massive and stable supply of carbon-free hydrogen and electricity with rational costs and massive investment as well as overcoming many technical difficulties are essential.

We will continue to work tirelessly to achieve green innovation in steelmaking.

Thank you for your kind attention !

GREINS (Green Innovation in Steelmaking) :

The Green Innovation Fund Project "Hydrogen Utilization in Steelmaking Processes" project is commissioned and subsidized by the New Energy and Industrial Technology Development Organization (NEDO) (JPNP21019). Nippon Steel Corporation, JFE Steel Corporation, Kobe Steel, Ltd. and the Research and Development Center for Metallic Materials (JRCM) have formed a consortium to work on this project. **GREINS** is an abbreviation for this project.