Technology Roadmap for "Transition Finance" in Iron and Steel Sector

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Ministry of Economy, Trade and Industry

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1．Premise｜Necessity of Technology Roadmap for Iron and Steel Sector

- Technology Roadmap for "Transition Finance" (hereinafter, technology roadmap) selects sectors of high importance of transition and those with high emissions with no alternative measures of decarbonization available today (for technological and economic reasons).

- Iron and steel is integrated as material for a wide range of products that support daily life and as the iron and steel industry is in the upstream of the supply chain, it serves as an industrial basis. Japanese iron and steel industry is developing high productivity blast furnaces and offers high-quality steel to the world, using world-leading technologies.

- With its lighter weight and higher strength of steel, **many steel products contribute to the transition of other industries (in the downstream stage such as transport machinery, energy, construction**) **and their demand is expected to expand in wide-range of application for the realization of a carbon neutral society.**

- At the same time, **the iron and steel industry emits large amounts of CO2 worldwide and is the largest CO2 emitting manufacturing industry in Japan. Transition toward net zero in the iron and steel sector is essential.**

- **Transition requires effective use of existing facilities and related equipment, R&D/implementation of innovative technologies for low-carbonization and raising significant funds, as well as updating/introduction of energy-saving facilities are needed.** In this regard, we examined domestic and overseas technologies and developed a pathway to 2050.

- Technology innovation and structural change of business for decarbonization will become advantages of companies. To attract world's ESG investments which grew to ¥3,500 trillion ($35 trillion : by GSIA) as of 2020, high-emitting industries are required to disclose their strategies with the understanding of investors' perspectives.

- In terms of contributing to increase the international competitiveness of Japanese iron and steel industry, the Technology Roadmap was developed through the discussion held with technology and finance experts and representatives of operators of iron and steel sector.

1. Premise | Objectives and Positioning of Technology Roadmap

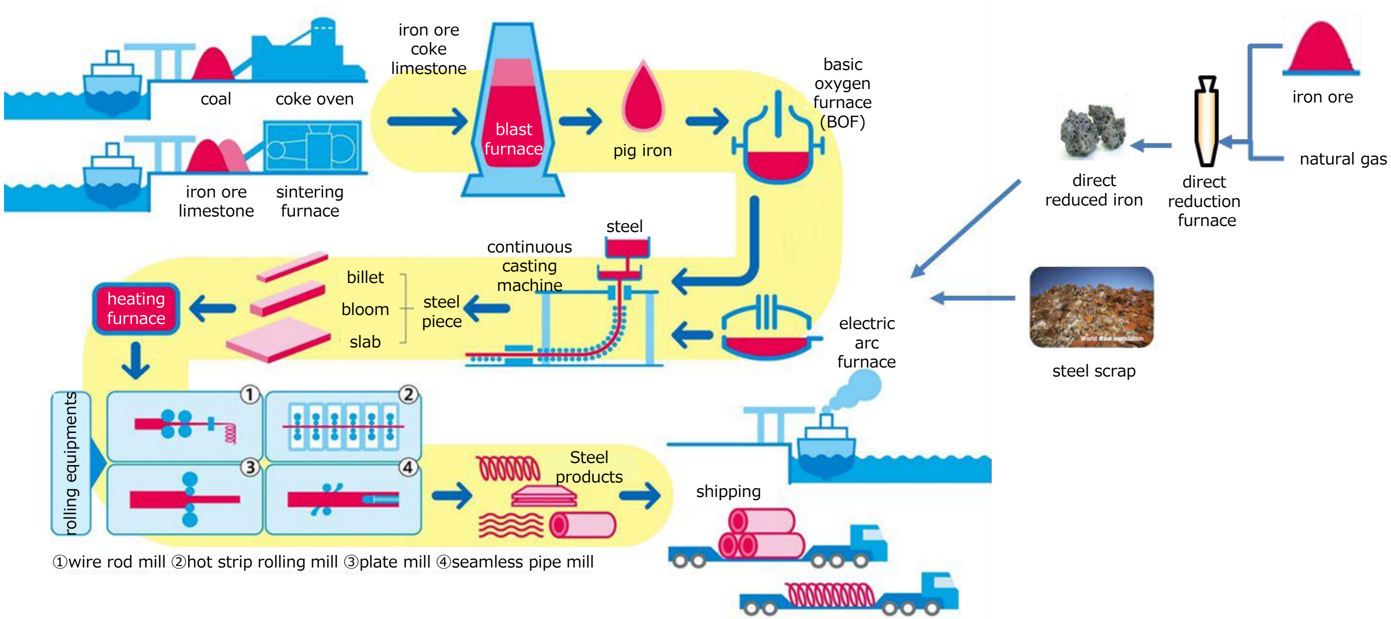
- The Technology Roadmap is designed to serve as a reference for **the iron and steel companies in Japan, when investigating measures against climate change using transition finance (Note)** based on "the Basic Guidelines on Climate Transition Finance" (Financial Services Agency, Ministry of Economy, Trade and Industry, Ministry of the Environment, May 2021).
- It is intended to help banks, securities companies and investors **to assess the eligibility of the fundraiser's decarbonization strategies and approaches.**
- The final goal of the Technology Roadmap is to achieve 2050 carbon neutrality and the Technology Roadmap provides envisions of low-carbonization/decarbonization technologies that are expected to be deployed by 2050 and when these technologies will be deployed based on information currently available.
- The Technology Roadmap is aligned with Nationally Determined Contribution (NDC) based on Paris Agreement*1, Green Growth Strategy*2, and R&D and Social Implementation Plan using Green Innovation Fund*3.
- Technologies to realize carbon neutrality in the iron and steel sector has not been established. Public and private sectors will collaborate to develop technologies that are not yet mature and indispensable toward 2050 carbon neutrality.
- **The iron and steel industry in Japan needs to work on "transition" including energy conservation and energy transition aiming at decarbonization without waiting for the establishment of decarbonizing technologies, while referring to the Technology Roadmap.**
- Meanwhile, looking ahead towards 2030 and 2040, the transition period, **it is essential to further advance efforts on energy saving/efficient technologies in addition to R&D.**

*1 : https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Japan%20First/JAPAN_FIRST%20NDC%20(INTERIM-UPDATED%20SUBMISSION).pdf
*2 : https://www.meti.go.jp/english/policy/energy_environment/global_warming/ggs2050/pdf/ggs_full_en1013.pdf
*3 : https://www.meti.go.jp/press/2021/09/20210915001/20210915001-2.pdf

(Note)" Transition finance refers to a financing means to promote long-term, strategic GHG emissions reduction initiatives that are taken by a company considering to tackle climate change for the achievement of a decarbonized society" - *Basic Guidelines*

1． Premise | Objectives and Positioning of Technology Roadmap

- Transition finance includes not only the investment on facilities and R&D toward low-carbonization/decarbonization within the company **but also for efforts/activities that contribute to the transition of other industries, cost of dismantlement/removal of existing facilities and response to other environment or social impact (such as land contamination associated with withdrawal from business, decommissioning of furnaces, etc. and impact on employment) arising from activities to reduce emissions.**
- In the iron and steel sector, **products contribute to decarbonization (eco products, noted in P8) can be subject to transition finance.** Moreover, Basic Guidelines on Climate Transition Finance (noted in P8) states "Transition finance is available for not only entities with strategies and plans for reducing emissions associated with their corporate economic activities, but also entities that plan to take initiatives that enable others to implement transition strategies through their own products and services".
- These efforts/activities are important elements for the decarbonization of whole society and economy. At the same time, as these efforts/activities are extremely broad, **the Technology Roadmap will cover the "technologies" for low-carbonization/decarbonization mainly in the iron and steel sector.**



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2. Overview of Iron and Steel Industry | Industrial Scale

- Each of the 13 integrated blast furnace steelworks in Japan has created and retains several thousand direct jobs (plus many affiliates and business partners) with producing and shipping more than 10 million tons of steel annually. The iron and steel industry has a broad base of affiliated companies and business partners thus servs as a key industry by supporting employment and local economies.
- The iron and steel industry accounts for 8.5% (9.6 trillion yen) of the total GDP of the manufacturing industry(2019).
- Global crude steel production is 1.87 billion tons. China accounts for 53% of the total. (Japan: about 100 million tons)(2019).

The Iron and Steel Industry
Total shipment value: 19 trillion yen.
Number of employees: 220,000

*Figures from "Major Group 22, Manufacture of Iron and Steel" in Japan Standard Industrial Classification

upstream **blast furnace, electric arc furnace**

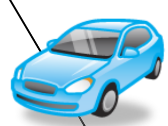
midstream **Rolling, processing, casting and forging**

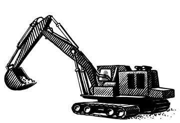
downstream

Iron and steel products(2016)
Sales: 24 trillion yen,
Number of employees: 80,000

examples

Industrial Machinery Industry
41 trillion yen, 1.16 million employees

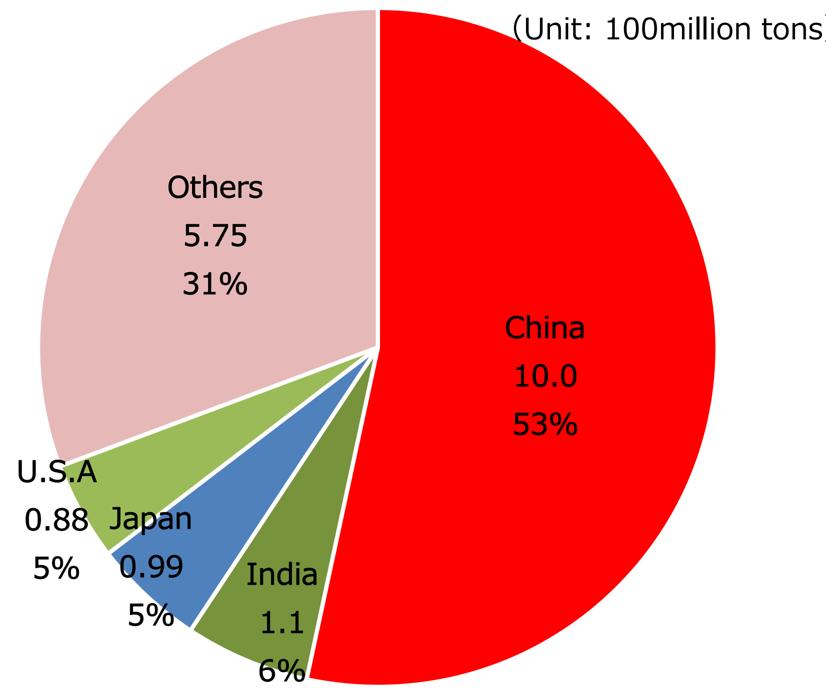




Automobile Manufacturing Industry
62 trillion yen, 920,000 employees

(Sources) METI's Census of Manufactures, Census of Commerce, System of National Accounts, Survey of Economic Structure

Crude steel production in 2019:
1.87 billion tons
(2.2 times the 2000 level)



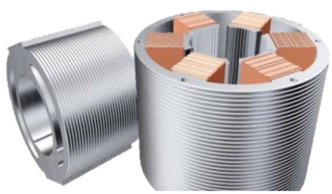
(Source) World Steel Association

2. Overview of Iron and Steel Industry | Current Status of CO2 Emissions

- Iron and steel is used in infrastructure sectors such as resources, energy, civil engineering, and construction, as well as in electrical steel sheets for automobiles and monopiles for offshore wind power. Therefore, **it remains an essential material even in a carbon-neutral society** and contributes to the transition to low-carbon economic activities in other sectors through efforts of sophisticating its functions, including the lightening of material.
- The IEA forecasts that there will be **significant demand for automobiles, infrastructure, electrical and electric equipment and other end uses globally** in 2050.

<Examples of Iron and Steel Products Contributing to Decarbonization>

Electrical steel sheets (used in motors for EVs, etc.)



Monopiles (used in windmill structures)

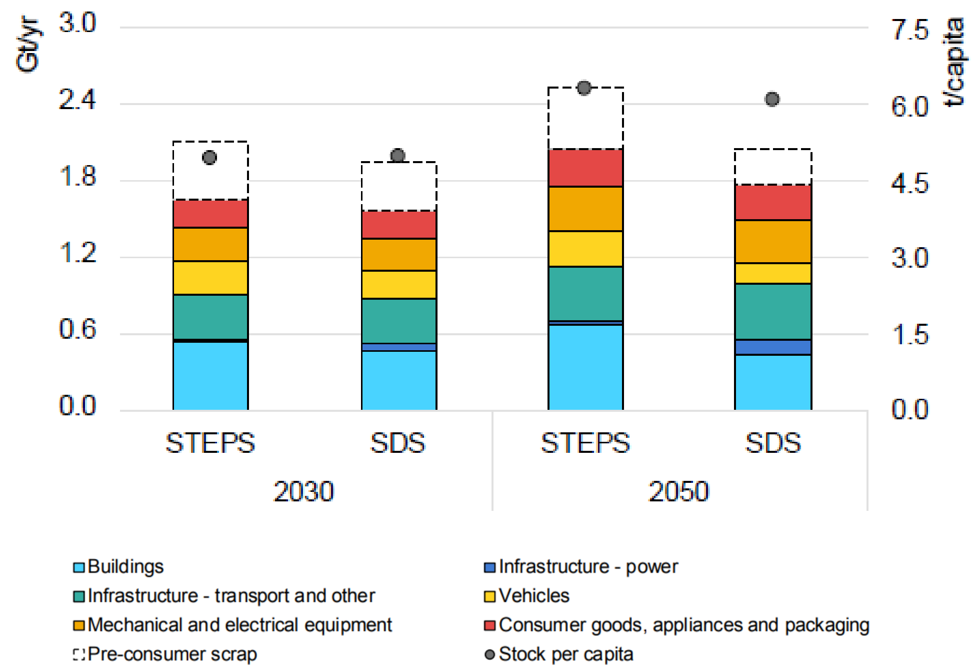
(Source) NEDO https://www.nedo.go.jp/fuusha/haikei.html

Iron and steel industry contributes to reducing CO2 at the stage where final products are used in society by developing high-functional steel materials essential for building a low-carbon society and supplying them to Japan and overseas. For example, regarding **the five types of steel*** whose quantitative reduction contributions are evaluated, **the reduction potential in the milestone year of 2030 is estimated to be approximately 42 million t-CO2.**

* Steel sheets for automobiles, grain oriented electrical steel sheets, heavy plates for shipbuilding, boiler tubes, and stainless steel sheets

(Source) Japan Business Federation (Keidanren)'s Commitment to a Low Carbon Society (Phase II of Commitment to a Low Carbon Society by the Iron and Steel Industry)

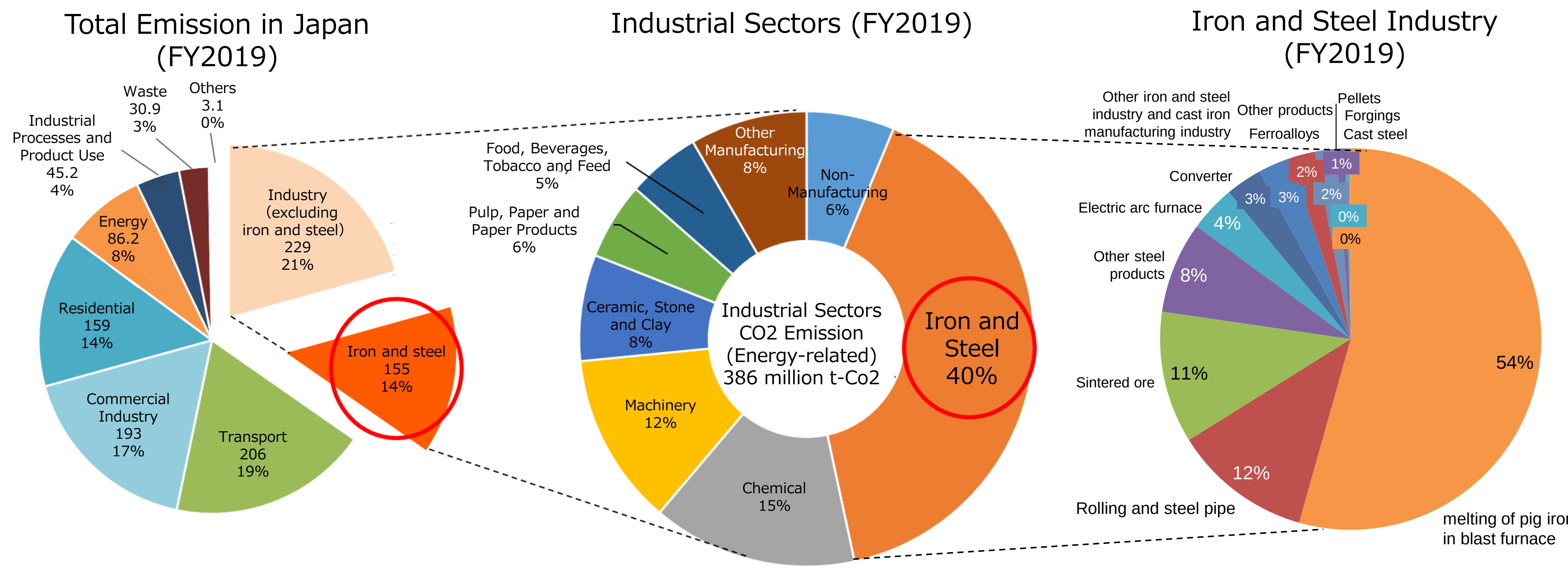
<Iron and Steel Demand Outlook>



(Source) Iron and Steel Technology Roadmap (2020 IEA)
*STEPS: Stated Policies Scenario, SDS: Sustainable Development Scenario

2. Overview of Iron and Steel Industry | Current Status of CO2 Emissions

- In fiscal 2019, CO2 emissions from the industrial sectors accounted for 35% of our country's CO2 emissions.
- In particular, **reducing CO2 emissions is an urgent issue in the iron and steel industry, which accounts for 40% of CO2 emissions in the industrial sectors (14% of CO2 emissions in Japan).**



*CO2 emissions (unit:1 million tons) are shown in the middle column.

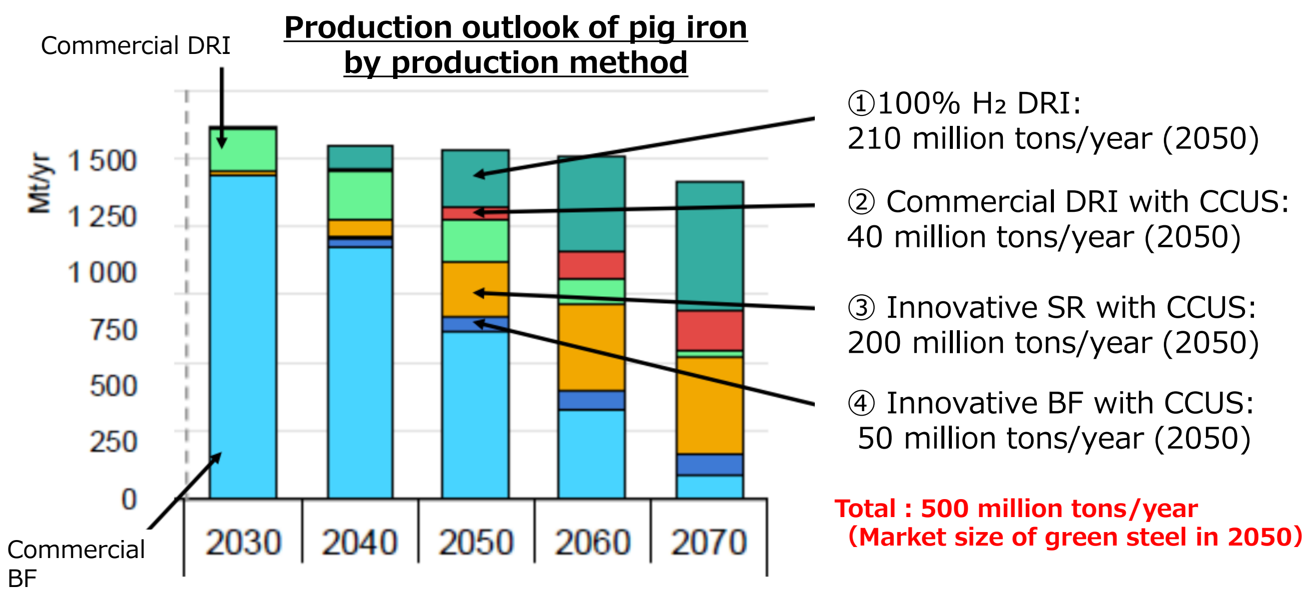
(Source) Japan's National Greenhouse Gas Emissions in Fiscal Year 2019 (Final Figures) by National Institute for Environmental Studies

(Source) "Comprehensive Energy Statistics" by the Ministry of Economy, Trade and Industry (Confirmed figures for FY2019)

2. Overview of Iron and Steel Industry | Trends toward Carbon Neutrality

- The IEA estimates that the market size of green steel will reach almost 500 million tons in 2050 and forecasts that almost all pig iron production will have adopted zero-emissions manufacturing in 2070.
- Domestic and overseas steelmakers have developed plans for carbon neutrality, and competition for capturing the green steel market is expected*.
- Decarbonization technology has not yet been established in the iron and steel industry. Therefore, the major premise is to advance decarbonization along with carbon capture, utilization and storage (CCUS) and use of decarbonized power sources. In addition, it is necessary to thoroughly utilize low-carbon technologies during the transition period.

IEA's revised pig iron output by manufacturing method



(Source) METI "Hydrogen Utilization in Iron and Steelmaking Processes", IEA "Energy Technology Perspective 2020"

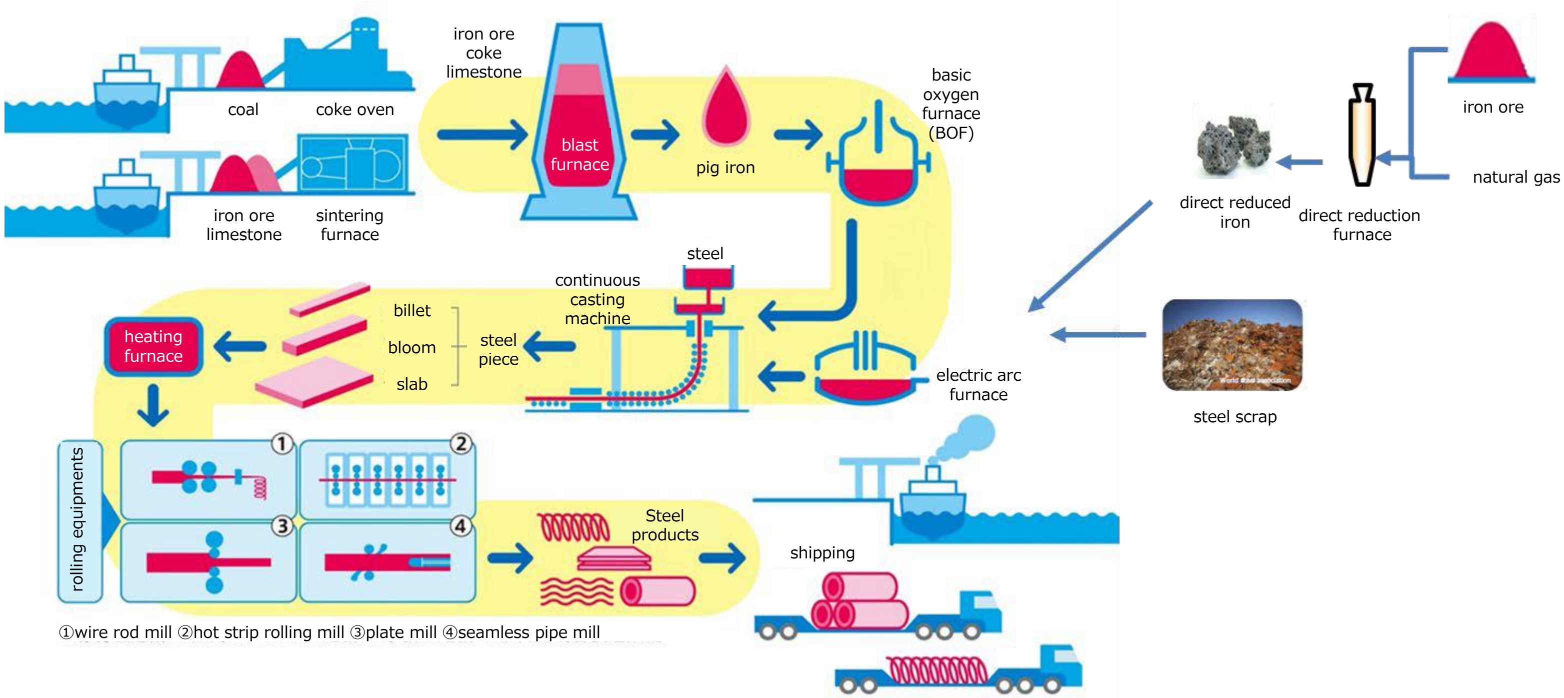
Trend of Major Overseas Steelmakers*

- Developed a plan of reducing CO2 through two routes; carbon recycling and direct reduction method. Plans to achieve the goal with offsets. (The Netherlands)
- Since 2016, the country has studied utilizing hydrogen to eliminate the use of fossil fuels by 2045 and plans to start commercial use in 2026. (Sweden)
- Plans to reduce CO2 emissions by 20% by 2030 and 50% by 2040 with gradual shift to direct reduction from blast furnaces, thereby aiming to achieve carbon neutrality by 2050. (South Korea)

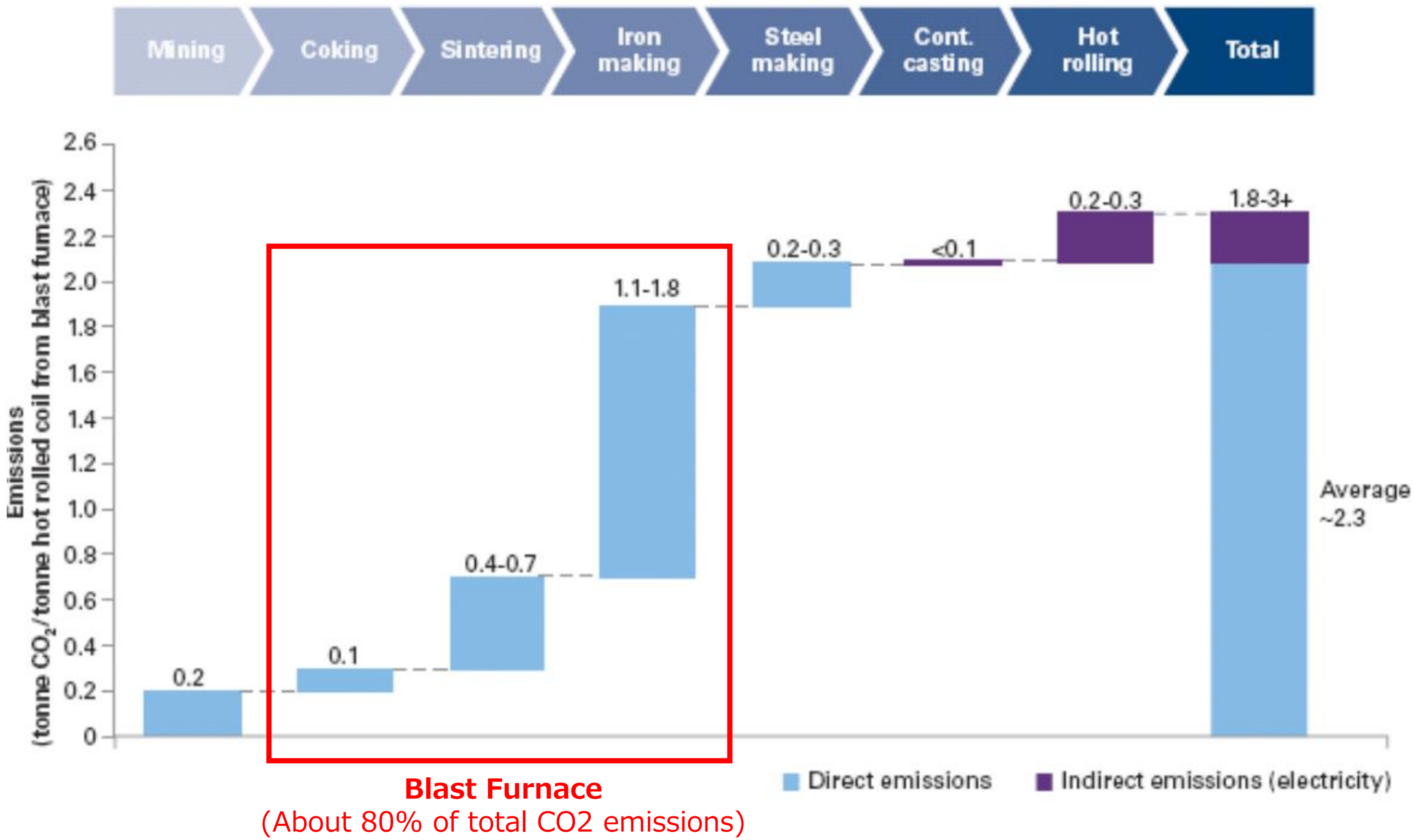
*Major manufacturers have started to implement carbon neutrality throughout the supply chain. For instance, some EU OEMs have started to source steel from manufacturers that are emitting less CO2.

2. Overview of Iron and Steel Industry | Steelmaking Process

- Iron is generally produced by **reducing and melting iron ore and coal (coke) in a blast furnace and a basic oxygen furnace (BOF)**, or by **melting steel scrap in an electric arc furnace**.
- In some areas in overseas where natural gas is abundant, a process in which high-grade iron ore is directly reduced with natural gas and then melted in an electric arc furnace is also adopted.
- **Technology to realize carbon neutrality in the steelmaking process has not yet been established.**



- **Producing 1 ton of steel generates about 2 tons of CO2, most of which is generated in the iron ore reduction process in a blast furnace.**

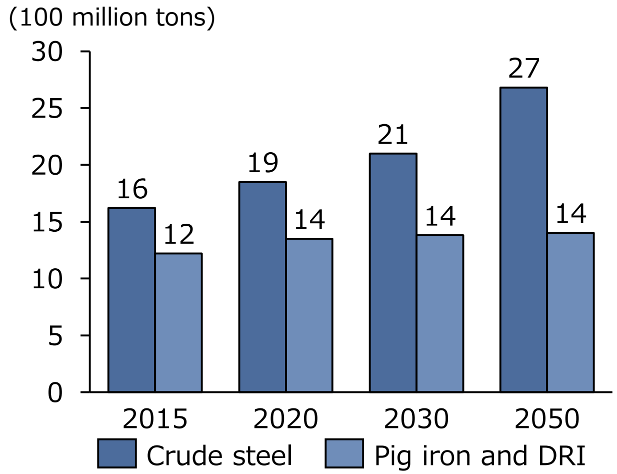


(Source) Carbon Trust "International Carbon Flows"(2011)

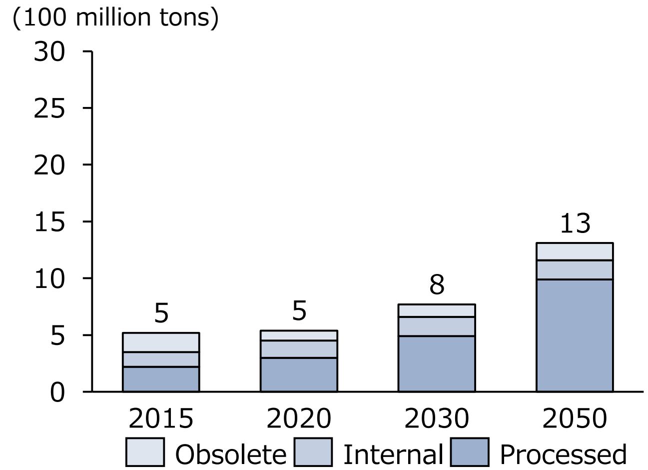
- Crude steel production is expected to increase as demand for steel materials expand toward 2050. Accordingly, the amount of scrap generated is expected to increase due to the expansion of steel stock accumulation.
- Under these circumstance, to make effective use of resources and achieve carbon neutrality in 2050, it is necessary to **make maximum use of not only high-quality scrap (with few impurities) but also low-quality scrap in all applications**.
- In addition, it is essential to continue **using blast furnaces for making high-grade steel. Therefore, multiple approaches are necessary to aim for decarbonization of the iron and steelmaking process.**

Forecast of crude steel and pig iron production and scrap consumption

Global production of crude steel and pig iron Future Assumption



Global amount of scrap generated Future Assumption*

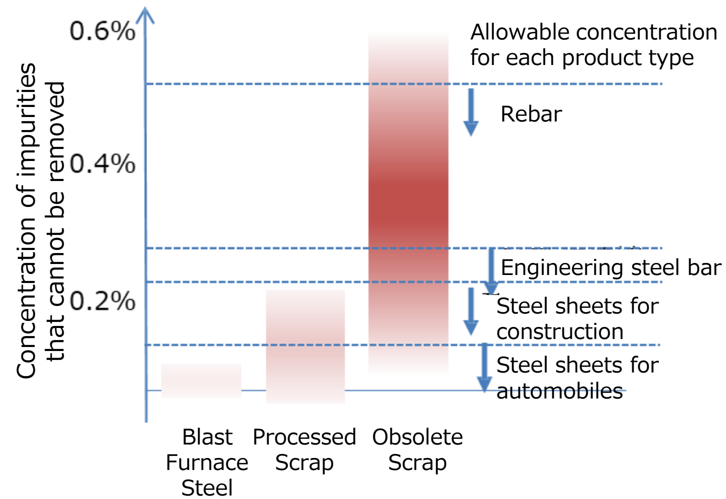


- Crude steel production will increase in line with the expansion of demand for steel materials, and the amount of scrap generated and used will rise mainly due to the expansion of steel stock accumulation.
- Scrap alone will not be sufficient to meet demand for steel materials, thus more pig iron than the current amount will be needed in 2050.

Source: Based on Japan Iron and Steel Federation Long-term Vision for Climate Change Mitigation "A Challenge Towards Zero-carbon Steel" November 2018

* Internal scrap: Generated at the steelmaking stage
* Processed scrap: Generated at the stage of making steel material
Obsolete scrap: Generated from disposal of final products that contain steel, etc.

Impurities of raw materials and allowable concentration for each product type



Source: Jones, A.J.T., Assessment of the Impact of Rising Levels of Residuals in Scrap, Proceedings of the Iron & Steel Technology Conference (2019) revised.

2. Overview of Iron and Steel Industry | Characteristics of Japanese Iron and Steel Industry

- In February 2021, the Japan Iron and Steel Federation stated it "**supports Japan's ambitious policy of achieving carbon neutrality by 2050**" and that "**(the Japanese iron and steel industry) will aggressively take on the challenges to realize zero-carbon steel**". The federation proclaimed that the industry would try to develop super-innovative technologies including hydrogen reduction ironmaking.
- Moreover, **between March and May 2021, major Japanese steel companies (Nippon Steel, JFE Steel and KOBELCO) announced that they would aim for carbon neutrality by 2050.**

Excerpt: Basic Policy of the Japanese steel industry on 2050 Carbon Neutrality aimed by the Japanese government (Japan Iron and Steel Federation)

(1) The Japanese steel industry supports Japan's ambitious policy of achieving carbon neutrality by 2050 and it will aggressively take on the challenge to realize zero-carbon steel with the aim of contributing to the Japanese government policy. Our challenge includes (1) contribution through our technologies and products and (2) initiatives to reduce CO2 emissions in steel production process (i.e., zero-carbon steel).

(2) Realization of zero-carbon steel is an extremely difficult challenge and that is unlikely to be realized in a straight line. Therefore, the Japanese steel industry will explore multiple pathways to the challenge by employing every possible means including, our actively ongoing efforts for the drastic reduction of CO2 emissions from blast furnace through COURSE50 and ferro coke technologies plus CCUS (carbon capture, utilization, and storage), development of super innovative technologies such as hydrogen reduction ironmaking, expanded use of scrap, recovery of low- to medium-temperature waste heat, and use of biomass.

(3) Challenges to develop super innovative technologies

- To realize decarbonization in iron making process and zero-carbon steel, it is necessary to endeavor to develop advanced technologies, such as CCUS, under a blast furnace (reduction with carbon) method with an improved reduction ratio with hydrogen. In addition, we need to spend additional huge costs to neutralize unavoidable remaining CO_2 emissions or implement the hydrogen reduction ironmaking which does not generate CO2. There is no other solution.
- Hydrogen reduction ironmaking is an iron making process that is totally different from the existing blast furnace process which we have reached over several thousand years in history. The detail of hydrogen-based iron making is still unknown, and it is a major hurdle for us. Some countries have just begun to develop such new technologies; thus, this is an extremely ambitious and challenging project.
- Furthermore, replacing the existing process with a new one at the stage of implementation will require a huge amount of capital investment, resulting in large capital and operating costs. But these additional costs are only for decarbonization and contribute neither to improving the performance of steel nor increasing its productivity of the steel.

2. Overview of Iron and Steel Industry | CO2 Emissions in Ironmaking Process

- **The technology to use carbon (charcoal or coal) for the reduction of iron ore has been an unchanging ironmaking method since ancient times.**
- Even in the current blast furnace method, **CO2 is inevitably produced in the reduction process using coke (coal).**

Producing 1 ton of steel generates about 2 tons of CO_2

$$Fe_2O_3 \xrightarrow{C \;\to\; CO_2} Fe$$

Iron ores exist in nature as iron oxides (Fe_2O_3)

Carbon (C), which is more easily combined with oxygen (O) than iron (Fe), takes oxygen away (reduction) from iron ores

The reduction results in the production of iron

Reduction with hydrogen rather than carbon is "Hydrogen reduction ironmaking" and Japanese companies are taking initiative on R&D and demonstration to establish the technology.

$$Fe_2O_3 \xrightarrow{H_2 \;\to\; H_2O} Fe$$

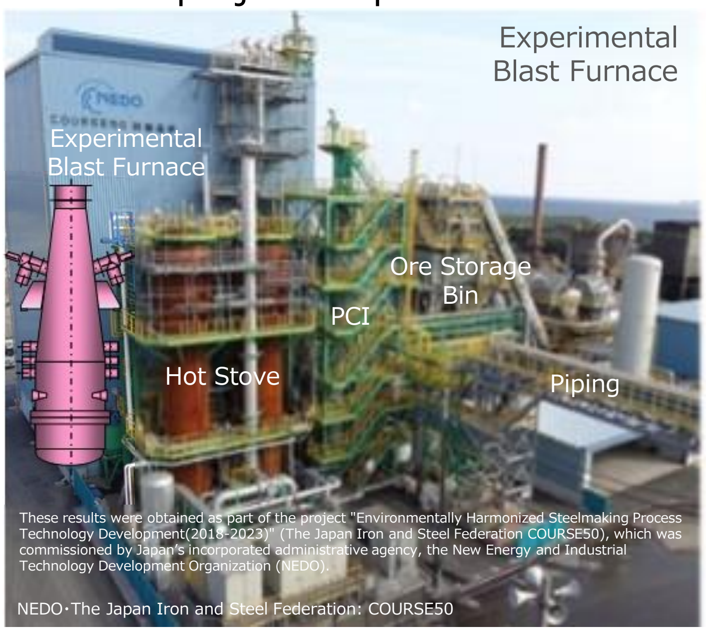
No CO2 generated in reduction reaction

- Japan is **the first country to start developing hydrogen reduction ironmaking technology** (COURSE50 project).

- Testing using a $12m^3$ experimental blast furnace (about 1/400 of an actual furnace) has been carried out since FY2013, ant it is **verified for the first time in the world that a 10% reduction of CO2 emissions in the reduction process can be achieved**. Technologies to further reduce CO2 emissions are under development.

⇒ **Hydrogen reduction ironmaking is a low-carbon technology for the reduction process,** and by combining it with CCUS and/or biomass, zero CO_2 emissions in this process will be possible. However, **in order to achieve carbon neutrality in the whole steelmaking process, it is essential to not only develop technology for hydrogen reduction ironmaking but also make better use of decarbonized power sources and conserve energy and improve the efficiency of steel production in each processes.**

COURSE50 project Experimental Blast Furnace and CO2 Absorption Facility



2. Overview of Iron and Steel Industry | Multiple Approaches to Achieve Carbon Neutrality

- The blast furnace method (blast furnace and BOF process) is excellent in energy efficiency because reduction and melting are carried out consistently. In addition, as the range of utilization of iron ore is wide and the technology to remove impurities (the ingredient that affects a product, the same shall apply hereinafter) has been established, it is possible to produce high-grade steel. **By applying hydrogen reduction and CCUS technology, it is possible to realize decarbonization with the blast furnace system widely adopted in the world**.
- In the direct reduction method (direct reduction and electric arc furnace process), energy efficiency is low because separate furnaces are required for reduction and melting, and it is difficult to remove the impurities in the electric arc furnace method. Therefore, there **remains a constraint on raw materials** in producing high-grade steel. On the other hand, **by replacing all of the reducing gas with hydrogen and establishing an impurity removal technology in an electric arc furnace, decarbonization can be realized without peripheral technology such as CCU.**
- We **aim to achieve carbon neutrality through multiple technological approaches**, taking into account the time frame of the establishment of technology and hydrogen infrastructure.

	Current technology	Innovative technology
Blast furnace method	○The range of utilization of iron ore is wide. ○High energy efficiency to melt. ○Able to manufacture high-grade steel by removing impurities. ×CO2 emissions are high due to the use of coal (coke).	○The range of utilization of iron ore is wide. ○High energy efficiency to melt. ○Able to manufacture high-grade steel by removing impurities. ×As the minimum necessary coke remains, CO2 is generated from the ironmaking process.
Direct reduction method	○As natural gas is used, CO2 emissions are lower than those of the blast furnace method. ×There are material constraints as impurities cannot be removed. ×Energy efficiency is low because additional melting process is required.	○Able to achieve zero CO2 emissions by 100% hydrogen reduction. ○Able to use low-grade ore utilized in blast furnace method by removing impurities in electric arc furnaces. ×Energy efficiency is low because additional melting process is required.

2. Overview of Iron and Steel Industry | Trends in technological development by overseas steelmakers

- Major steelmakers in Europe, China, and South Korea have also embarked on R&D and demonstration projects to achieve carbon neutrality by 2050.
- By utilizing hydrogen and CCUS, they aim to reduce CO2 emissions from blast furnace ironmaking by about 30% by 2030 and achieve carbon neutrality by 2050.

<major European steelmaker>

* The EU considers supporting the iron and steel industry (included in the 120 trillion yen economic stimulus package). They have declared supportive measures for each stage from R&D to actual installation of facilities, and member states have declared further support for individual projects by steel manufacturers.

・Two technological development scenarios: blast furnace method and direct reduction method, are pursued simultaneously.
・In blast furnace ironmaking, low-carbon technologies through 1) hydrogen input; 2) reuse the carbon recovered from the exhaust gas as a reducing agent (CCU); and 3) CO2 storage, are under development.
・The goal is to establish an iron and steelmaking process that can reduce CO2 emissions by 35% by 2030.

<major Chinese steelmaker>

* A fund practically led by the Chinese government was formed to support the iron and steel industry (approximately 850 billion yen to China Baowu Steel Group).

・An oxygen blast furnace technology that reduces coal consumption by injecting pure oxygen instead of hot air is under development.
・The goal is to establish a technology that reduces CO2 emissions by 50% or more compared with a conventional blast furnaces.

<major Korean steelmaker>

* The Korean government considers supporting the iron and steel industry (included in the 3.8 trillion yen economic stimulus package).

・Promote an efficient blast furnace operation and energy conservation through effective use of on-site exhaust gas and AI technology. At the same time, a fluidized-bed direct reduction technology that can utilize low-grade raw materials are under development.
・The gradual shift from blast furnaces to direct reduction aims to reduce CO2 emissions by 20% by 2030 and 50% by 2040 and achieve carbon neutrality by 2050.

* It should be noted that the amount of CO2 reduction varies depending on the base year and the current level of efficiency, thus it is inappropriate to compare the numbers alone. Japanese iron and steel industry has the highest level of efficiency in the world.
(According to IEA ETP 2014, the energy conservation potential of Japan is 1 GJ/t steel, the lowest in the world. According to RITE survey (2018), the energy efficiency of BOF and electric arc furnaces is the highest in the world) (Source: Japan Iron and Steel Federation “Commitment to a Low Carbon Society”).

2. Overview of Iron and Steel Industry | Summary for Carbon Neutrality in 2050

- **Iron and steel continues to be an important material even in carbon neutral society** as a material for infrastructure including electric power, civil engineering and construction, for automobiles (for electrical steel sheets) and for renewable energy(for offshore wind monopole) that foresees further growth in demand.
- Furthermore, **the demand for green steel** is anticipated **to increase** towards 2050 and competition among domestic and oversea companies are expected for market share.
- Japanese iron and steel industry **aims to establish the world's first innovative technologies such as hydrogen reduction ironmaking, parallel to efforts to promote low-carbonization.**
- Currently, technologies to realize carbon neutrality in the process of iron and steelmaking has not yet been established. To promote smooth transition to carbon neutrality, **it is important to;**
    - **realize unprecedented technological development through multiple approaches aiming carbon neutrality**
    - **provide funds through transition finance for activities and efforts that indirectly contribute to carbon neutrality as well as direct approaches including R&D, demonstration and facility investment.**

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3. Technology Pathways to Decarbonization | ①Low-Carbon and Decarbonization Technologies for Carbon Neutrality

Low-carbon technology

		Technology	Overview	Emission Intensity*1	Implementation year*2	Main References*3
Low-carbon technology	Blast Furnaces	**Energy saving/efficient technologies (Best practices)**	[Upstream section] ✓ Utilization of next-generation coke ✓ Recovery of waste heat and by-product gas ✓ Introduction of high productivity power generation system ✓ Plastic recycling, etc. in coke ovens ✓ Utilization of scrap ✓ Enhancement of production efficiency through the introduction of AI and ICT ✓ Improvement in thermal conductivity ✓ Renovation of coke oven to improve efficiency [Downstream section] ✓ Consolidation and improvement of processes ✓ Waste heat recovery ✓ Improvement of burners and introduction of high productivity equipment Reduction of CO2 emissions through the above measures	–	Implemented	• Commitment to a Low Carbon Society, etc.
	Continuous Casting and Rolling	**Improvement in thermal conductivity, Power saving technologies**	✓ Reduction of manufacturing costs by promoting energy saving through improved thermal conductivity in melting and rolling processes	–	Late 2020s	• Green Growth Strategy Through Achieving Carbon Neutrality in 2050
		Electrification of heat application	✓ CO2 reduction in reheating process during rolling by electrification of heating	–	Late 2020s	• Green Growth Strategy Through Achieving Carbon Neutrality in 2050
	Electric Arc Furnaces	**Energy saving/efficient technologies in electric arc furnaces (Best practices)**	✓ Introduction of high productivity arc furnace ✓ Waste heat recovery Reduction of CO2 emissions through the above measures	–	Implemented	• Commitment to a Low Carbon Society • ASEAN Technologies Customized List (EAF)
		Removing impurities/ Large-scale electric arc furnaces	✓ Impurities removal for high-grade steel production and enlargement for mass production of pig iron	0.0~*5	2030s	• Green Innovation Fund - Social Implementation Plan*4

*1: Emission Intensity includes the downstream process. Calculated from the CO2 reduction of the target technology based on the existing emission intensity. The CO2 reduction is accounted only from the relevant process.
*2: Refers to the starting year of *introduction and expansion/cost reduction phase* in Social Implementation Plan and *available year* from IEA.
*3: Underlined when referenced for Implementation Year.
*4: R&D and Social Implementation Plan in the Green Innovation Fund.
*5: Emission Intensity of 0.0 is when decarbonization includes the downstream process.

3. Technology Pathways to Decarbonization | ①Low-Carbon and Decarbonization Technologies for Carbon Neutrality

Category	Process	Technology	Overview	Emission Intensity*1	Implementation year*2	Main References*3
Low-carbon technology	Blast Furnaces	**Ferro-Coke**	✓ Utilization of coke (ferro-coke) produced by effectively using low-grade iron ore and coal that cannot be utilized in the conventional ironmaking process	1.74~2.18 (10% reduction)	2020s	• NEDO Implementation Plan • Environment Innovation Strategy
Low-carbon technology	Blast Furnaces	**CO2 capture and separation (Part of COURSE50)**	✓ Utilization of CO2 capture and separation technology that makes better use of waste heat from steelworks	1.58~2.0 (20% reduction)	Late 2020s	• Green Innovation Fund - Social Implementation Plan*4 • IEA ETP2020
Low-carbon technology	Blast Furnaces	**Utilization of on-site hydrogen (Part of COURSE50)**	✓ Iron ore reduction technology that utilizes on-site hydrogen (blast furnace hydrogen reduction technology)	1.74~2.18 (10% reduction)	Late 2020s	• Green Innovation Fund - Social Implementation Plan • IEA ETP2020
Low-carbon technology	Blast Furnaces	**Utilization of reduced iron (Part of Super COURSE50)**	✓ Utilization of reduced iron to cut the use of coke	0.0~1.51 *5 (Reduction by 50% or more)	2020s	• Green Innovation Fund - Social Implementation Plan
Low-carbon technology	Blast Furnaces	**Utilization of biomass (Part of Super COURSE50)**	✓ Utilization of biomass as a substitute for coke		2040s*5	• Green Innovation Fund - Social Implementation Plan • IEA ETP2020
Low-carbon technology	Blast Furnaces	**Use of captured CO2 (Carbon recycling technology)**	✓ Utilization technology of reducing agents (synthetic methane), CO2 recycling steelmaking system, CO2 reduction technology, etc.*5			• Green Innovation Fund - Social Implementation Plan • IEA ETP2020 • NEDO documents
Low-carbon technology	Blast Furnaces	**Utilization of external hydrogen*6 (Part of Super COURSE50)**	✓ Hydrogen reduction technology in blast furnaces that also utilize external hydrogen			• Green Innovation Fund - Social Implementation Plan • IEA ETP2020
Low-carbon technology	Direct Reduction	**Direct hydrogen reduction (based on natural gas and H2)**	✓ Hydrogen reduction technology that uses direct reduction furnaces (Technology that uses hydrogen as part of the reducing material)	0.0~1.1 *7, 8	2030	• Green Innovation Fund - Social Implementation Plan • IEA ETP2020 • Material Economics
Decarbonization technology	Direct Reduction	**Direct hydrogen reduction *5**	✓ Hydrogen reduction technology that uses direct reduction furnaces (Technology that uses hydrogen as 100% of the reducing material)	0.0~ *7, 8	2040s	• Green Innovation Fund - Social Implementation Plan • IEA ETP2020 • Material Economics

*1: Emission intensity includes the downstream process. Calculated from the CO2 reduction of the target technology based on the existing emission intensity. The CO2 reduction is accounted only from the relevant process.
*2: Refers to the starting year of introduction and expansion/cost reduction phase in Social Implementation Plan and available year from IEA.
*3: Underlined when referenced for Implementation Year.
*4: R&D and Social Implementation Plan in the Green Innovation Fund.
*5: Part of the carbon recycling technology has been implemented since the late 2020s. The GI Fund-Social Implementation Plan considers the utilization of reducing agents (synthetic methane) as a mean for 50% reduction in emission intensity.
*6: Implementation Year considers the establishment of hydrogen infrastructure in Japan (IEA assumes that both H-DRI (based on natural gas and H2) and H-DRI will be introduced in 2030).
*7: Emission Intensity is calculated as a mean of H-DRI and DRI. The emission intensity varies depending on the proportion of hydrogen used.
*8: Emission Intensity of 0.0 is when decarbonization includes the downstream process.

3. Technology Pathways to Decarbonization | ②Technology Roadmap for Iron and Steel

2020 — 2025 — 2030 — 2040 — 2050

Ways for Decarbonization (include collaboration with other industries)

Blast Furnace

Energy saving/efficient technologies : Utilization of AI･IoT / Recovery of waste heat & by-product gases / WtE (plastics, tires, etc.) / Utilization of Scraps / Next Generation Coke/ Renovation of coke oven to improve efficiency / High productivity power generation system, etc.

Ferro-Coke

Hydrogen reduction ironmaking (Utilization of on-site hydrogen)

Hydrogen reduction ironmaking (Utilization of external hydrogen*)

CO2 capture and separate

- Pursuit efficiency and energy saving for low-carbonization.
- Utilize externally sourced hydrogen to minimize the amount of cokes used, on the condition of hydrogen infrastructure establishment.
- Utilize biomass as a substitute for cokes.
- Utilize CCUS and collaborate with other industries to achieve decarbonization.

Strand Casting・Rolling

Energy saving/efficient technologies : Process consolidation and improvement/ Wasted heat recovery / Refurbishment of burners, Installation of high productivity facilities, etc.

Improvement in thermal conductivity, Power saving technologies

Electrification of heat application

+Carbon free electricity

Electric Arc Furnace

Energy saving/efficient technologies : High productivity electric arc furnace/ Waste heat recovery, etc.

Removing impurities/ Large-scale electric arc furnaces

+Carbon free electricity

- Utilize carbon-free energy (renewable energy, carbon-free thermal power generation, etc.).
- Enable the replacement of blast furnace by impurities removal and scale up.

Direct Reduction

Direct reduction（natural gas）※1

Direct hydrogen reduction (based on natural gas and H2)

※2

Direct hydrogen reduction

+CCUS

- Direct reduction furnace which partially uses natural gas achieves decarbonization by CCUS with collaboration with other industries.

※1 Has not been implemented domestically due to several conditions (production scale & quality, cost, etc.) unmet.
※2 IEA estimates the technology be available by 2030, however the Technology Roadmap determine the implementation year in consideration with the establishment of hydrogen infrastructure.
※3 Products contributes to decarbonization (Eco-products, noted in P8) are not listed in the Technology Roadmap, though can still be the use of proceeds for transition finance.

3．Technology Pathways to Decarbonization｜②Technology Roadmap【Appendix】

R&D ⋯⋯▶ Demonstration ⋯⋯▶ Deployment ◀——▶

2025 | 2030 | 2040 | 2050

Blast Furnace | Improve current facilities. COURSE50 aims to deploy at least one by 2030

Technology	Roadmap
Energy saving/efficient technologies	Deployment
Ferro-coke	Test on an experimental blast furnace, modifying actual furnace ⋯▶ demonstration test on an actual furnace ◀—▶
Hydrogen reduction ironmaking (Utilization of on-site hydrogen)	Development of underlying technology・Test on a small-scale experimental blast furnace ⋯▶ Test on a medium-scale experimental blast furnace (the first phase) ⋯▶ ◀—▶
Hydrogen reduction ironmaking (Utilization of external hydrogen)	Test on a medium-scale experimental blast furnace (the second phase) ⋯▶ Demonstration test on an actual furnace ⋯▶ ◀—▶
CO2 capture and separation	Demonstration ⋯▶ ◀—▶

Strand Casting・Rolling | Develop technology to reduce CO2 during reheating process

Technology	Roadmap
Energy saving/efficient technologies	Deployment
Improvement in thermal conductivity, Power saving technologies	Development of basic technology ⋯▶ Demonstration ⋯▶ ◀—▶
Electrification of heat application	Development of basic technology ⋯▶ Demonstration ⋯▶ ◀—▶

Electric Arc Furnace | Introduce high-quality steel manufacturing technology and energy efficient technologies for decarbonization, and increase the use of renewable energy

Technology	Roadmap
Energy saving/efficient technologies	Deployment
Removing impurities/ Large-scale electric arc furnaces	Development of underlying technology・Test on a small-scale test electric arc furnace ⋯▶ Construct an actual furnace (the first phase) ⋯▶ Test on a Large-scale test electric arc furnace (the second phase) ⋯▶ ◀—▶

Direct Reduction | Promote R&D and introduction of facilities to make direct hydrogen reduction as the main process method in the future

Technology	Roadmap
Direct reduction (natural gas) ※	※ Has not been implemented domestically due to several conditions (production scale & quality, cost, etc.) unmet.
Direct hydrogen reduction (based on natural gas and H2)	⋯▶ ◀—▶
Direct hydrogen reduction	Development of underlying technology・Test on a small-scale test furnace ⋯▶ Construct an actual furnace (the first phase) ⋯▶ Test on a medium-scale direct reduction furnace (the second phase) ⋯▶ ◀—▶

3. Technology Pathways to Decarbonization | ③Scientific Basis/Alignment with the Paris Agreement

- The Technology Roadmap is aligned with the Paris Agreement and Japanese policies aimed to achieve carbon neutrality.
- It is focused on achieving 2050 carbon neutrality by steady low-carbonization and implementing innovative technologies whilst sustaining and enhancing the Japanese iron and steel industry.

Reference/ Evidence

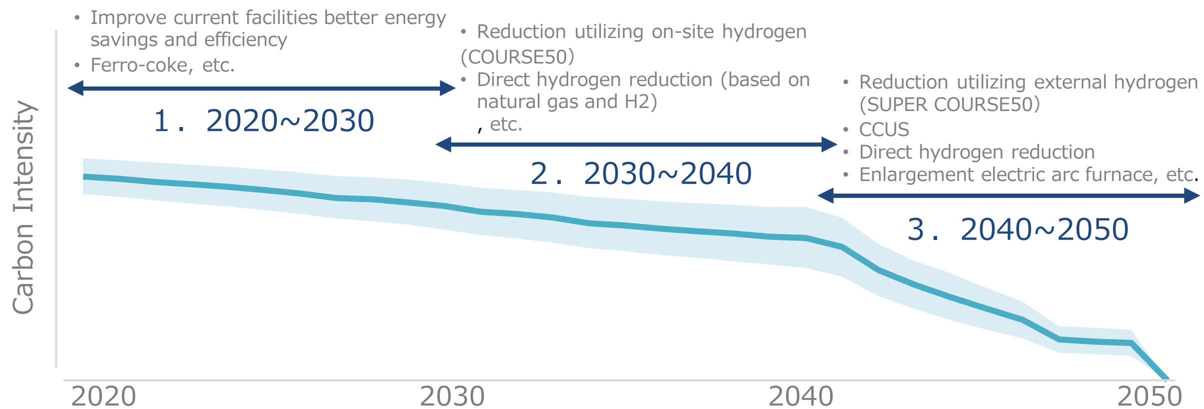
Government Policies

✓ Green Growth Strategy Through Achieving Carbon Neutrality in 2050 (Carbon recycling, materials)
✓ R&D and Social Implementation Plan about " Hydrogen utilization in iron and steelmaking processes " project
✓ Environment Innovation Strategy
✓ Strategic Energy Plan
✓ The Plan for Global Warming Countermeasures
✓ Roadmap for Carbon Recycling Technologies

International Scenarios/ Roadmaps, etc. aligned with Paris Agreement

✓ Clean Energy Technology Guide (IEA)
✓ Energy Technology Perspective 2020 (IEA)
✓ Industrial Transformation 2050 (Material Economics)
✓ Science Based Target initiative

Assumed CO2 Reduction Pathway※



1 2020~2030
The Japanese iron and steel industry already meets the world's best standards on energy efficiency, though further efforts will be made for low-carbonization through energy efficiency in blast furnaces and other means. Moreover, high-quality steel such as eco products that are expected to grow in demand will be produced. This income will be the foundation of future R&D and demonstration for decarbonization technology.

2 2030~2040
Along with increased energy savings and efficiency, new technologies as COURSE50 will be introduced and establish innovative technologies for decarbonization through continuous R&D and demonstration.

3 2040~2050
Assuming hydrogen infrastructure and CCUS to be introduced, innovative technologies such as hydrogen reduction ironmaking will achieve immense reduction of CO2 by 2050 and hence reach carbon neutrality.

※This only illustrates the assumption of overall Japanese iron and steel industry's decarbonization pathway. In reality, decarbonization will be achieved based on each company's long-term strategy and hence, will not necessary be the reflection of this assumption.

Table of Contents

4. Toward Decarbonization and Achievement of the Paris Agreement

- The Technology Roadmap is intended to exemplify low-carbon and decarbonization technologies envisioned today and indicate an estimation of when these technologies are to be established for commercialization.
- Technology development is assumed to require long-term development, and it is possible that other low-carbon and decarbonization technologies which are not described in the Technology Roadmap will be developed and adopted. In addition, there exists some uncertainties, including as economic feasibilities.
- Commercialization of low-carbon and decarbonization technologies in the iron and steel sector will also depend on the development of societal systems, such as decarbonized power sources, hydrogen supply, and CCUS. Carbon neutrality in the iron and steel sector will be achieved in coordination with other sectors.
- Therefore, the Technology Roadmap will be revised and updated regularly and continuously to maintain the credibility and usability of the Technology Roadmap by considering the progress of other technologies, the trends of businesses and policies, and dialogues with the investors.
- The iron and steel companies will aim to achieve carbon neutrality by making the best combination of technologies listed in the Technology Roadmap according to their business decision based on long-term strategy.
- In addition, efforts for reducing CO2 emissions may include the utilization of carbon credits and the purchase of carbon offset products, not limited to “the technology” of the Technology Roadmap.

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