Carbon Neutrality Initiatives in Japanese Steel Industry

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GREINS project overview

Challenge of reducing CO₂ emissions in the steel industry

Details of GREINS project development

Industry-Academia Collaboration ～Carbon Neutrality Initiatives of ISIJ～

"GREINS" = "GREen INnovation in Steelmaking"
Hydrogen Reduction Steel Making aimed at reducing CO$_2$ emissions.

2008, Blast furnace hydrogen reduction technology COURSE50 project started.
"COURSE50" : "CO$_2$ Ultimate Reduction System for Cool Earth 50"

2017, Scientific verification for the first time in the world
Reduction of CO$_2$ emissions by 10% in a blast furnace using the experimental blast furnace

Multi-track technical development project;
- Blast furnace process
- Direct reduction ironmaking process
- Electric arc furnace process

https://www.greins.jp/en/message/message01/
GREINS is carried out by the Hydrogen Steelmaking Consortium.

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.

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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Global and Japan’s CO₂ emissions from Energy (2020)

Global:
- China: 31.8%
- USA: 13.4%
- EU: 7.6%
- India: 6.6%
- Russia: 4.9%
- Korea: 1.7%
- Others: 30.7%

Global CO₂ emissions: 31.7 billion ton

Japan:
- Steel Industry: 13.6%
- Nippon Steel: 8.0%
- Other Steel Companies: 5.6%
- Industries (except Steel Industry): 23.3%
- Households: 17.2%
- Business: 18.8%
- Transportation: 19.1%
- Confersion to energy: 8.1%

Japan’s emissions is 3.1% of global emissions.

Source of reference:
- Global: Ministry of Environment: (000098246 (1).pdf) “Global CO₂ emission from Energy”
Overview of blast furnace-converter process

(1) Iron oxide is removed of oxygen (reduced) and melted,

(2) Transport the molten iron

(3) removed of impurities,

(4) solidified into semi-finished products with standardized sizes,

(5) processed into steel products.

Iron one

Fe$_2$O$_3$
Iron oxide

C
Carbon

Coal

Iron oxide

Sintering machine

Coke oven

Blast furnace

Fe
Molten iron

Reducing

Melting

CO$_2$

Blast furnace

Converter

Continuous caster

Molten steel

Refining

Molding

Rolling

Annealing

Steel products

[2] Transport the molten iron

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Revised from Nippon Steel Carbon Neutral Vision 2050
Breakdown of CO₂ emissions during steelmaking process

Most of CO₂ emission is due to ironmaking process conducted using blast furnaces (approx. 80%).

- CONVERTER: 0.2-0.3 t-CO₂/t-crude steel
- CONTINUOUS CASTING: <0.1 t-CO₂/t-crude steel
- FROM ROLLING TO FINISHED PRODUCTS: 0.2-0.3 t-CO₂/t-crude steel
- OVERALL AVERAGE: 1.8-3 t-CO₂/t-crude steel

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
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Research and development items of GREINS project

1. Development of hydrogen reduction technology using blast furnaces
   -1) Development of hydrogen reduction technologies utilizing hydrogen from within steelworks (COURSE50)
   -2) Development of low-carbon technologies using external hydrogen and CO\textsubscript{2} contained in blast furnace exhaust gas

2. Development of direct hydrogen reduction technology to reduce low-grade iron ore using only hydrogen
   -1) Development of direct hydrogen reduction technology
   -2) Development of technology to remove impurities in electric furnaces using directly reduced iron
Hydrogen reduction technology in blast furnaces: Direct use of hydrogen

Conventional blast furnace
- Iron ore
- Coking coal

COURSE50 blast furnace
- Injecting hydrogen generated in the works
- Iron ore
- Coking coal
- Direct reduced iron

Super COURSE50 blast furnace
- Injecting external hydrogen
- Iron ore
- Coking coal
- Direct reduced iron

Carbon reduction
- CO₂

Hydrogen generated in the steelworks
- Normal temperature hydrogen-containing gas (coke oven gas, etc.)

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

Hydrogen reduction

External hydrogen
- Maximum CO₂ reduction & Maximum use of CCU/CCS: Carbon neutrality
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 (CO₂ reduction by 10%)

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

Super COURSE50 experimental blast furnace (EBF)

Hydrogen injection operation test is underway in the experimental blast furnace at East Nippon Works Kimitsu Area of Nippon Steel Corporation.
Results of Hydrogen injection test in EBF

COURSE50 EBF: Carbon consumption reduction of 16% by injecting room temperature hydrogen from tuyeres
Super COURSE50 EBF: Carbon consumption reduction of 22% by injecting high temperature hydrogen from tuyeres

Fig. Example of operation trend of experimental blast furnace.
Fig. Relationship between total H₂ input and carbon consumption rate.

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.

![Diagram showing the process of converting CO$_2$ to methane]

- 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 CO₂ 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

<table>
<thead>
<tr>
<th></th>
<th>Existing shaft furnaces</th>
<th>Hydrogen-reducing shaft furnaces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction materials</td>
<td>Natural gas</td>
<td>Hydrogen</td>
</tr>
<tr>
<td>H₂ concentration</td>
<td>60~80%</td>
<td>~100%</td>
</tr>
<tr>
<td>Heat supply</td>
<td>natural gas/exhaust gas combustion</td>
<td>heating hydrogen, etc.</td>
</tr>
</tbody>
</table>
| Raw materials          | High-grade pellets      | Lower-grade Pellets              

Fe₂O₃ + 3H₂ → 2Fe + 3H₂O  \(-886 \text{ MJ/t-Fe}\)
Fe₂O₃ + 3CO → 2Fe + 3CO₂  \(+222 \text{ MJ/t-Fe}\)

Business Strategy Vision
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.

**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.
Innovative CO₂ Capture Technology with energy-saving

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

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

![Graph showing CO₂ capture energy reduction](image)

**Commercialized plant No.1**
(AIR WATER CARBONIC INC.)

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

<table>
<thead>
<tr>
<th>Specification</th>
<th>Plant No.1 (from 2014)</th>
<th>Plant No.2 (from 2018)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emission source</td>
<td>Steelmaking hot-stove</td>
<td>Coal-fired power</td>
</tr>
<tr>
<td>CO₂ use</td>
<td>Generates industrial CO₂</td>
<td>Manufactures feed additives</td>
</tr>
</tbody>
</table>

**Fig. Reducing CO₂ capture energy by developing new absorbents.**


Source: https://www.eng.nipponsteel.com/english/whatwedo/energy_solutions/escap/escap

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ISIJ committee of carbon neutral iron & steel making

was established in 2022 to unite industry and academia to promote activities that contribute to carbon neutrality in the steel industry

- Discussions on flexible strategies based on academic principles
- Complementary role to large-scale project led by steel-maker supported by national budget

Research grant system of ISIJ

- Grants for Research Persons on Carbon-Neutral Iron and Steel
  2022 FY 24 / 92 (Number of adoptions / applications)
  2023 FY 23 / 89
  2024 FY qualifying in progress
- Grants for Promotion of Iron and Steel Research
- Grants for Research Groups; 24 projects (number in progress at the end of Dec. 2022)
Cokemaking Technology for Low CO₂ Emission and High Quality while Extending Available Resources.

- Newly developed pre-treatment of cokemaking raw materials with biomass could increase coke strength.
- A new co-processing with biomass and waste plastic was proposed and found to improve carbonisation yield and coke strength.
- The clarification of the pyrolysis behaviour of tar under pressure has led to dry distillation technology under low energy consumption conditions.

(1) Modification technology
Kyoto Univ., Nagoya Univ.,
National Institute of
Advanced Industrial Science and Technology,
Mitsubishi Chemical, Nippon Steel Stainless Steel

(2) Conversion technology of unused carbon resources
Nagoya Univ., Kyushu Univ., Mie Univ.,
Nippon Steel Stainless Steel,
JFE Steel, Kansai Coke and Chemicals

(3) New carbonization technology
Hokkaido Univ., Tohoku Univ.,
National Institute of
Advanced Industrial Science and Technology,
Kobe Steel, Nippon Steel Stainless Steel,
JFE Steel

2019～2021, Now moving on to the next stage
“CCU for iron and steel making”

Point is the development of CCU from steelmaking flue gases, including CO₂, CO and S, rather than from concentrated CO₂.

(1) Catalytic conversion technology
National Institute of Advanced Industrial Science and Technology, Hokkaido Univ., Kyushu Univ., Nippon Steel, Kobe Steel

(2) Conversion technology for heat storage and heat control
Hokkaido Univ., JFE Steel, Kobe Steel

(3) CO₂ absorption, fixation and mineralisation technologies
Tohoku Univ., Nihon Univ., Nippon Steel, Kobe Steel
Disseminating CN research activities

The 1st Symposium on Carbon Ultimate Utilization Technologies for the Global Environment (CUUTE-1)

- 14th~17th, Dec, 2021 at Nara, Japan
- Contribution; 84 papers (domestic: 69, overseas: 15)

The 2nd Symposium on Carbon Ultimate Utilization Technologies for the Global Environment (CUUTE-2)

12th~15th, Nov, 2024 at Nara, Japan
Deadline of Abstract Submission: 29th Feb., 2024

https://cuute2.com/

Topics

1. Perspective for Low Carbon Society
   (1) Megatrends in industrial sector
   (2) Sector coupling
   (3) System modeling and analysis

2. Advanced Carbon and Energy Carrier Utilization
   (1) Iron and steelmaking industry
   (2) Chemical industry
   (3) Hydrogen and derived energy carriers
   (4) Generation and utilization of heat and power

3. CO₂ Utilization and Storage
   (1) CO₂ capture/separation technologies
   (2) CO₂ conversion processes
   (3) CO₂ utilization/sequestration technologies

ISIJ, an academic institute, provides an open platform for global researchers in the field of low-carbon ironmaking and steelmaking to present and publish their research results and discuss the scientific validity.

We welcome your participation in the activities of ISIJ.
Summary

✔ The Japanese steel industry has been the first in the world to engage in hydrogen reduction steelmaking from the earliest stage, through the COURSE50 project supported by NEDO.

✔ Based on the technologies gained in COURSE50, we launched a multitrack technical development project (GREINS) to realize a carbon neutrality in steelmaking as one of NEDO Green Innovation Fund Projects sponsored by METI.

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

✔ Academic societies are collaborating to strengthen our multi-track approach and to promote exploratory research with an eye on the future.

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

Thank you for your attention