GREINS Project by Green Innovation Fund

The Challenge of Japanese Steel Industry to achieve Carbon Neutrality

November 20, 2023

Hydrogen Steelmaking Consortium
(Nippon Steel, JFE Steel, KOBELCO, and JRCM)

GREINS

"GREINS" means " Green Innovation in Steelmaking"

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GREINS project overview

Challenge of reducing CO_2 emissions in the steel industry

Details of GREINS project development

Challenges in realization of carbon-neutral steelmaking and summary

"GREINS" means " Green Innovation in Steelmaking"

We will challenge ourselves to develop innovative technologies aimed at reducing CO_2 emissions.

Seiji Nomura
Project Leader
Nippon Steel RESEARCH & DEVELOPMENT
Fellow

Steel supports our lives as an excellent material that constitutes social infrastructure and durable consumer goods, such as buildings, railroads, cars, and home appliances. The steel industry plays a role as the foundation of all industries. On the other hand, since iron is made by reducing iron ore with carbon (coal, etc.), the production process inevitably generates CO_2. In order to achieve carbon neutrality in the steel industry, it is necessary to develop innovative technology that will radically change that process, which has continued for about 300 years since before the Industrial Revolution in the 18th century.

Since fiscal 2008, Japan has been promoting the development of blast furnace hydrogen reduction technology under the COURSE50 project (supported by NEDO), and has verified for the first time in the world that it is possible to reduce CO_2 emissions by 10% in an experimental blast furnace. Based on the result, from fiscal 2021, we have been promoting a multitrack technical development project that includes the blast furnace process, the direct reduction ironmaking process, and the electric arc furnace process as part of "the Green Innovation Fund Project/Hydrogen Utilization in Iron and Steelmaking Processes."

Steel is a strong, versatile material with excellent recyclability. Moreover, the decarbonization of the Japanese steel industry, which supplies large amounts of high-grade steel stably, is extremely important in realizing carbon neutrality throughout Japan as well as in supporting the industrial competitiveness of our country. This is an extremely difficult challenge that no one in the world has succeeded in, but we would like to promote this project with all-Japan cooperation and be the first in history to realize the development of this innovative technology.

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

Organization

- The "Hydrogen Utilization in Iron and Steelmaking Processes" project (GREINS) is carried out by the Hydrogen Steelmaking Consortium, which consists of four partners: Nippon Steel Corporation, JFE Steel Corporation, KOBELCO, and JRCM (the Japan Research and Development Center for Metals).
- The Consortium conducts joint research with 13 research institutes.
- To decarbonize the steel industry, which emits huge amount of CO_2 during the production, this project is developing a new steel production process in which low-grade iron ore is reduced by green hydrogen instead of using carbon-based reducing agents.

Hydrogen Steelmaking Consortium

NIPPON STEEL JFE KOBELCO JRCM

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
- TOKYO Institute of Technology
- KYOTO University
- Research Institute of Innovative Technology for the Earth (RITE)
- KYUSHU University

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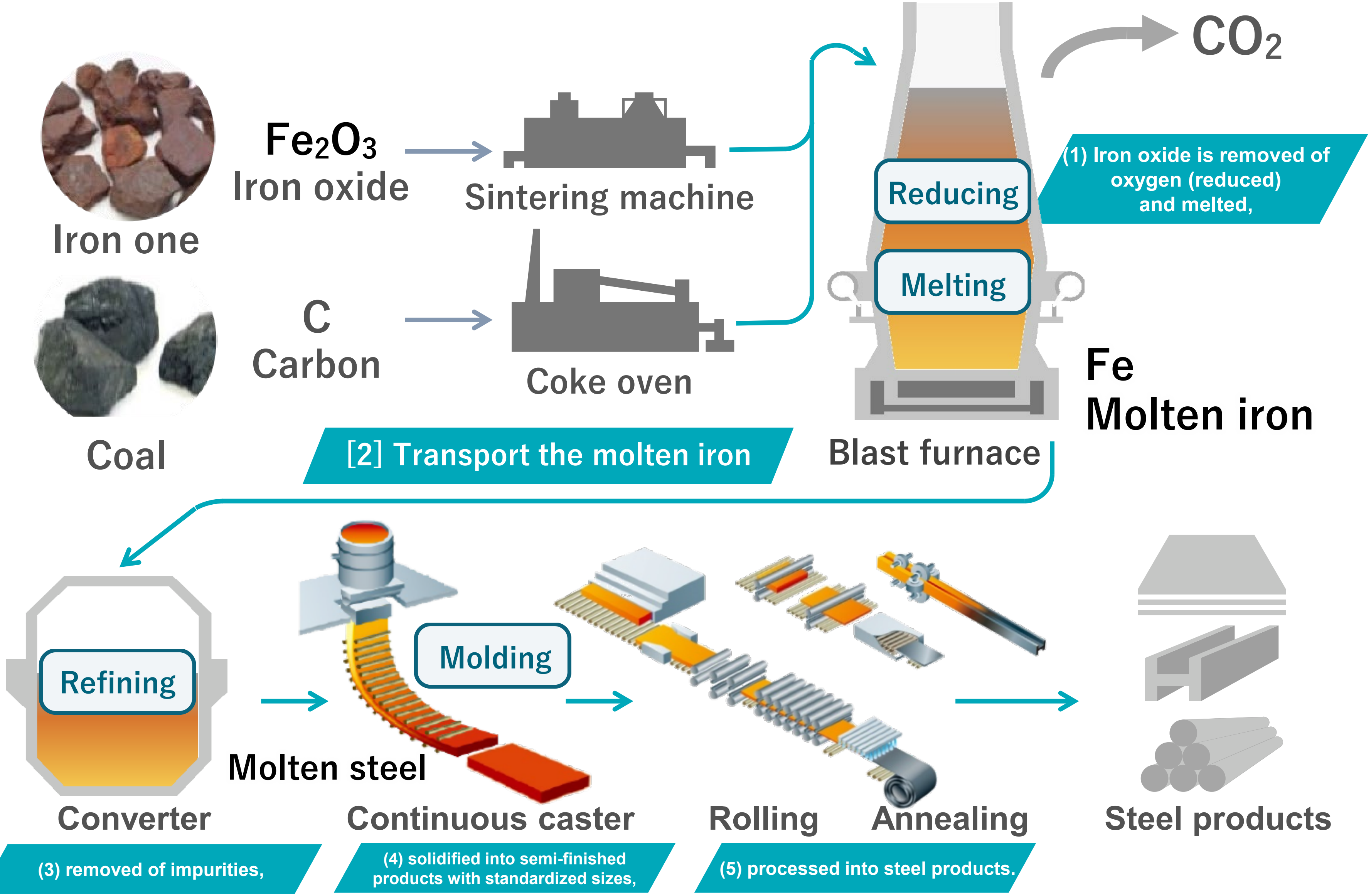
Overview of blast furnace-converter process

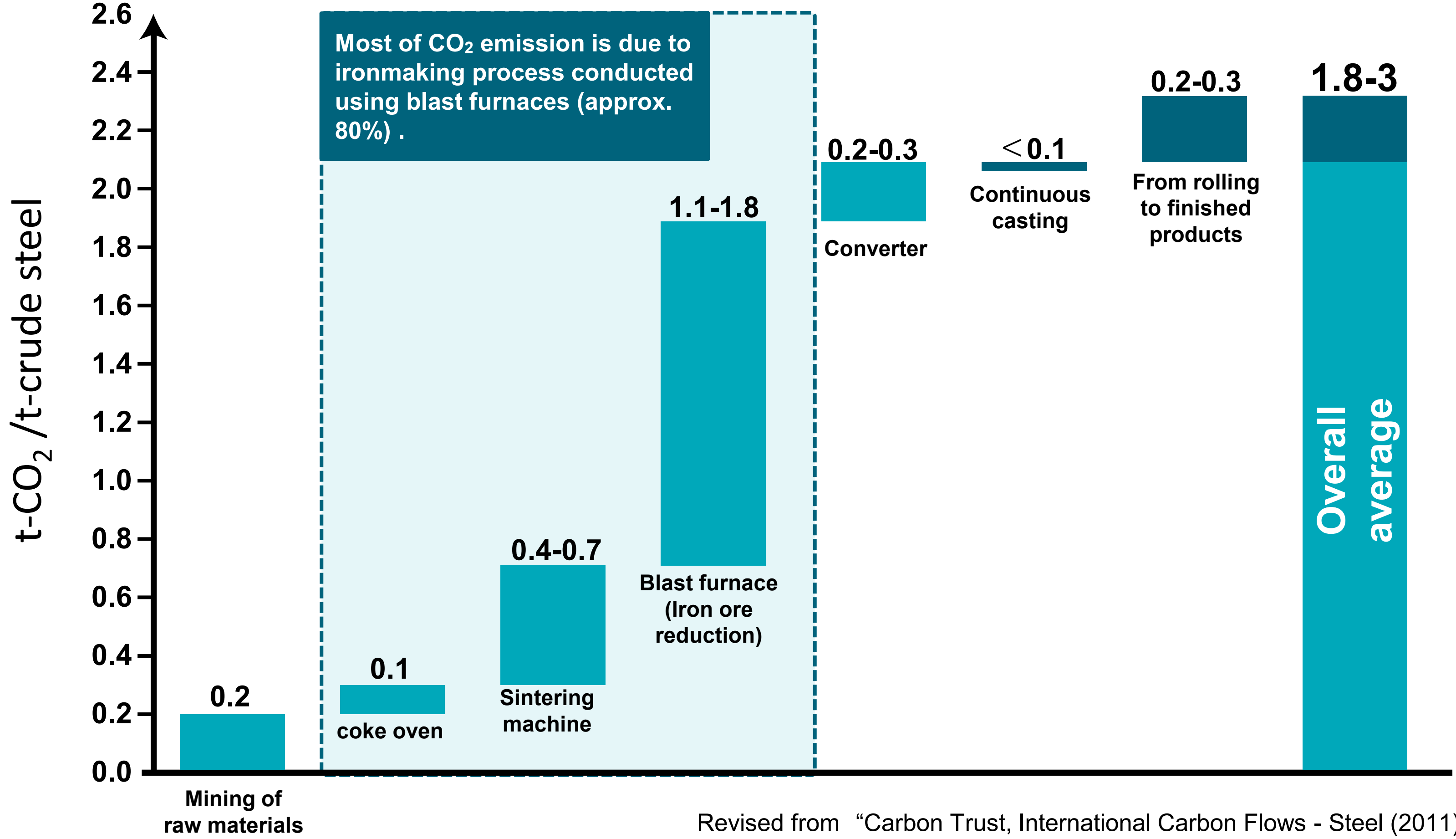


Revised from Nippon Steel Carbon Neutral Vision 2050
https://www.nipponsteel.com/en/ir/library/pdf/20210330_ZC.pdf

CO_2 emissions in various steelmaking process

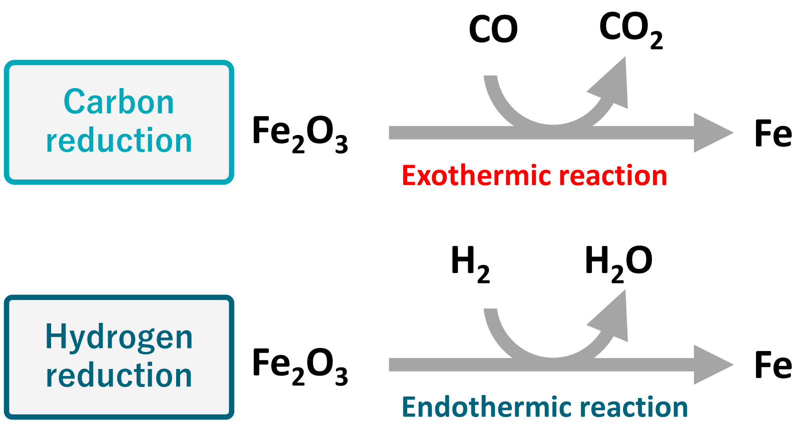
- About 14% of whole domestic CO_2 emission is discharged from steel industry.
- To realize carbon neutrality, reducing CO_2 in ore reduction process is necessary.

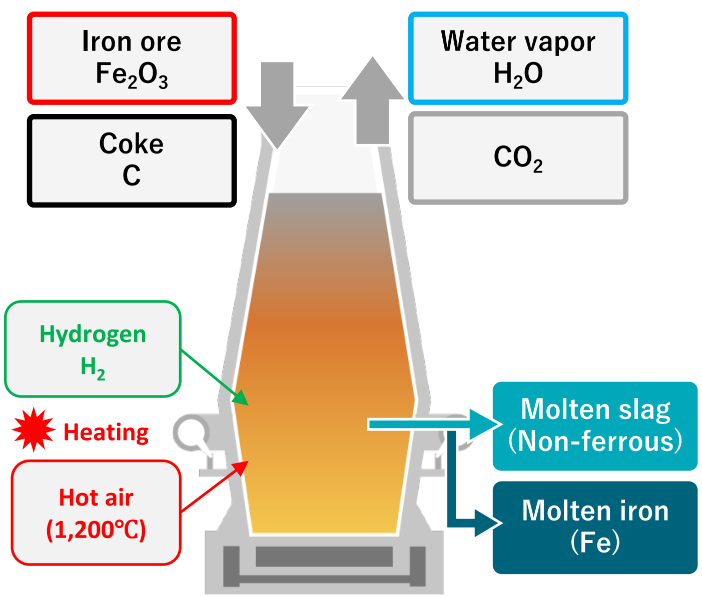
A breakdown of CO_2 emission during steelmaking process



Revised from "Carbon Trust, International Carbon Flows - Steel (2011),"

Challenges of reducing CO_2 (1) - Hydrogen injection into blast furnace -





Problems

Reduction with carbon is exothermic but that with hydrogen is **endothermic, causing the temperature drops**. **Pre-heating of hydrogen is necessary for the large amounts of hydrogen injection**.

	Conventional BF	Hydrogen BF
Heated gas (Risk of explosion)	Air (No)	Hydrogen (Yes)
Blower	Several thousand Nm^3/min.	**＋ Large amount of preheated hydrogen**
Heating method	Blast furnace (heat exchange with preheated fire bricks)	**Safe and high-efficiency preheating technology to be developed**

Challenge

Development of technology for endothermic

Revised from Nippon Steel Carbon Neutral Vision 2050
https://www.nipponsteel.com/en/ir/library/pdf/20210330_ZC.pdf

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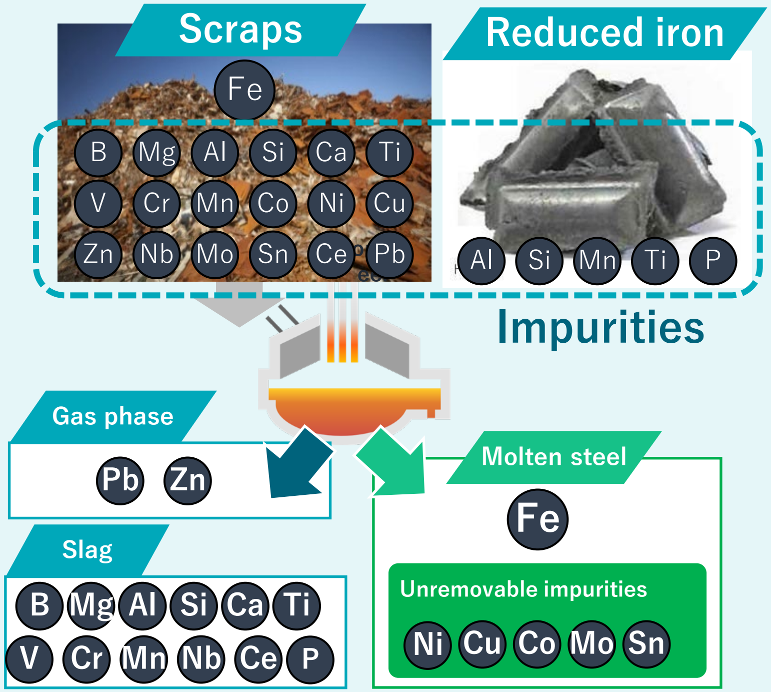
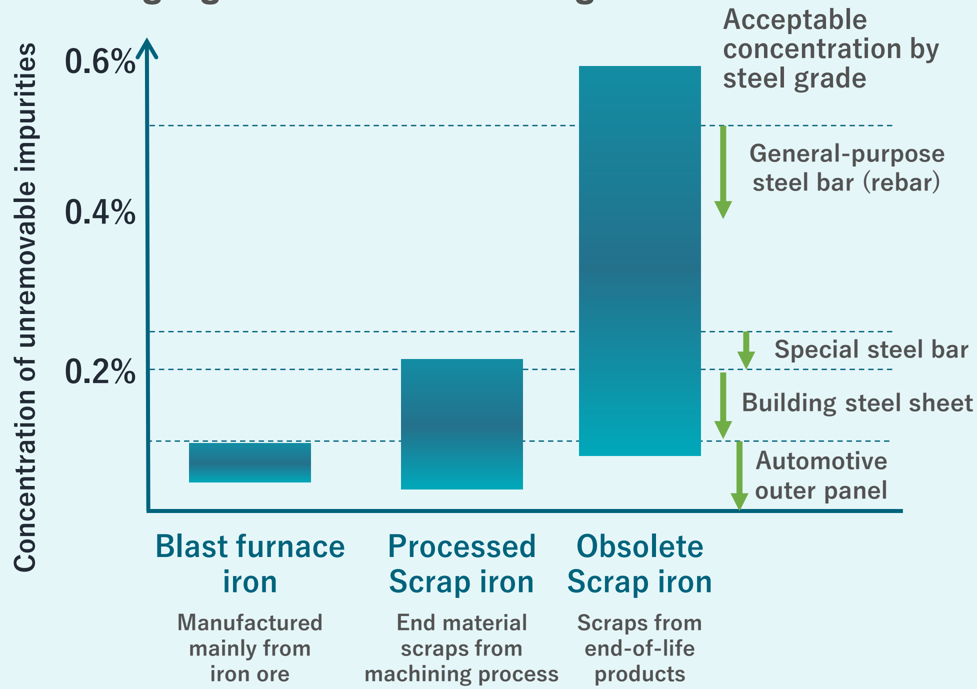
Challenges of reducing CO_2 (2) -Expansion of usage volume of scrap and reduced iron-

- Quality constraints due to (1) impurities such as tramp elements mixed in scrap iron and phosphorus in reduced iron and (2) nitrogen mixed in molten steel
- These issues have resulted in constraints on steel grades that can be produced using electric furnaces. It is particularly difficult to manufacture high-grade steel from low-grade raw materials.



Revised from Takehito Hiraki et al., “The 23rd Annual Conference of Japan Society of Material Cycles and Waste Management (2012) 23_269,



Revised from Jones, A.J.T., Assessment of the Impact of Rising Levels of Residuals in Scrap, “Proceedings of the Iron & Steel Technology Conference (2019),”

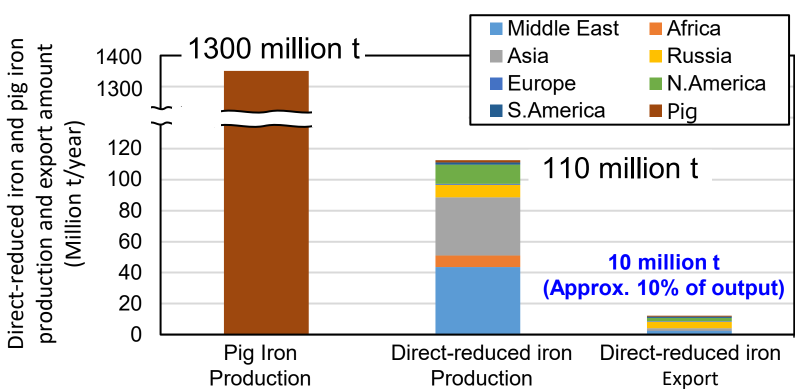
Challenge

High-grade steel production from low-grade raw material by electric arc furnace based on the refining technology for harmful elements

What steelmaking processes will be required going forward?

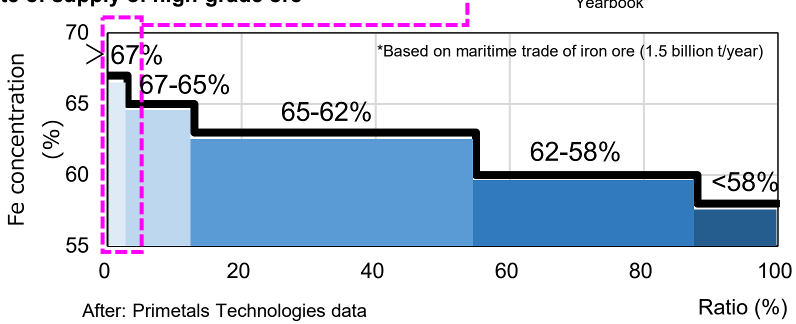
- The distribution volumes of high-grade ore for direct-reduced iron are limited. Therefore, the utilization of low-grade ore is essential for the technology popularization purposes.
- It is currently difficult to produce high-grade steel by electric arc furnaces. Steel production using blast furnaces will therefore continue going forward.
- In Asia, as geographical conditions dictate the use of low-grade ore, the blast furnace-converter method is predominant method. Development of reducing CO_2 in blast furnaces would make it possible to reduce a huge amount of CO_2 .

Global direct-reduced iron production and export

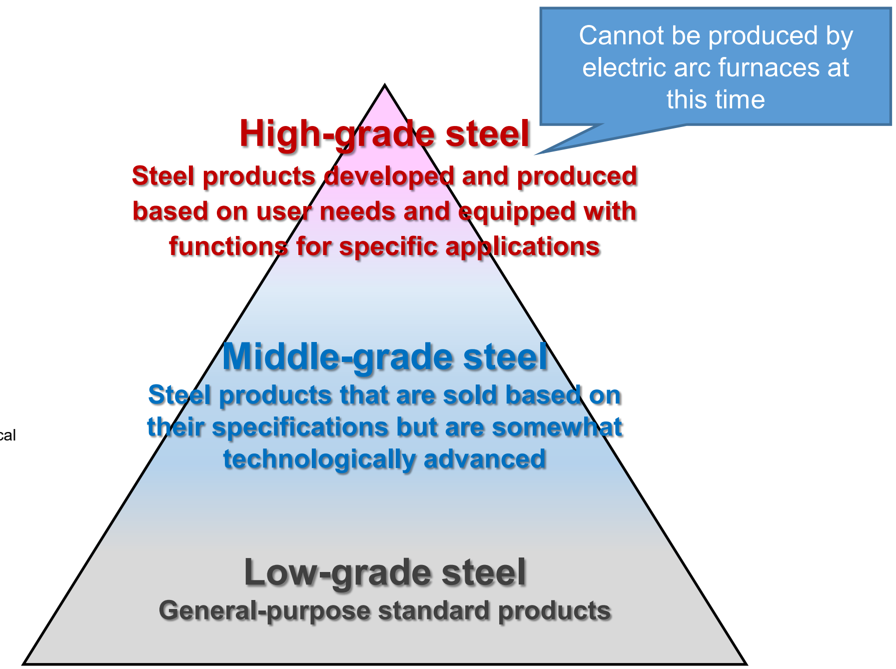


Edited based on 2019 Worldsteel "Steel Statistical Yearbook"

State of supply of high-grade ore



After: Primetals Technologies data

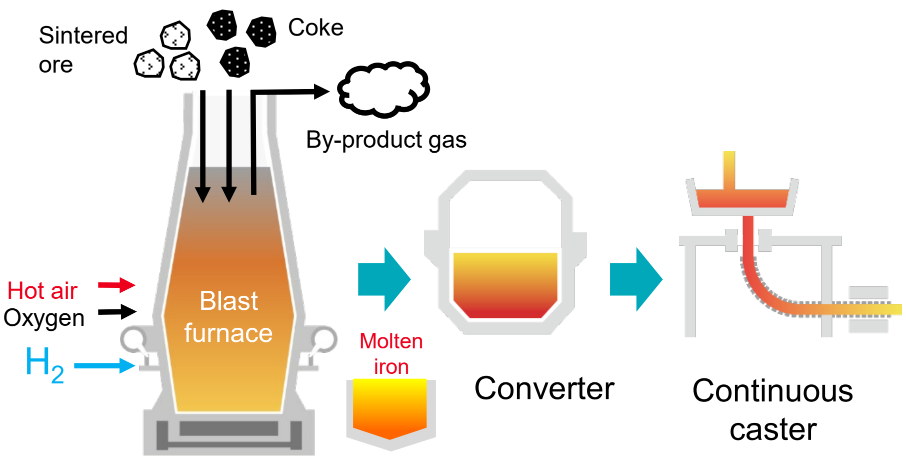


https://www.meti.go.jp/committee/kenkyukai/sansei/kaseguchikara/pdf/010_s03_02_03_01.pdf

Importance of double-track initiatives

✔ **High-grade steel production by carbon-neutral steelmaking process has not yet been established. In the GREINS project, we are pursuing development for both the blast furnace-converter process and the direct reduction-electric arc furnace process.**

Hydrogen reduction technology in blast furnace



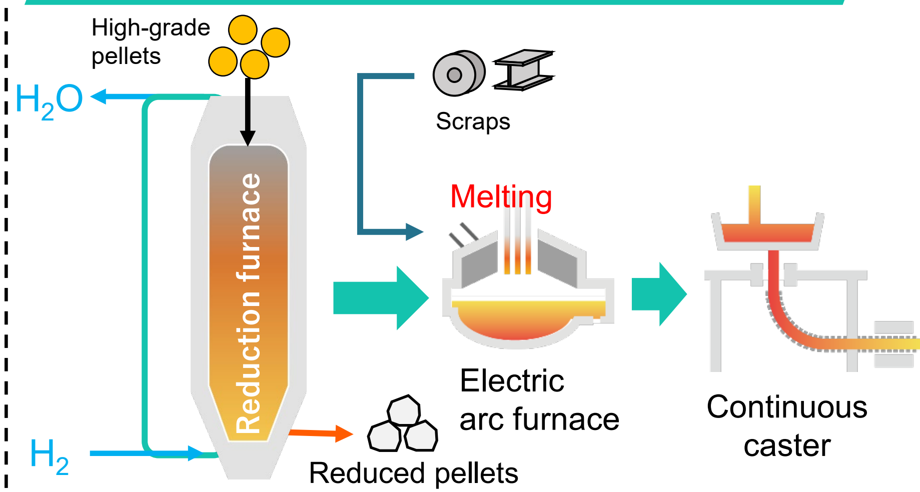
○Merits

- Easier to use low-grade iron ore
- Production of high-grade steel possible

○Demerits

- Utilization of CCUS indispensable in order to realize carbon neutrality

Direct hydrogen reduction technology to reduce low-grade iron ore



○Merits

- Realize carbon-neutral steelmaking process if green hydrogen/power are supplied sufficiently

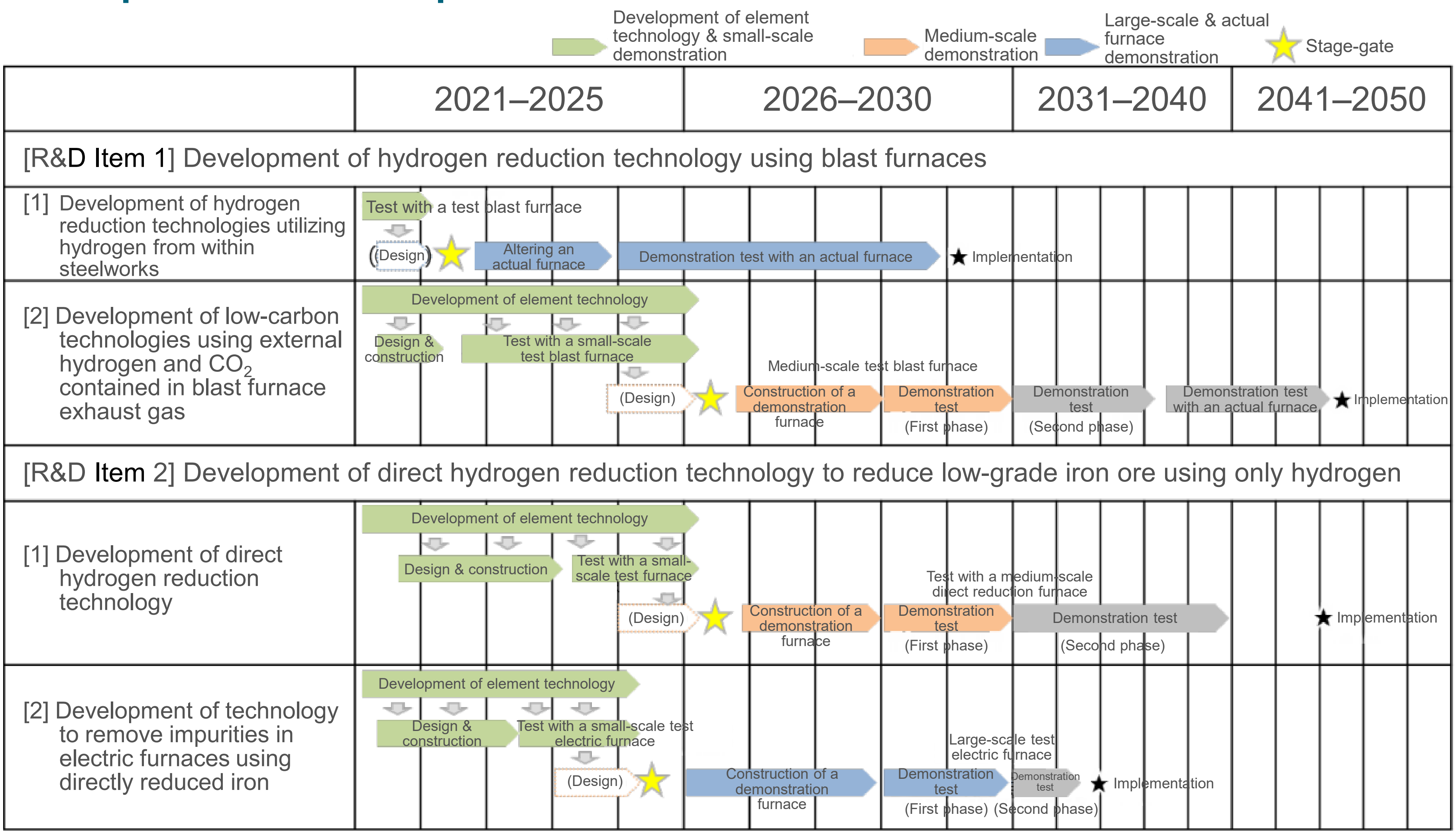
○Demerits

- Uncertain whether low-grade ore can be used or not (No announcement of commercial use at this time)
- Challenges with impurities and nitrogen constraints for high-grade steel

Project Schedule

METI's R&D and social implementation plan regarding the "Hydrogen Utilization in Iron and Steelmaking Processes" project

✔ The Consortium will advance development of the stage-gate review scheduled for FY2025 and FY2026 and subsequent activities to be implemented in cooperation.



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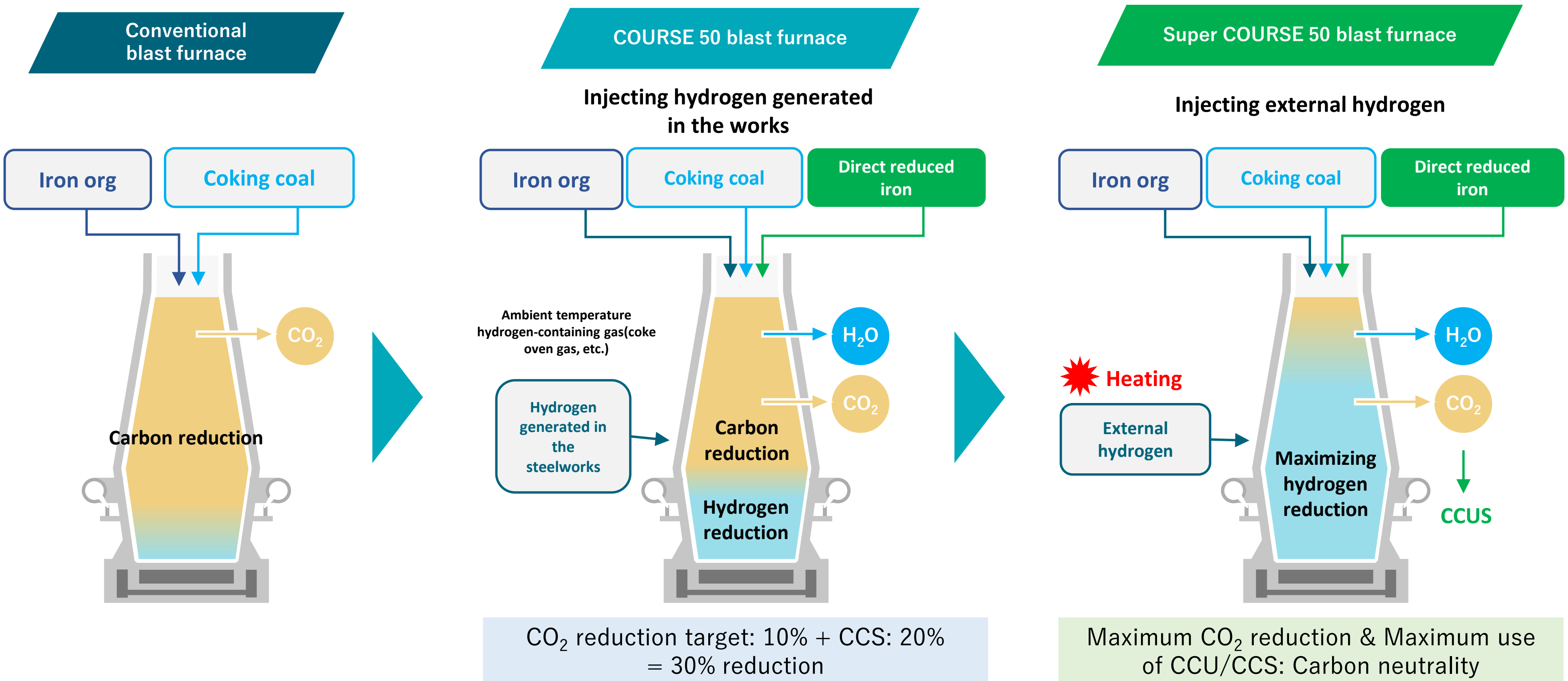
Hydrogen reduction technology in blast furnaces: Direct use of hydrogen

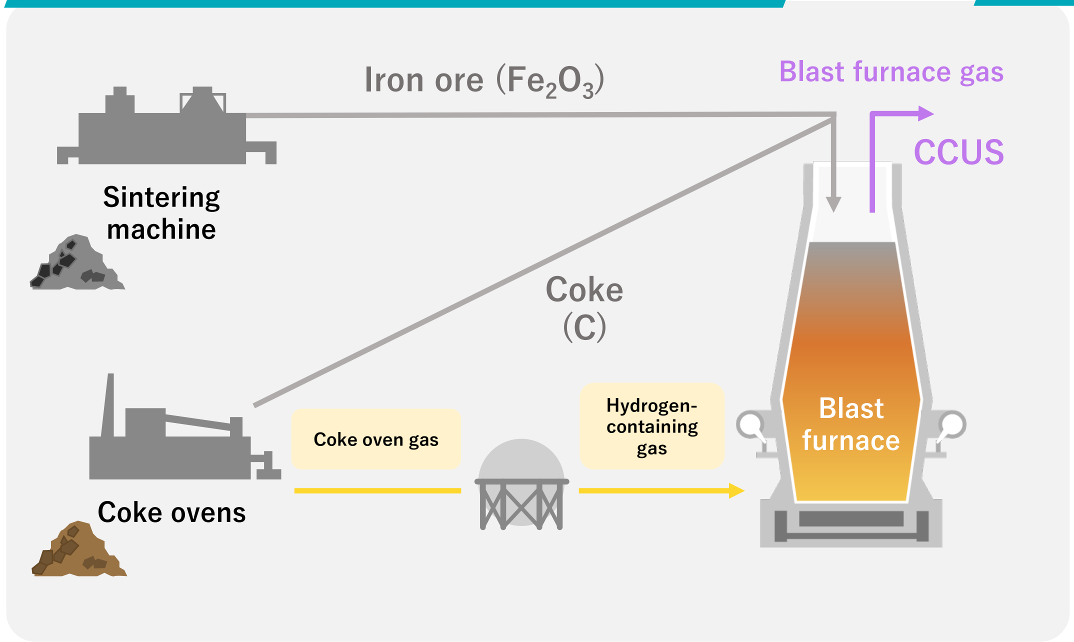
- **COURSE50**: The goal of this project is to reduce CO_2 emissions by 30% or more from iron and steelmaking processes using technologies such as hydrogen reduction in blast furnaces and CO_2 capture and/or separation (CCUS) by 2030. **Hydrogen-containing gas is supplied within the steelworks and blown into the blast furnace at room temperature.**
- **Super COURSE50**: Aims to maximize hydrogen reduction in the blast furnace and therefore minimize CO_2 emissions by directly **using high temperature external hydrogen.**



Demonstration of COURSE50: Mass injection test of hydrogen-containing gas in a 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 FY2025**.

Blast furnace hydrogen reduction technology (CO_2 reduction by 10%)



Demonstration test in FY2025 with Kimitsu No.2 Blast Furnace of Nippon Steel corporation

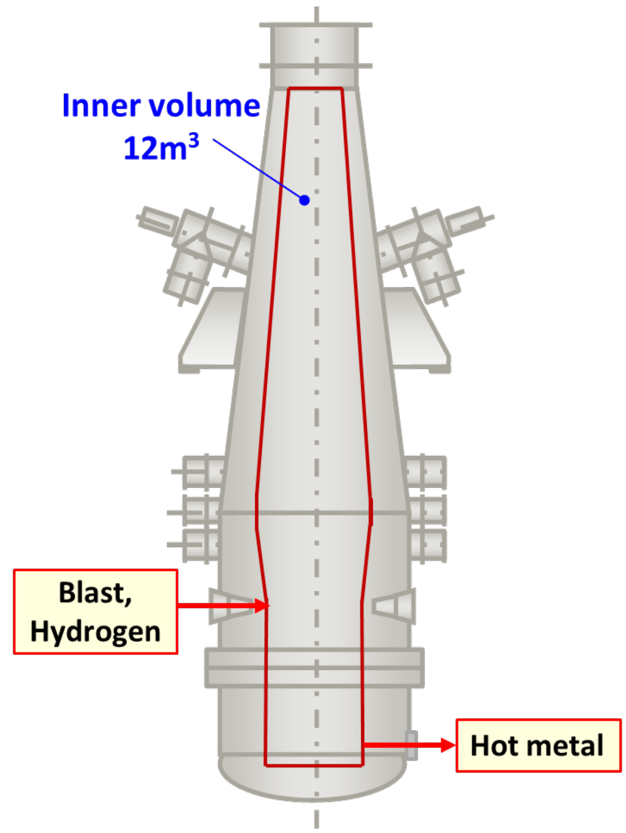
https://www.nipponsteel.com/en/news/20230209_100.html

Super COURSE50 experimental blast furnace (EBF)

- **Hydrogen injection operation test** is **underway** in **the experimental blast furnace** (12m^3) at East Nippon Works Kimitsu Area of Nippon Steel Corporation.

Experimental blast furnace (EBF) facilities

Vertical cross-section of EBF



Results of Hydrogen injection test in EBF

- **In the COURSE50 EBF**, continuous stable operation during an operation period of 32 days was carried out. As a result, CO_2 emissions were reduced **by 16% by injecting hydrogen at room temperature.** (See figures below)
- **In the Super COURSE50 EBF** remodeled COURSE50 EBF, we have confirmed that **heated hydrogen injection** reduces CO_2 emissions **by 22%,** the highest level in the world.

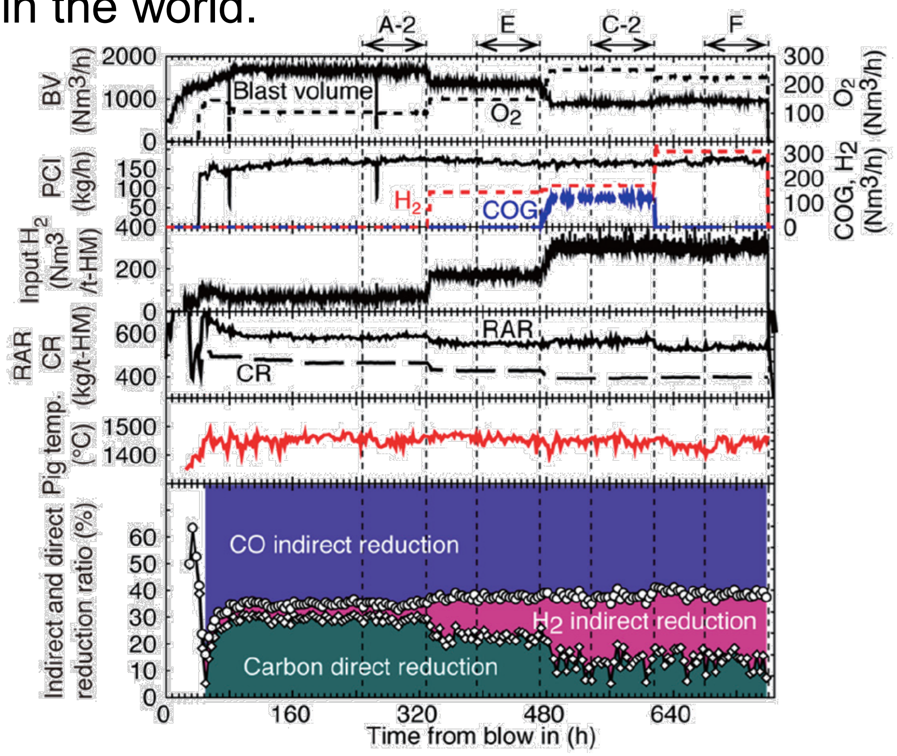


Fig. Example of operation trend of experimental blast furnace.

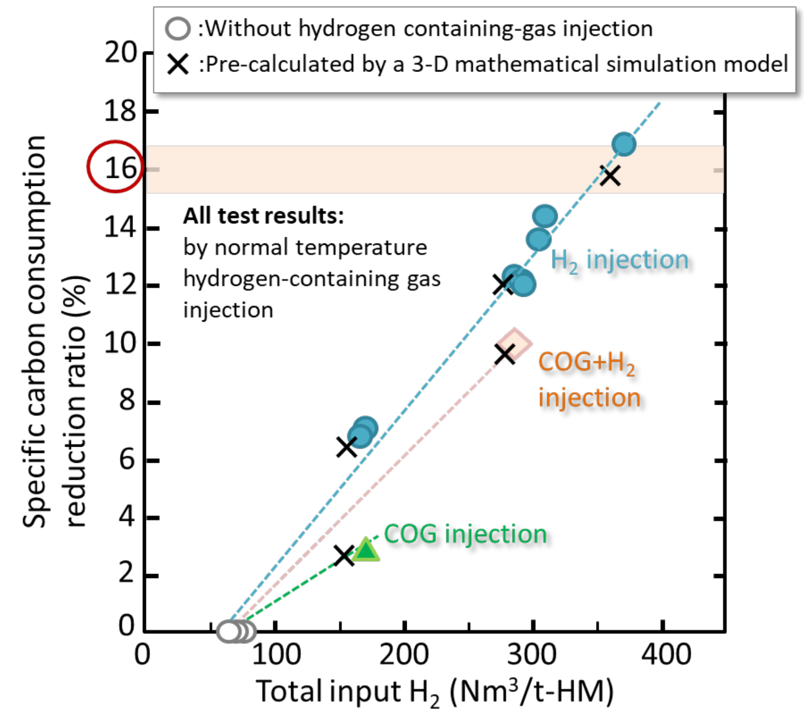
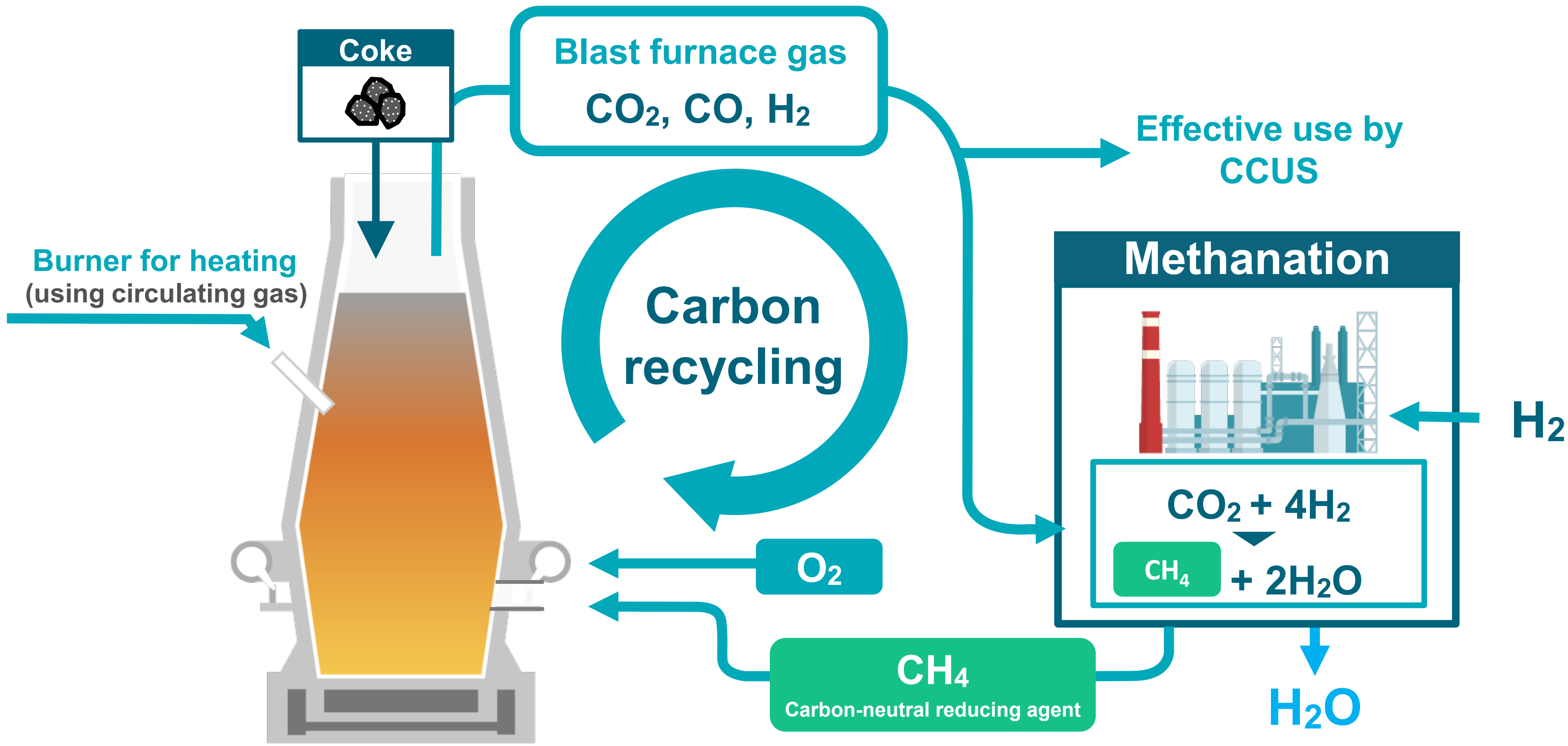


Fig. Relationship between total H_2 input with reduction rate of carbon.

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

Hydrogen reduction technology in blast furnace: Indirect use of hydrogen

- Conversion of CO_2 generated in a blast furnace into methane and repeated use of it as a reducing agent.
- Part of the reducing agent is changed from coke to carbon-neutral methane to reduce CO_2 emissions.



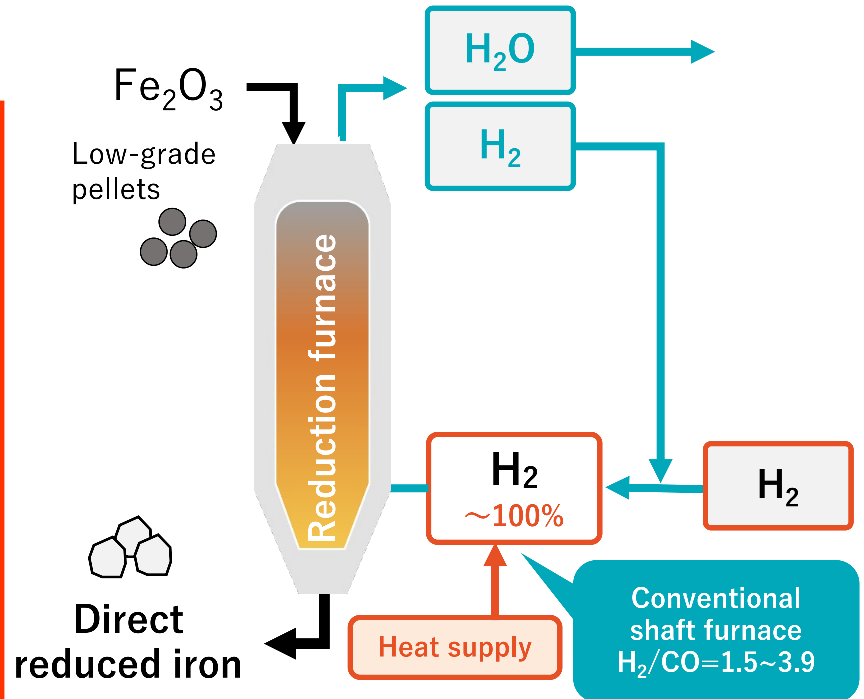
▪Construction of small carbon recycling BF(150m^3 scale).
▪Experiments will start in 2025 at JFE Steel, East Japan Chiba Works.

Direct hydrogen reduction technology to reduce low-grade iron ore

- Demonstrating technology that reduces **CO_2 emissions by 50% or more relative to the existing blast furnace method through technology that directly reduces low-grade iron ore using hydrogen by the year 2030**
- **Proceeding to pursue the development of technology to enable the utilization of low-grade pellets**

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



$$Fe_2O_3 + 3H_2 \rightarrow 2Fe + 3H_2O \quad -886 \text{ MJ/t-Fe}$$
$$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2 \quad +222 \text{ MJ/t-Fe}$$

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

- Construction of small test shaft furnace(1t/hr).
- Experiments will start in FY2025 at Nippon steel, Hasaki R＆D Center.

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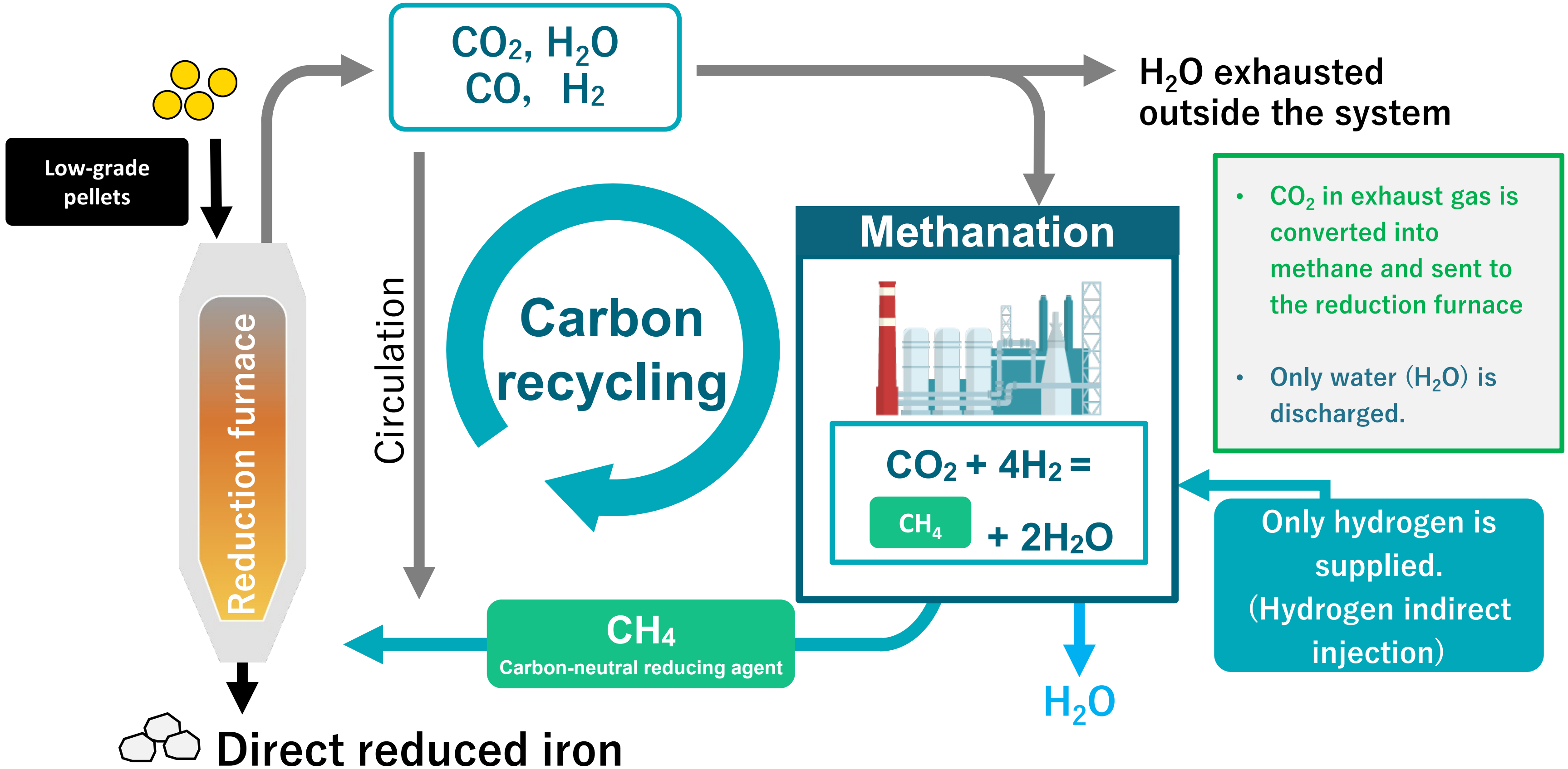
Development of carbon recycling direct reduction method

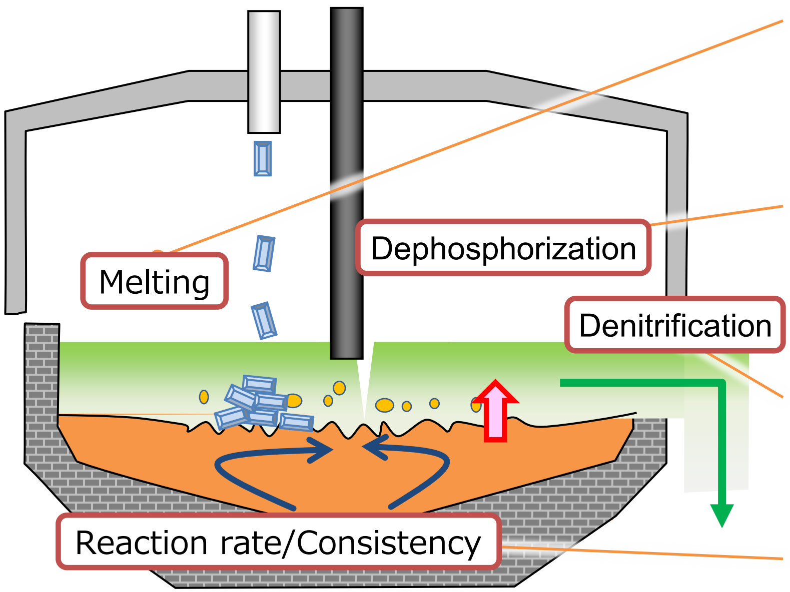
✔ Proceeding to also develop **a carbon recycling direct reduction method that uses methanation technology to capture carbon inside the system, and direct reduction is conducted using hydrogen only.**



・Construction of bench-test furnace.
・Experiments will start in FY2024 at JFE Steel, East Japan Chiba Works

Development of EAF Technology for High-grade Steelmaking

- 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 integrated electric arc furnace process** (approx. 300 tons) by 2030.
  - (1) Development of element technology and verification in a small-scale test electric arc furnace and secondary refining (3–10 tons)
  - (2) Demonstration test in a large-scale test electric arc furnace and secondary refining (approx. 300 tons)



Improvement of DRI dissolution rate
Optimization of DRI specifications, feeding position and rate, and improvement of agitation

Phosphorus reduction
Promotion of dephosphorization by improving agitation 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.

- Construction of small test EAF(10t). Experiments will start in FY2024 at Nippon steel, Hasaki R＆D Center.
- Construction of small test EAF(10t). Experiments will start in FY2024 at JFE Steel, East Japan Chiba Works.
- Modification of small commercial furnace (20t). Experiments started in FY2022 at KOBELCO, Takasago Works.

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Challenges in realization of carbon-neutral steelmaking

Increased costs for realizing carbon-neutral steelmaking

- **Massive R&D expense**
  Several hundred billion yen is needed by 2030. Further significant development costs are required toward 2050. (Additional support to Green Innovation Fund is needed)
- **Massive investment into development into commercial production equipment**
  Approximately 10 trillion yen in investment in plant and equipment aimed at realizing CN is envisioned to be required for steel industry overall
  (Establishment of another support measures for investment for acting equipment)
- **Green hydrogen/power costs and investment in infrastructure development**
  (Setting of industrial prices that put Japan on equal footing with overseas)

Social cooperation needed to realize carbon-neutral steelmaking

- **National strategy to realize "virtuous cycle of environment and economic growth"**
- **Reinforcement of industrial competitiveness by ensuring equal footing in international competition**
- **Unified realization of various government policies that link to business opportunities**
- **Formation of consensus on bearing costs across society as a whole**
- **Promotion of cooperation with other industries, etc.**

Summary

- The four companies belonging to the Hydrogen Steelmaking Consortium will continue their efforts aimed at technological development and social implementation pertaining to this project and contribute to the realization of a sustainable society moving forward, by sharing the joint utilization of the resources (human resources, plant/equipment and knowhow) of each company.

"GREINS" means " Green Innovation in Steelmaking"

This presentation is based on results obtained from a project, JPNP21019, commissioned by the New Energy and Industrial Technology Development Organization (NEDO)