Nippon Steel Carbon Neutral Vision 2050
A Challenge of Zero-Carbon Steel

March 30, 2021
NIPPON STEEL CORPORATION
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Abbreviations:
1. Scenario to realize Zero-Carbon Steel
Nippon Steel Carbon Neutral Vision 2050 — The Challenge of Zero-Carbon Steel

Adopting "Nippon Steel Carbon Neutral Vision 2050 – The Challenge of Zero-Carbon Steel,” as our own new initiative against climate change, a critical issue affecting human beings, we will strive to achieve carbon neutrality by 2050 as our top priority management issue.

Key Phrase Activity Logo

Make Our Earth Green

We have decided to actively work to achieve zero-carbon steel as a top priority management issue, and have established a new "Key Phrase" to summarize our environmental management and an "Activity Logo" to represent our activities as our "Environmental Brand Mark". We will make a concerted effort to tackle these extremely difficult issues.
Zero-Carbon Steel: Our CO\textsubscript{2} emissions reduction scenario

**2030 Target**

- 30% or more reduction in total CO\textsubscript{2} emissions vs. 2013

**Means**
- Actual implementation of the COURSE50 in the existing BF and BOF process
- Reduction of CO\textsubscript{2} emissions in existing processes
- Establishment of an efficient production framework.

**Vision 2050**

- Aim to become carbon neutral

**Total CO\textsubscript{2} emissions (MT/Y)**

- 30% reduction (Vs. 2013)

<table>
<thead>
<tr>
<th>Year</th>
<th>Emissions (MT/Y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>102</td>
</tr>
<tr>
<td>2019</td>
<td>91</td>
</tr>
<tr>
<td>2030</td>
<td>70</td>
</tr>
</tbody>
</table>

**2030 Target**
- Carbon Neutral

**2050 Vision**

**Means**
- Mass-production of high-grade steel in large size EAFs
- Hydrogen reduction steelmaking (by Super-COURSE50 use of BFs; direct reduction of 100% hydrogen)
- Multi-aspect approach, including CCUS* and other carbon offset measures.

*[Scope of Scenario]*
- Domestic
- SCOPE I + II
  - (Receipt of raw materials to product shipment) + (CO\textsubscript{2} at the time of purchase power production)

*Carbon dioxide Capture, Utilization, and Storage

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Current steelmaking process

INPUT
- Iron ore
- Coal
- Scrap

PROCESS
- BF + BOF process
- BOF
- Rolling mill
- EAF process

OUTPUT
- Steel

BF
CO₂
EAF process
CO₂
Carbon neutral steelmaking process

- **Breakthrough technologies**
  - 3 external conditions required for realizing zero-carbon steel

**INPUT**
- Scrap
- Iron ore
- Coking coal

**PROCESS**
- BF and BOF route
- BOF
- Rolling mill
- Increased use of scrap

**OUTPUT**
- High-grade steel production in large size EAF
- CCUS *
  - Chemicals, biofixing, underground storage

**BF and BOF route**
- Super-COURSE50 BF
- 100% hydrogen use in direct reduction process
- Directly reduced iron

**EAF route**
- Increased use of scrap
- Directly reduced iron

**INPUT**
- Iron ore
- Coking coal
- Scrap

**OUTPUT**
- CO₂

- * Carbon Capture, Utilization, and Storage
Our roadmap of CO$_2$ emissions reduction measures

- **2020**: 20% CO$_2$ reduction target
- **2030**: -30% (vs FY2013)
- **2050**: Carbon neutral

**BF and BOF route**
- **Lower CO$_2$ emission in existing processes**: (advance in existing technology, expanded use of scraps and waste plastics, etc.)
- **Lower carbon power**: (higher-efficiency power generation facilities, use of low carbon fuel in coal-powered generation, etc.)
- **Building of an efficient production system**: (centralized production at an integrated steel mill, etc.) (some transfers from BFs to EAFs, etc.)
- **Dev’t**: CCS (underground storage)/CCU (re-use)

**EAF route**
- **Dev’t**: Production of high-grade steel in large size EAFs
- **Dev’t**: 100% hydrogen use in direct reduction
- **Dev’t**: Hydrogen injection into BF
- **Dev’t**: CCS (underground storage)/CCU (re-use)

**Breakthrough technology development**
- **Super-COURSE50**
- **COURSE50**

**External conditions**
- **Practical implementation**
- **Actual demonstration test**
- **Development**
- **Test**
2. CO$_2$ emissions in steelmaking process
CO₂ emissions in steelmaking process

- Steel is an “Earth-friendly material” as steel produces less CO₂ per unit of production and during its entire life cycle, compared to other materials, and is highly recyclable.

- The total amount of CO₂ emitted by the steel industry is high since steel has an overwhelmingly wider range of applications and is used extensively in large quantities compared to other materials.

Japan’s CO₂ emission by sector

**By emitting sector**
- Non-energy source: 7%
- Households: 5%
- Commercial-use: 6%
- Transportation: 18%
- Energy conversion: 39%
- Industry: 25%

**By using sector**
- Households: 16%
- Commercial-use: 19%
- Transportation: 20%
- Energy conversion: 8%
- Industry: 39%

Source: Ministry of the Environment, National Greenhouse Gas Inventory Report of Japan 2020

Automotive material’s CO₂ emission in production
- Steel
- Aluminum
- Carbon fiber reinforced plastics

Packaging material’s CO₂ emission in production
- Steel
- Aluminum
- Plastic (polypropylene)
- Paper (milk carton)

Source: Ministry of the Environment, National Greenhouse Gas Inventory Report of Japan 2020
Iron ore needs to be reduced

In nature, iron exists as oxides, iron ore.
To produce steel products, oxygen must be removed (= reduced) from iron ore.
The use of carbon (coal) is the best, stable, cost-effective method for reducing iron ore in large quantities.
The reaction, however, emits CO₂.

From **iron ore** that exists as iron oxides (e.g., Fe₂O₃) in nature,

Carbon (C) removes the oxygen (O) (reduction) in the iron ore as carbon is more reactive than iron (Fe).

One ton of steelmaking emits about 2 tons of CO₂

Fe₂O₃ → C → CO₂ → Fe

Steel is produced.

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(Appendix) BF method steelmaking process

1) Iron oxide is removed of oxygen (reduced) and melted,
2) transported in liquid state,
3) removed of impurities,
4) solidified into semi-finished products with standardized sizes,
and 5) processed into steel products.
The majority of CO₂ emissions in the steelmaking process is derived from the iron ore reduction process in the blast furnace.
Three eco-friendly efforts to address climate change

**Eco Process** (The way we manufacture is “eco-friendly”)
Japan’s steelmaking process is the most energy-saving in the world.

![Energy intensity in BOF steel production (Japan = 100) Source: RITE](image)

**Eco Products** (What we produce is “eco-friendly”)
Provides a wide variety of high-performance steel products, contributing to reduction of CO₂ emissions in use

- **High strength steel sheets for vehicles**
  - Achieve higher fuel efficiency with lightweight, higher safety and high processability

- **Electrical steel sheets**
  - Reduce energy loss of motors and transformers

- **High-strength stainless steel**
  - HYDREXEL™ for high-pressure gaseous hydrogen
  - Improves the strength, safety, workability, and life of the hydrogen infrastructure

**Eco Solution** (Sharing our “eco-solutions”)
Transfers best-available energy-saving technologies mainly in developing countries

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Steel stock in the form of final products, such as infrastructure (i.e., buildings and bridges), industry (i.e., machinery and ships), and durable consumer goods (i.e., automobiles and home appliances) is 30 billion tons or 4 tons per capita globally, although 8-12 tons per capita in developed countries. Expected to reach 10 tons per capita in China by 2050 and in India by 2100.

Global steel stock: **70 billion tons** in 2050

Assumption:
- Steel stock per capita of **7 tons** in 2050,
- Global population growth from 7.4 billion in 2015 to 9.8 billion in 2050,
- Economic growth in emerging countries, and
- Efforts to SDGs.
Primary steel production is necessary to increase steel stock in the future. Primary steel production is necessary to increase steel stock in the future.

Crude steel production needed to meet global steel stock growth will continue to increase.

Availability of scrap increases as the increase of steel stock.

Even if all the scrap is recycled, it is insufficient to meet the annual need for crude steel production, and steel production from iron ore will need to be at the same scale in the future.

In order to achieve zero-carbon steel, it is necessary to reduce CO₂ emissions not only from scrap recycling but also from iron ore reduction.

3. Breakthrough technology development
(1) High-grade steel production in large-sized EAFs
Current EAFs for high-grade steel in Nippon Steel

New EAF at Hirohata, Setouchi Works
Announced in Nov. 2019, installation in the 1st half of FY2022

Produces high-grade, high-quality steel sheets, including electrical steel sheets

- **Newly built**
  - EAF
  - Secondary refining
  - Continuous casting
  - Hot-rolling
  - Pickling/cold-rolling/annealing
  - Hot-dip galvanizing
  - Electro-galvanizing
  - Pickling
  - Cold-rolling
  - Annealing
  - Finishing

- **Shut down**
  - Smelting furnace
  - Basic oxygen furnace

Slab from other steelworks

Pig iron, internal scrap and processed scrap are used to produce high-grade steel for the moment

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New EAF at AM/NS Calvert, USA
Announced in Dec. 2020, installation in the 1st half of FY2023

Production of quality products, such as third-generation advanced high-tensile steel sheets (980MPa and more) and Interstitial Free steel (for deep-drawing processing for vehicle exterior panels) is planned.

- **Newly built**
  - EAF
  - Secondary refining
  - Continuous casting
  - Hot-rolling
  - Pickling/cold-rolling
  - Pickling
  - Cold-rolling
  - Annealing
  - Continuous annealing
  - Finishing
  - Electrical steel sheet line
  - Hot-dip galvanizing

Slab from other sites

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Production of high-grade steel in large-scale EAF

Since steel scrap has already been reduced, there is little CO₂ emissions associated with the recycling process resulting in low CO₂ intensity.

BF-BOF route: approx. 2.0 t-CO₂/t-steel
Scrap-EAF route: approx. 0.5 t-CO₂/t-steel

- Replace of some of domestic BFs with EAFs
- Use of scrap and DRI
  (Reduction with natural gas, finally with 100% hydrogen)
- Use of carbon-free power to minimize CO₂ emissions

**Problems**
- Quality restrictions due to impurities in scrap or nitrogen contamination during melting
- Scale of facilities and productivity need to be improved

**Challenge**
Development of high-grade steel manufacturing technology in a large EAF
High-grade steel production in large-scale EAF

Challenge 1: Impurities

Steel products that can be manufactured with a scrap-based EAF are limited, i.e. high-grade steel is difficult due to:
1) impurities such as copper contained or mixed in scrap, and
2) nitrogen contamination from the air

![Scrap composition diagram](image)

Modified from Takehito Hiraki et al. The 23rd Research Presentation, Japan Society of Material Cycles and Waste Management (2012) 23_269

![Impurities in molten steel](image)


Challenge

Manufacturing of high-grade steel in scrap-based EAF by eliminating unremovable impurities

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High-grade steel production in large-scale EAF

Challenge 2: Productivity

These are many problems in the production of high-grade steel in large-scale EAF:

(1) The productivity of EAF is lower than BOF. Compared to the strong agitation with an oxygen gas jet in a BOF, refining with natural convection in an EAF takes a long time, in addition to the long melting time from DRI or steel scrap. These will be more pronounced in large-scale EAFs.

(2) Gangue and void in DRI impede heat transfer, causing a long melting time. Gangue also raises the refining load and lowers the efficiency.

Average size of EAF
< 100 t/charge (≒ 0.7 Mt/year)

Nippon Steel’s average size of BF (after completion of structural measures)
≒ 4,900 m³/unit (≒ 4.0 Mt/year)

Achieving high productivity in a large-scale EAF that can replace a BF in steelmaking by establishing the DRI melting and refining technology
4. Breakthrough technology development
(2) Hydrogen injection into BF
(COURSE50 and Super COURSE50 projects)
Hydrogen injection into BF (COURSE50 & Super COURSE50)

Conventional BF
- Iron ore
- Coking coal
- Carbon reduction

COURSE50 BF
- Byproduct hydrogen injection
- Iron ore
- Coking coal
- Hydrogen
- Partial hydrogen injection
- Reduction of CO₂ emissions by 30%: 10% with hydrogen + 20% with CCS

Super COURSE50 BF
- Outsourced hydrogen injection
- Iron ore
- Coking coal
- Hydrogen
- Maximum hydrogen injection
- Carbon neutral with a maximum use of hydrogen + CCU/CCS

COURSE50 and Super COURSE50 retrofit to existing BFs, partially replacing coking coal to hydrogen + iron ore to DRI
Reduction of iron ore with hydrogen

**Reduction with hydrogen**

Hydrogen replaces coke as reducing agent, producing $\text{H}_2\text{O}$ with no $\text{CO}_2$ emissions.

**Reduction with carbon**

Coking coal

Iron ore $\text{Fe}_2\text{O}_3$  $\text{C}$  $\text{CO}_2$  Steel $\text{Fe}$

**Reduction with hydrogen**

Hydrogen

Iron ore $\text{Fe}_2\text{O}_3$  $\text{H}_2$  $\text{H}_2\text{O}$  Steel $\text{Fe}$

**Hydrogen steelmaking today**

DRI with natural gas is operated in several locations in the world but not in Japan due to the high cost of natural gas.

There is no case of hydrogen injection into BF so far, due to the difficulty of supplying cost-effective hydrogen.

Cf. 1 "Hydrogen Basic Strategy" scenario by METI

<table>
<thead>
<tr>
<th>Year</th>
<th>Hydrogen cost</th>
<th>Hydrogen supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present</td>
<td>¥100/Nm$^3$</td>
<td>2 million tons</td>
</tr>
<tr>
<td>2030</td>
<td>¥30/Nm$^3$</td>
<td>3 million tons</td>
</tr>
<tr>
<td>2050</td>
<td>¥20/Nm$^3$</td>
<td>20 million tons</td>
</tr>
</tbody>
</table>

Cf. 2 Hydrogen cost equivalent to coking coal

$¥8$/Nm$^3$

Cf. 3 Hydrogen required to produce all the current domestic pig iron (75 Mt/year)

75 billion Nm$^3$/year (7 Mt/year)
BF and the role of coke

BF is an ultra-large reactor that produces iron continuously and efficiently from iron ore. Oxygen in the hot blast blown through the tuyere and the coke produces a high temperature reduction gas which then reduces the iron ore, input from the top, to iron, and is continuously output as molten pig iron. 10,000 tons/day of iron (the amount used for 10,000 passenger cars) is continuously produced by the BF.

The role of the coke

1. Reducing agent (carbon C)
2. Source of heat (heat generated by combustion)
3. Support of raw materials at high temperature, maintaining ventilation in the furnace
4. Byproduct gas production in coke making, as an energy source in the steelworks (for power generation, heating furnace, etc.)
Hydrogen injection into BF, Challenge 1: Heating of hydrogen

Reduction with carbon

Fe₂O₃ → Fe

Exothermic

Reduction with hydrogen

Fe₂O₃ → Fe

Endothermic

Reduction with carbon is exothermic but that with hydrogen is endothermic, causing a temperature decrease. Pre-heating of hydrogen is necessary for the large amount hydrogen injection.

- **Problems**

<table>
<thead>
<tr>
<th></th>
<th>Conventional BF</th>
<th>Hydrogen BF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heated gas (Risk of explosion)</td>
<td>Air (No)</td>
<td>Hydrogen (Yes)</td>
</tr>
<tr>
<td>Blower</td>
<td>Several thousand Nm³/min.</td>
<td>+ Large amount of preheated hydrogen</td>
</tr>
<tr>
<td>Heating method</td>
<td>Blast furnace (heat exchange with preheated fire bricks)</td>
<td>Safe and high-efficiency preheating technology to be developed</td>
</tr>
</tbody>
</table>

**Challenge**

Development of technology to inject a large amount of hot flammable gas into BF
Hydrogen injection into BF, Challenge 2: gas permeability

BF is a reactor that continuously performs 1) heating, 2) reduction, and 3) melting (separation of non-ferrous components).

Less carbon (coke) and more hydrogen input to BF leads to
1. less coke support, which causes less gas permeability, worse reactions in the BF, and
2. less contact with high-temperature gas, making it difficult to melt.

Challenge
Ensuring maximum gas permeability for stable reaction and melting with less coke in the BF
Hydrogen injection into BF, Challenge 3: Scale up

The actual BF is hundreds of times larger than the experimental BF. Scaling up faces less uniform gas flow, heat distribution, sticking of ore, and melt flow.

**Experimental BF:** 12 m$^3$
**Productivity:** 30 t/day

**BF:** 5,000 m$^3$
**Productivity:** 10,000 t/day

**Challenge**

Scaling up technology to simulate a large-scale BF.
Outline of the COURSE50 Project

Reduction in CO₂ emissions by 30% with the world-first hydrogen use in BF + CO₂ capture

(1) Reduction of CO₂ emissions
Reducing CO₂ emissions by 10%, partially replacing coke with hydrogen

(2) CO₂ capture
Reducing CO₂ emissions by 20%, capturing CO₂ from BF gas

COURSE50: CO₂ Ultimate Reduction System for Cool Earth 50 Project

100% supported by NEDO (New Energy and Industrial Technology Development Organization)
Operated by Nippon Steel, JFE Steel, Kobe Steel and Nippon Steel Engineering
Initiatives of the COURSE50 Project

Nippon Steel, two other BF steelmakers, and Nippon Steel Engineering began development in 2008. The hydrogen reduction technology was experimented at a test BF in the East Nippon Works Kimitsu Area.

<table>
<thead>
<tr>
<th>Year</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>2008</td>
<td>Phase 1, Step 1, Basic technology development</td>
</tr>
<tr>
<td>2008-2012</td>
<td>Phase 1, Step 2, Comprehensive technology development</td>
</tr>
<tr>
<td>2013-2017</td>
<td>2018 - Phase 2, Development for practical use</td>
</tr>
</tbody>
</table>

**COURSE50 Experimental BF**

- Blast furnace
- Material tank
- PCI
- Experimental BF

**COURSE50 CO₂ separation and storage technology**

- Absorption tower
- Stripper
- Reboiler

Implementation and spread of operation at the time of relining, aiming for achievement by 2050.
5. Breakthrough technology development
(3) 100% hydrogen use in direct reduction
100% hydrogen use in direct reduction process

BF process

Fe₂O₃ → Reduction → Molten iron (liquid) Fe

CO₂ → Melting

Iron ore → Reduction → Coal

BF → Molten iron (liquid) Fe

100% use of hydrogen results in zero CO₂ emissions in the reduction process

DRI pellet (solid) Fe

H₂ → Reduction

Fe₂O₃ → Endothermic

DRI pellet (solid) Fe → To be melted in the following process (BF, EAF)

Challenge

High-hurdle unproven processes that have never been demonstrated before

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Technical issues in direct reduction process

The current direct reduction process uses methane (natural gas) instead of coal as a reducing agent.

1) Methane contains carbon and emits CO₂.
2) Presorting and pelletizing of iron ore are required.
3) Since the reduced iron is solid, not liquid, the following remelting (EAF or BF + BAF) and slag separation are required. Carbon intensity of grid power generation used in EAF should also be accounted for.
4) Lower productivity than BF
   DRI: ca. 50,000 tons/day
   BF-BOF: ca. 100,000 tons/day

Cf. Direct reduction furnaces in operation:
MIDREX (Kobe Steel), FINEX (POSCO), etc.
Challenges of 100% hydrogen use in direct reduction

We are challenging direct reduction using 100% hydrogen, not methane (natural gas), as a reducing agent.

1) Hydrogen reduction is endothermic. → Hydrogen preheating to be required.
2) Powdering of raw materials at low temperature and sticking of products. → Less powdering and less sticking ore (only 10% of commercially available ores) to be fed.

In addition to the issues of the existing DRI process,

Technologies for blowing a large amount of preheated flammable gases at high-temperature into the furnace, and expanding ores applicable to the hydrogen process
**(Ref.) Hydrogen steelmaking trials**

Since renewable hydrogen is relatively easily obtained in Europe, demonstration trials of direct reduction with hydrogen have just started in such countries.

<table>
<thead>
<tr>
<th>Company</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ArcelorMittal, Hamburg (Germany)</td>
<td>Development of a hydrogen use in an existing commercial natural gas DRI plant (100,000 tons/year). Construction cost: €120 million (¥13 billion)</td>
</tr>
<tr>
<td>SSAB (Sweden) HYBRITT Project</td>
<td>Development of hydrogen steelmaking using a newly built direct reduction plant (7,000 tons/year) Construction cost: €150 million (¥18 billion) Subsidized by the Swedish Energy Agency Production plan: 1.3 million tons/year from 2026</td>
</tr>
<tr>
<td>Baowu Steel Group (China)</td>
<td>Launch of the &quot;China low carbon metallurgical technology innovation alliance&quot; and establishment of a &quot;low-carbon metallurgical innovation research center&quot;. Started research on the industrialization of hydrogen steelmaking using the existing 400m³ test BF in Xinjiang.</td>
</tr>
</tbody>
</table>
6. CCUS (Carbon Capture, Utilization and Storage)
CCUS (Carbon Capture, Utilization and Storage)

Considerable amount of CO₂ will still be emitted even from breakthrough BFs. Such CO₂ can be captured, utilized to chemicals, or stored underground (CCUS).

**Challenges**

- **Capture**: Development and implementation of CO₂ capture technology
- **Utilization**: Development of technologies using CO₂ for chemicals/fuels, and implementation of technologies
- **Storage**: Storage infrastructure including reservoir, relevant laws and tax incentives
- **External conditions**: Incentives for CCU chemicals, fuels or carbon recyclables and those for their commercialization
CO₂ storage underground (CCS, Carbon Capture and Storage)

Capture CO₂ and store it underground

Problems

Cost and storage reservoir

Environment Policy Division, Industrial Technology and Environment Bureau, Ministry of Economy, Trade and Industry: CCS R&D/Verification-Related Businesses/Research on CO2 Storage Areas (June 20, 2019)
CCU (Carbon Capture and Utilization): CO₂ recycling

Converting captured CO₂ into feedstock of chemicals, etc.

Use in oil fields
- Enhanced Oil Recovery
- Extraction of crude oil with CO₂

Direct use of CO₂
- Welding, dry ice, etc.

Carbon recycling
- Converting CO₂ into chemicals

Chemicals
- Synthesis of polymers etc. with CO₂ and hydrogen
  - Oxy-compounds (polycarbonate, urethane, etc.)
  - Biomass-derived chemicals
  - General purpose materials (olefin, BTX, etc.)

Fuels
- Fuel synthesis using CO₂ and hydrogen
  - Microalgae biofuels (jet fuel, diesel oil)
  - Fuel derived from CO₂ or biofuels (not from microalgae) (methanol, ethanol, diesel, etc.)
  - Gas fuel (methane)

Mineralization
- Absorption into concrete
  - Concrete products and concrete structures
  - Carbonates, etc.

Others
- Absorption by organisms (photosynthesis)
  - Negative emissions (BECCS, Blue Carbon, etc.)

Problems
- Conversion cost is relatively high.
- A large amount of carbon-free hydrogen is required for chemical conversion (reduction) since CO₂ is chemically stable.
- Except for mineralization, the storage is temporal and the CO₂ is eventually re-released into the atmosphere through combustion and decomposition.
- The amount of chemicals and fixed amount of CO₂ is limited.
CCUS by Nippon Steel (COURSE50 Project)

**Development of CO₂ capture technology**

**Chemical absorption**

- Absorption tower: Absorbs CO₂ at ambient temp.
- Stripper: Strip CO₂ at high temp.
- Absorbent (Amine)
- BF gas
- CO rich off gas
- Absorbent with CO₂
- Waste heat
- 99% CO₂
- Reboiler

- High-performance absorbent, developed
- High-performance heat exchanger for waste heat recovery, developed
- Capturing performance, demonstrated through pilot plant.

Achieving the stripping energy near the theoretical value, expected.

- Capturing cost less than ¥2,000/t-CO₂, expected

**Unused waste heat recovery technology**

Recovering waste heat at 200 - 400°C, currently unrecovered, and using it as a heat source for the CO₂ capture enables a reduction in CO₂ capture cost.

High-performance micro heat exchanger with low pressure loss developed.

*Source: Prepared by Nippon Steel based on the data on NEDO’s website*
CCUS by Nippon Steel (commercialized)

**ESCAP™ energy-saving CO₂ capture facility**

ESCAP® (Energy Saving CO₂ Absorption Process)
- Based on the energy-saving CO₂ absorption technology developed by COURSE50, Nippon Steel Engineering Co., Ltd. commercialized the technology for industrial use, by adding its own technology.
- By using the absorption solution jointly developed by Nippon Steel and RITE (Research Institute of Innovative Technology for the Earth), high-purity CO₂ can be captured from CO₂ containing gas with low energy.
- In the facility using the chemical absorption, high-purity CO₂ applicable for food and other use can be produced from the gas with high impurities, reducing heat consumption by more than 40% compared to conventional technologies.
- Also applicable to chemical feedstock, CO₂ removal in chemical processes, EOR (Enhanced Oil Recovery), and CCS (CO₂ stored in the ground).

**Example**

ESCAP™ at Air Water Carbonic Inc. (located in Nippon Steel's Muroran Works)
Completion: November 2014
Capacity: 120 t-CO₂ /day; Purity: 99.9 vol.%+

*The first commercial facility based on the chemical CO₂ absorber in the world, using hot-blast stove exhaust gas from steel works as the source of CO₂.*

ESCAP™ at Sumitomo Joint Electric Power Co., Ltd.
Completion: July 2018
Capacity: 143 t-CO₂ /day; Purity: 99.9 vol.%+

*The first commercial CO₂ capture facility for food application from the combustion exhaust of coal-fired power in Japan*
CCUS by Nippon Steel (technology under development)

**Chemicals**

**CO₂ to para-xylene**
NEDO Program "Development of Technology for Carbon Recycling, Next Generation Thermal Power Generation, etc." (fiscal 2020-23)

By Toyama University, Chiyoda Corp., Nippon Steel Engineering, Nippon Steel, Hychem, and Mitsubishi Corp.

**CO₂ to polyurethane intermediate**
NEDO Program "Unexplored Challenge 2050" (fiscal 2018-22)

By Osaka City University, Tohoku University, Nippon Steel, and Nippon Steel Engineering

**Fuels**

**CO₂ to olefin and kerosene**
JST Program "Game Change Technology: Realizing a low-carbon society, which is a global challenge" (fiscal 2017-21)

By Toyama University and Nippon Steel
7. Technological challenges and required external conditions
Technological challenges and required external conditions

Production of high-grade steel in large scale EAF

- Scrap: Elimination of the effect of hazardous impurities using DRI
- EAF: Improvement of productivity with larger scale and higher efficiency
- Cost-effective fossil-free power

Hydrogen injection into BF (COURSE50, Super-COURSE50)

- Preheating and injection of high-temp hydrogen for endothermic reactions
- Stable gas flow in BF with less coke
- Scaling-up from experimental to actual super-large-scale BF
- Establishment of the technology to offset remaining CO₂ emissions (CCUS)

- Implementation of CCU and CCS
- Large supply of carbon-free hydrogen

100% hydrogen use in direct reduction

- Establishment of the technology of hydrogen direct reduction
- Large-amount supply of carbon-free hydrogen
Challenges to realize zero-carbon steel and collaboration with society

Take on the challenge to develop and practically implement breakthrough technologies ahead of the other countries to realize zero-carbon steel, as Nippon Steel’s top priority issue, which is essential for Japan’s steel industry to continue to lead the world and to maintain and strengthen the competitiveness of Japanese industry in general.

3 factors to increase costs for the zero-carbon steel project

1) Huge R&D costs
2) Huge CAPEX for practical implementation
3) Increase in operational cost, even if inexpensive carbon free hydrogen and zero-emission power are to be secured

The production cost of crude steel may more than double the current cost.

3 collaborations required for realizing zero-carbon steel

1) A national strategy to realize a “virtuous cycle of environment and growth”
   - Long-term and continuous government support for R&D in the field of breakthrough innovation etc.
   - Establishment of inexpensive and stable large-scale hydrogen supply infrastructure
   - Realization of carbon free power at an international competitive cost
   - Promotion of national projects for the development and commercialization of CCUS

2) Realization of government’s comprehensive policies to secure equal-footing in international competition, strengthen industrial competitiveness, and lead to business chances

3) Formation of consensus on the issue of cost bearing by society
   - Establishing a system for society as a whole to bear the enormous costs of realizing zero-carbon, such as R&D costs, CAPEX for replacing existing facilities, and significant increase in production costs.
(Reference)
Carbon pricing
## Energy and environment-related taxes by country

- Several countries have coal taxes, but mostly only for commercial heating. (Some have industrial coal taxes but coal is virtually tax-free due to refunds and tax incentives at an equivalent rate).
- Virtually no country has taxes on coal, coke or byproducts for steelmaking.

<table>
<thead>
<tr>
<th>Country</th>
<th>Nature of the tax</th>
<th>Coal taxation</th>
<th>Exemptions and preferential treatment for coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweden</td>
<td>Carbon Tax</td>
<td>Up to ¥38,300/t</td>
<td>Tax exempt for steelmaking and power generation</td>
</tr>
<tr>
<td>Norway</td>
<td>Carbon Tax</td>
<td>No tax</td>
<td>-</td>
</tr>
<tr>
<td>Germany</td>
<td>Energy Tax</td>
<td>Up to ¥1,240/t</td>
<td>Taxable only for business heating. Tax exempt for ETS companies</td>
</tr>
<tr>
<td>Italy</td>
<td>Energy Tax</td>
<td>Up to ¥600/t (business)</td>
<td>Taxable for heating applications only</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Up to ¥1,200/t (home)</td>
<td></td>
</tr>
<tr>
<td>U.K.</td>
<td>Climate change tax</td>
<td>From ¥4,800/t</td>
<td>Tax exempt for raw materials and reductant</td>
</tr>
<tr>
<td>France</td>
<td>Coal Tax</td>
<td>Up to ¥15,220/t</td>
<td>Tax-exempt for raw materials and reductant, and ETS companies</td>
</tr>
<tr>
<td>Spain</td>
<td>Hydrocarbon tax + electricity tax</td>
<td>Up to ¥560/t (business)</td>
<td>Tax exempt for steelmaking, power generation, and some other industries</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Up to ¥2,430/t (home)</td>
<td></td>
</tr>
<tr>
<td>Belgium</td>
<td>Energy Tax</td>
<td>Up to ¥48/t</td>
<td>No tax for raw materials and reductant. Some tax-exempt for ETS companies</td>
</tr>
<tr>
<td>U.S.A.</td>
<td>Energy Tax</td>
<td>No tax</td>
<td>-</td>
</tr>
<tr>
<td>China</td>
<td>Energy Tax</td>
<td>No tax</td>
<td>-</td>
</tr>
<tr>
<td>S. Korea</td>
<td>Energy Tax</td>
<td>From ¥4,410/t</td>
<td>Taxable for power generation only</td>
</tr>
<tr>
<td>India</td>
<td>None</td>
<td>No tax</td>
<td>-</td>
</tr>
<tr>
<td>Australia</td>
<td>None</td>
<td>No tax</td>
<td>-</td>
</tr>
</tbody>
</table>
Germany's electricity rates for the power-consuming industrial use are about one third of the prices of industrial electricity in Japan. Germany has various exemption schemes, and most taxes and transfer fees are reduced for power-consuming industries.

<table>
<thead>
<tr>
<th></th>
<th>Germany</th>
<th>Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Base charge</strong></td>
<td>18.3</td>
<td>19.5-22.8</td>
</tr>
<tr>
<td><strong>Taxes, public charge, and surcharge</strong></td>
<td>2.7</td>
<td>11.7</td>
</tr>
<tr>
<td><strong>Power-consuming industries (after tax-exempt)</strong></td>
<td>6.0-7.4</td>
<td>21.1</td>
</tr>
</tbody>
</table>

(Unit) ¥/kWh @ ¥126/€
EU Emissions Trading System (ETS) (Europe)

- Emissions of EU ETS companies are about 2 billion tons of CO₂ p.a.
- In Phase 2 (2008-2012), the allocated allowances and verified emissions were roughly balanced.
- In Phase 3 (from 2013), due to no free allocation to power generators and the decrease in allowances in other sectors each year, there were significant gaps between them resulting in a lack of allowances.

Source: (EU) Emissions Trading System (ETS) data viewer (European Environment Agency) form EU Transaction Log (EUTL)
CO₂ emissions by the EU steel industry total about 150 million tons per year.

The EU steel industry continued to have surplus allowances and its CO₂ emissions did not decrease.

Source: (EU) Emissions Trading System (ETS) data viewer (European Environment Agency) form EU Transaction Log (EUTL)
Outline of the China Emissions Trading System

✓ China, the world's largest CO₂ emitting country, started emissions trading nationwide on February 1, 2021 with the aim of achieving a decarbonized economy by 2060.

✓ Starting with power generators with high annual greenhouse gas emissions, steel, building materials, petrochemicals, chemicals, non-ferrous metals, paper, and aviation sectors are also to be included in coming five years.

✓ For the moment, the government allocates free allowances and will start to allocate cap for auction "at the appropriate time, depending on the situation."

<Reference> Remarks by CISA Executive Chairman
"When designing systems that include CO₂ emissions trading, we need to ensure that good companies take the lead by making sure that profits flow to good companies in the industry, not to outside. We hope that the reduction of carbon emissions will not reduce the competitiveness of the industry, but rather promote greater competitiveness among companies."
Carbon pricing

(1) Since the energy costs borne by the Japanese steel industry are higher compared to the costs in other countries even now, carbon pricing, such as carbon taxes and emissions trading systems, will become an additional burden, and will have a significant impact on international competitiveness. The loss of competitiveness of the Japanese steel industry will shaken the foundations of all the manufacturing industries that are competing in the world using Japan's high-performance steel.

(2) While the “zero carbon” of the steel industry is important in realizing Japan’s green growth strategy, the zero-carbon steel technology has not been established anywhere in the world, and we need to take up an extremely difficult challenge of technology development from scratch. In addition to long-term R&D investment, the huge cost is required for new capital investment for the conversion of existing equipment when implementing the technology. Further burdens such as carbon pricing will mean for the industry to be deprived of the source of innovation toward decarbonization. Since each steel company has already positioned the zero-carbon technology development as its priority issue, carbon pricing for the promotion of the development is not needed.

International Comparison of Industrial Electrical Fees (USD/MWH)

* In Germany, industries exposed to international competition are exempt of the FIT payments.

Source: EA, 2019 (except China), Nippon Steel Research Institute (NSRI) for China (greater than 220 kV in Jiangsu Province)

High electricity rates are a big handicap in international competition
Border adjustment mechanism

In the EU and the USA, introducing of border adjustment mechanism is started to be considered for imports from countries that are insufficient in climate change actions.

Border adjustment mechanism
- A border adjustment mechanism is to take adjustment measures at the border according to carbon emissions.
- For example, imports from countries with high emissions may be subject to customs duties at the border.

(Europe)
- The Green Deal will impose carbon prices on certain items from outside the EU. Announcement was made to propose the details of the system by June 2021 and plan to introduce the mechanism by 2023.

(USA)
- President Biden is committed to the measures (listed in the Democratic Party Summary).

Problems of the border adjustment mechanism
1. Inconsistency with WTO rules (The measures must be consistent with the EU ETS but if the free allowance of the EU ETS sustains, it would become excessive compensation of the EU and may be inconsistent with WTO rules.)
2. Lack of international rules to ensure the transparency of carbon intensity measurement methods and data in products.

[Reference] European Parliament: A non-binding preliminary vote on border adjustment mechanism
The focus was on the continuation or abolition of the EU ETS free allocation of allowance, associated with border adjustment mechanism.
On February 5, 2021, the abolition of the free allocation was decided but the EUROFER strongly opposed it, describing it as "a death sentence."
On March 10, 2021, the continuation of the free allocation was passed by a close margin and the EUROFER welcomed the border adjustment mechanism.
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