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The Path to Green Steel

Pursuing Zero-Carbon Steelmaking in Japan

February 2023

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About Renewable Energy Institute

Renewable Energy Institute is a non-profit think tank which aims to build a sustainable, rich society based on renewable energy. It was established in August 2011, in the aftermath of the Fukushima Daiichi Nuclear Power Plant accident, by its founder Mr. Masayoshi Son, Chairman & CEO of SoftBank Group, with his own resources.

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List of Acronyms

BF	Blast furnace
BF-BOF	Blast furnace - basic oxygen furnace
BF-BOF+CCS	Blast furnace - basic oxygen furnace combined with carbon capture and storage
BNEF	Bloomberg NEF
BOF	Basic oxygen furnace
CCS	Carbon capture and storage
CCUS	Carbon capture, utilization and/or storage
CO_2	Carbon dioxide
DAC	Direct air capture
DR	Direct reduction
DR-EAF	Direct reduction - electric arc furnace
DRI	Direct Reduction of Iron
EAF	Electric arc furnace
ETC	Energy Transitions Commission
ETS	Emissions Trading System
FMC	First Movers Coalition
GHG	Greenhouse gas
H_2	Hydrogen
H_2DR-EAF	Hydrogen-based direct reduction - electric arc furnace
H_2-DRI	Hydrogen Direct Reduction of Iron/ Hydrogen Direct Reduced Iron
HBI	Hot Briquetted Iron
IDDRI	Institute for Sustainable Development and International Relations
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
Nm^3	Normal Cubic Meter
SBT SBTi	Science Based Targets Science Based Targets Initiative

Definition of Green Steel

In this report, steel produced with reduced CO_2 emissions is referred to using a variety of different terms, including "green steel," "zero-emission steel," "decarbonized steel," and "low-carbon steel," according to the context.

The most specific definition of "near-zero emission steel" (NZS) is released by the International Energy Agency's (IEA), which, in the communiqué of the G7 Climate, Energy and Environment Ministers' Meeting held in May 2022, was seen as a starting point toward a common understanding of this concept.

As shown in the details provided in "Definition of Near Zero-Emission Steel" at the end of this report, NZS is essentially defined as "a steel product produced by generating less than 400 kg of CO_2 equivalent per tonne (kgCO2e/t), including the procurement of raw materials." Currently, steel produced using the blast furnace-basic oxygen furnace (BF-BOF) process reportedly generates more than 2 tonnes of emissions per tonne of crude steel, so the IEA definition represents a rather stringent standard for primary steelmaking. The IEA definition demands an even tougher standard when scrap iron is used. This is controversial because it may tend to inhibit conversion to recycled steelmaking using electric arc furnaces (EAFs).

Aside from this, the "Global Steel Transformation Tracker" of the German think tank Agora Energiewende defines "low-carbon steelmaking" as steelmaking that emits less than half as much CO_2 than the conventional BF-BOF process.

"Green steel" and other terms are not always clearly defined, so there is a vital need to clarify definitions and standards. In the years ahead, as discussions and initiatives progress, common definitions are likely to emerge, along with the evaluation of recycled steel production.

Key Findings

1. Accelerated Decarbonization is crucial for Japan's Steel Industry

- Emissions from the steel industry account for 48% of Japan's industrial CO2 emissions and 13% of the country's total energy-related CO2 emissions. The decarbonization of the steel industry is a critical pillar in the strategy toward reaching carbon neutrality and will become more important in the future, as total emissions from thermal power generation are expected to fall through the expansion of renewable energy sources.
- Blast furnaces currently account for 76% of Japan's steel production. Approximately half of the blast furnaces currently in use in Japan, with average equipment life of 25 years, will reach their end of operational lifetimes by 2030. As we head towards 2050 carbon neutrality, decisions must be made on how to decarbonize the steel industry and not to reinvest a significant amount of money in blast furnaces which may become stranded assets.
- Low-carbon steelmaking projects have been launched around the world to reduce emissions by half or more, and the total planned production volume of such low-carbon steel exceeds 100 million tonnes, which is equivalent to the total annual production volume of Japan. There is also a growing demand for "green steel," particularly from European automakers. Accelerated decarbonization efforts are needed for Japan's steel sector, both in terms of supply and demand, in order to be competitive in the global market.

2. Bottlenecks of blast furnace + CCS pathway

- In Japan, so-called "COURSE50" and "SuperCOURSE50" projects, which use hydrogen in blast furnaces along with CCS, have comprised the main efforts to decarbonize the steel industry. However, their carbon reduction targets are 30% and 50%, respectively, and cannot be claimed as methods aiming at zero-carbon steelmaking.
- In addition, COURSE50 shows only a 10% reduction in overall CO2 emissions with the use of hydrogen alone, with a theoretical maximum reduction percentage in the low twenties in blast furnaces.
- Ultimately, both COURSE50 and SuperCOURSE50 will rely on CCS to capture and store the CO2 emitted for the majority of their reductions in order to decarbonize. If relying on this pathway, the amount of storage required in 2050 is estimated to be about 47 million tonnes per year. Based on the government's 2050 scenario, the estimated amount of CO2 storage required for thermal power generation is about 250 million tonnes. On the other hand, the government's "CCS Long-Term Roadmap" sets the annual storage capacity in 2050 at 120 to 240 million tonnes, which means that in their plan, the entire storage capacity will be used up by thermal power generation measures alone. Moreover, there is no concrete information on the location of possible storage sites in Japan.

3. Challenges of H2-DRI making in Japan

- Half of the low-carbon steelmaking projects that have been initiated in Europe and elsewhere use the hydrogen-based direct reduction method. However, the prerequisite for this method is the availability of large quantities of inexpensive green hydrogen.
- Japan's hydrogen strategy provides for a limited supply of hydrogen until 2030, and even less green hydrogen. It is not in line with the pace of steel decarbonization required for developed countries.
- Reflecting Japan's slow pace in expanding renewable energy generation, the cost of domestically produced green hydrogen is projected to be the highest of 25 selected countries in the world in 2030. Even with imports, Japan's reliance on marine transportation will make its hydrogen costs high.

4. Power source decarbonization enables green steel production in electric furnaces

- Electric furnace steelmaking can produce green steel if the power sources used are decarbonized. In order to maximize this potential, maximum utilization of scrap steel and importation of direct-reduced iron as the new source of iron is necessary. In addition, technological development is needed for the production of high-grade steel that can be used for example for automobiles.

5. Three Pillars for Zero-Carbon Steelmaking in Japan

There are three decarbonization pillars for the Japanese steel industry: maximum use of scrap steel by electric furnaces; utilization of H2-DRI imports; and introduction of DRI making utilizing domestically produced hydrogen in optimal locations in Japan. Crude steel production in Japan will shift from a focus on blast furnaces to electric furnaces. The rational choice for Japan is to make maximum use of the large amount of scrap steel that exists in Japan, import or produce a limited amount of hydrogen direct-reduced iron domestically, and make steel in electric furnaces.

[Pillar 1] Maximum utilization of recycled iron by electric furnaces

As a basic strategy toward zero-carbon steelmaking, it is essential to take measures to utilize scrap steel as much as possible. From now, it is necessary to develop technologies and invest in equipment to manufacture products using recycled steel that has not been conventionally manufactured using electric furnaces. Measures are also needed on the scrap steel side. In particular, in order to ensure the quality of scrap steel once consumed in the market and to recover it efficiently from every corner, comprehensive measures are required, including those by the private sector and government, from the design of products and buildings to intermediate treatment and recovery.

[Pillar 2] Utilization of H2-DRI imports

H2-DRI requires a large amount of hydrogen and a large amount of renewable energy for hydrogen production. It is rational to produce H2-DRI in regions (overseas) with low renewable energy generation costs and abundant iron ore, and then import it to Japan as hot briquetted iron (HBI). This would not only reduce the total cost of zero-carbon steelmaking in Japan and help ensure international competitiveness but also avoid the excessive infrastructure investment required to import large amounts of hydrogen.

[Pillar 3] Introduction of H2-DRI making utilizing domestically produced hydrogen in optimal domestic locations

The introduction of H2-DRI plants should be pursued as an option for domestic zero-carbon ironmaking as we can take advantage of the various benefits of domestic production. In order to keep production costs low, it would be rational to concentrate hydrogen production and H2-DRI in locations suitable for domestic renewable energy generation.

6. Transition Strategies for Steel Decarbonization in Japan

[Strategy 1] "Electric Furnace Phase-in and Blast Furnace Phase-out Plan" with consideration to local economic development

In order for zero-carbon steelmaking methods to become dominant in Japan and continue the development of Japanese technology in the steelmaking and manufacturing process, as well as assist the local communities that have long-supported the steel industry with their workforce and skills, an "electric furnace phase-in/blast furnace phase-out plan" will need to be developed to introduce electric furnaces as the blast furnaces are shut down. It is necessary to have dialogue and strategize with local stakeholders under the leadership of the government and local authorities, taking into account local employment and the economy.

[Strategy 2] Leading the world in building supply chains and the international H2-DRI market

The H2-DRI market is expected to play a major role as a decarbonization solution not only in Japan but also in many other countries around the world that do not have the conditions and technology to develop their own plants. Japan should lead the world in forming an "international green DRI market" to accelerate global decarbonization by supporting the realization of H2-DRI plants at an early stage and building a collaborative structure that will also contribute to local economies and society.

[Strategy 3] Select optimal sites for H2-DRI making in Japan in conjunction with offshore wind development

Regions with high potential for offshore wind power, a large-scale renewable energy source, are candidates for H2-DRI plants. Some of these regions have blast furnace steel production currently underway. In order to realize H2-DRI making in Japan, strategic collaboration is needed among three parties: offshore wind developers, hydrogen producers, and H2-DRI producers.

[Strategy 4] Reduce domestic demand and maximize utilization of scrap steel by shifting to a circular economy

In Japan, where population decline is certain, it is necessary to consider decarbonization strategies for the steel industry, at least on the assumption that the scale of domestic demand will shrink. Furthermore, it is essential to consider GHG emissions and resource balance, recycling from a life-cycle perspective while pursuing longer product life and reducing product weight. At the same time, dealing with issues such as designing products and buildings suitable for recycling, forming closed loops, and supporting the advancement of intermediate treatment is key in order to utilizing valuable recycled steel sources without degrading their quality as much as possible.

[Strategy 5] Develop policies to increase demand for green steel

Realizing the future demand for green steel will reduce the risk of investment in zero-carbon steelmaking. In order to increase the demand for green steel, the following pull policies are recommended:

1） Clarify and utilize the definition of green steel as the basis for demand expansion measures
2） Establish and expand green steel purchasing initiatives that involve the private sector
3） Promote public procurement of green steel and create a mechanism for this purpose
4） Create mechanisms to reduce embodied carbon

In addition to the decarbonization strategy for steel production described above, a fundamental revision of Japan’s energy policy is essential, including its electricity and hydrogen strategies. The 2030 and 2050 renewable energy targets need to be raised and its cost needs to be further reduced. If the current government policy of treating grey and blue hydrogen with high CO2 emissions in the same way as green hydrogen remains in place, the produced steel will not be considered green, even if H2-DRI is used. An urgent revision of the hydrogen strategy is needed. Carbon pricing is a further essential policy to decarbonize the steel industry, such as the introduction of an effective carbon tax and a mandatory emissions trading system.

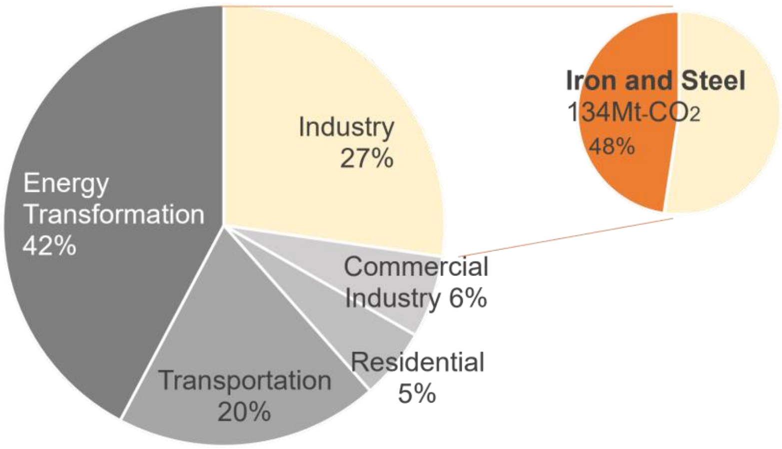
Introduction: Decarbonizing the Steel Industry, a Critical Pillar to Achieve Carbon Neutrality in Japan

The steel industry accounts for 48% of Japan's industrial CO_2 emissions

The steel industry consumes enormous quantities of energy and generates a large amount of CO_2. Globally, it accounts for 8% of total final energy consumption, 25% of industrial energy-related CO_2 emissions (direct emissions), and 7% (2.6 Gt-CO_2) of total CO_2 emissions.[1] With the sharp decline in emissions from the electricity sector, the steel industry will become the leading CO_2 emitter before long. This directly impacts the carbon footprint of many products and structures made with steel in a wide range of economic activities. Due to the need for very high temperature heat, electrification of the steelmaking process is reportedly difficult. On top of this, the use of coal, not only as an energy source but also as a reducing agent, makes decarbonization even more difficult. For these reasons, the steel industry has been considered a "hard to abate" sector.

In Japan, energy-derived CO_2 emissions (direct emissions) from the steel industry account for 48% of all industrial emissions and 13% of total emissions (Fig. 1). Across the businesses, the steel industry is also the top emitter of GHG emissions,[2] accounting for approximately 30% of total emissions (Fig. 2). Thus, decarbonization of the steel industry can have a significant impact on the realization of carbon neutrality, both in Japan and globally.

Figure 1 Energy-related CO_2 Emissions from the Steel Industry (FY2019)



(Note) FY 2019 data is referenced here, due to the substantial drop in production in 2020 caused by the COVID-19 pandemic.
(Source) National Institute for Environmental Studies, CO2 Emissions by Sector (Before electricity and heat distribution)

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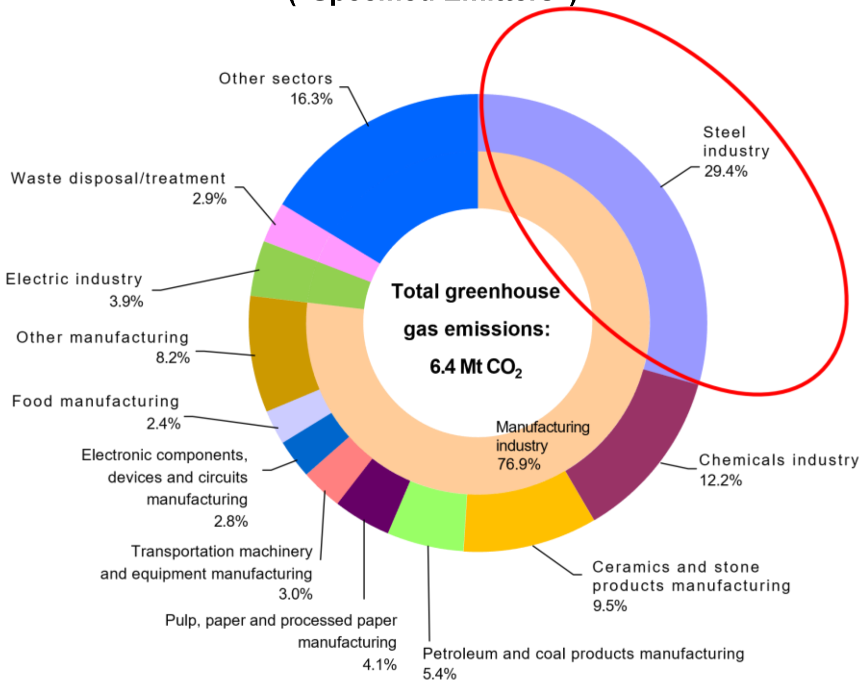
[1] IEA, "Iron and Steel Technology Roadmap" (October 2020)

[2] Ministry of the Environment, "Greenhouse Gas Emissions Selection, Reporting, and Publication System FY 2018 Aggregated Results" (12,150 reporting companies); Nippon Steel, JFE Steel, Kobe Steel, and Nippon Steel Nisshin are ranked 1, 2, 4, and 10, in order of highest emitters.

Figure 2 Proportion of Total GHG Emissions from the Steel Industry ("Specified Emitters")



(Source) Ministry of the Environment and Ministry of Economy, Trade and Industry, "Totaled Results of GHG Emissions in 2018 with the GHG Emissions Calculation, Reporting and Publication System Based on the Law Concerning the Promotion of the Measures to Cope with Global Warming" (March 2022)

In December 2021, Renewable Energy Institute published an "information-package" titled "Towards Carbon Neutral Steel in Japan: Learning from the Latest Trends in the European Union."[3] In this document, Renewable Energy Institute outlined a variety of steel industry projects that have already succeeded in implementing decarbonized steelmaking, despite the significant challenges of decarbonization. Renewable Energy Institute also highlights the urgent need for Japan's steel industry to pursue decarbonization.

Since Russia launched its invasion of Ukraine in February 2022, Europe has faced a sharp decline in natural gas supplies from Russia. In the short-term, this may increase the use of coal-fired power and may drive up CO_2 emissions. At the same time, however, this crisis is also seen as an opportunity to accelerate the shift away from fossil fuels over the medium term. Accordingly, the European Commission announced its REPowerEU plan.[4]

The plan is to accelerate the adoption of renewable energy to substitute for fossil fuels from Russia, as well as to replace natural gas, coal, and oil in industrial production processes "by any means possible" by 2030, thereby reducing Europe's dependence on fossil fuels. Policies have also been initiated to promote the decarbonization of the steel industry and other heavy industries, together with energy countermeasures. It is worth noting that even in the industrial sphere, this energy crisis is accelerating the process of decarbonization more than weakening it.

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[3] https://www.renewable-ei.org/activities/reports/20211214_1.php

[4] https://energy.ec.europa.eu/system/files/2022-05/COM_2022_230_1_EN_ACT_part1_v5.pdf

Japan’s steel industry has made some pioneering efforts to initiate the transition to decarbonized steelmaking. These include the development of high-grade steel sheet production technology using large electric furnaces, the use of hydrogen-based direct reduction ironmaking technology, and collaboration with foreign mining companies aiming for utilizing direct reduction iron.

This report looks at how Japan’s steel industry can build on these pioneering efforts to promote and accelerate the decarbonization process, as well as policies needed to facilitate this.

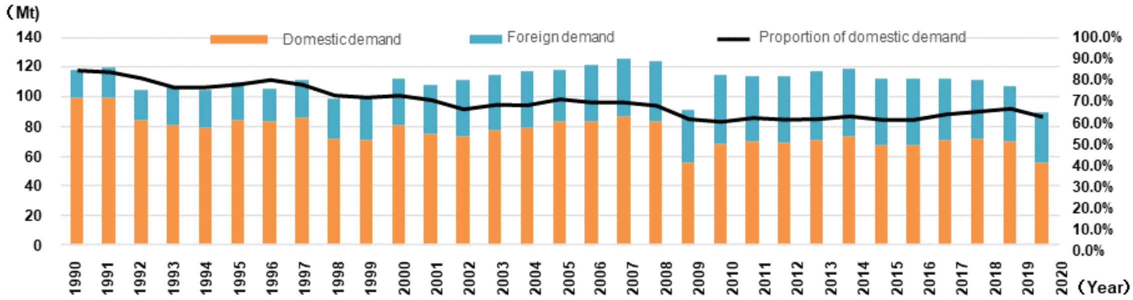
Chapter 1: Current State of the Japanese Steel Industry and Key Technologies for Decarbonization

1-1 Current Status of the Steel Industry in Japan

Firstly, here is an overview of the current state of Japan's steel industry. Japan is the world's third largest producer of crude steel after China and India, accounting for 5% of total world output.[5] In terms of corporations, Nippon Steel is the world's fourth largest raw steel producer, while JFE Steel ranks 13th.[6]

As Fig. 3 shows, annual crude steel production in Japan has consistently topped 100 million tonnes per year, except for 2009, in the aftermath of the global financial crisis. Production fell sharply in 2020. This is most likely occurred because the foreign demand, which had been strong, fell due to the COVID-19 pandemic, while the domestic demand, which had been steadily falling for many years, further contracted.

Figure 3 Breakdown of Japan's Crude Steel Production and Consumption (Domestic and Foreign Demand)



(Source) Iron and Steel Division, Manufacturing Industries Bureau, the Ministry of Economy, Trade and Industry, "Current Status and Challenges of the Metals Industry" (December 21, 2021)

A feature of Japan is that a large proportion of its crude steel production goes to foreign demand. Close to 40% of domestic production is exported, mainly to Asia.[7] The biggest sources of domestic demand are the construction and automotive industries (Fig. 4). Interestingly, the auto industry accounts for large slices of both ordinary and special steel production, as well as a significant proportion of exports. Thus, auto industry demand trends have a large impact on steel production.

What is the outlook for crude steel production? In its Sixth Strategic Energy Plan, the Japanese government forecast crude steel production in 2030 to be 90 million tonnes. Its forecast for 2050 anticipates falling domestic demand due to continued population decline, as well as falling exports. Although the total demand for steel is likely to keep growing in the developing world, exports are expected to fall because countries will increasingly produce their own steel requirements, as a matter of policy. Furthermore, a global oversupply of steel is foreseen. For example, a study by the Nippon Steel Research Institute projects steel

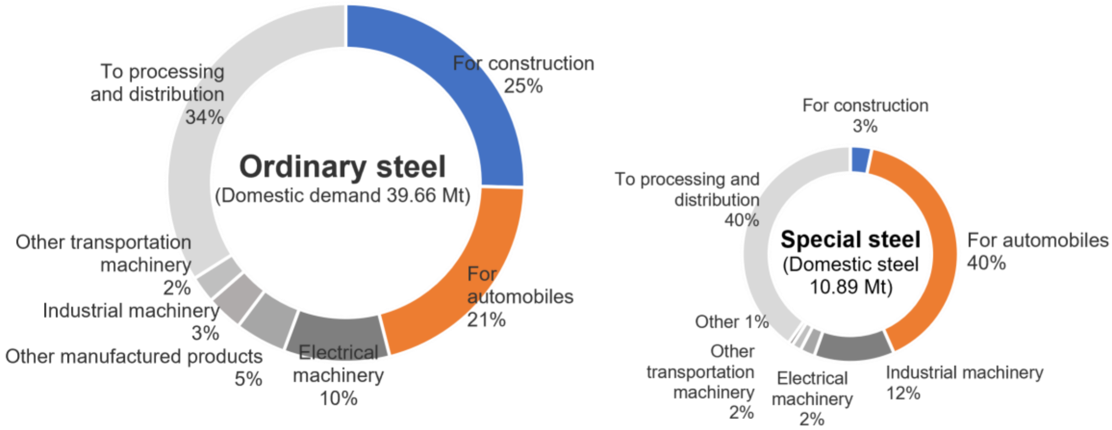
[5] World Steel Association, "World Steel in Figures 2022." These are 2021 values. If the EU is considered one country, it would rank No. 2 in the world; Japan ranks No. 4.

[6] As above

[7] 79% (FY2020) is destined for Asia. The Japan Iron and Steel Federation, "Steel Statistics Handbook 2021"

production under a moderate scenario (based on government assumptions for 2030) to fall to 75.22 million tons by 2050, down 24% from 2019.[8]

Figure 4 Ordinary and Special Steel Orders by Application (FY2019)



(Note)FY 2019 data is referenced here, due to the substantial drop in production in 2020 caused by the COVID-19 pandemic
(Source) The Japan Iron and Steel Federation, "Iron and Steel Statistical Abstract 2021" (October 2021)

Steelmaking is classified as primary steelmaking, in which crude steel is produced from iron ore, or secondary steelmaking (recycled steelmaking), in which scrap iron is used to produce crude steel. In primary steelmaking in Japan, iron ore is reduced in a blast furnace to produce pig iron. The pig iron is then converted into crude steel in a basic oxygen furnace (BOF) by removing impurities. On the other hand, in secondary steelmaking, crude steel is produced in an electric arc furnace (EAF) using scrap iron as the main raw material. Although some scrap iron is used in a BOF, pig iron made in blast furnaces is rarely used in EAFs (Table 1).

Table 1 Iron Source Consumption and Crude Steel Production by Process (FY2019) (thousand tonne)

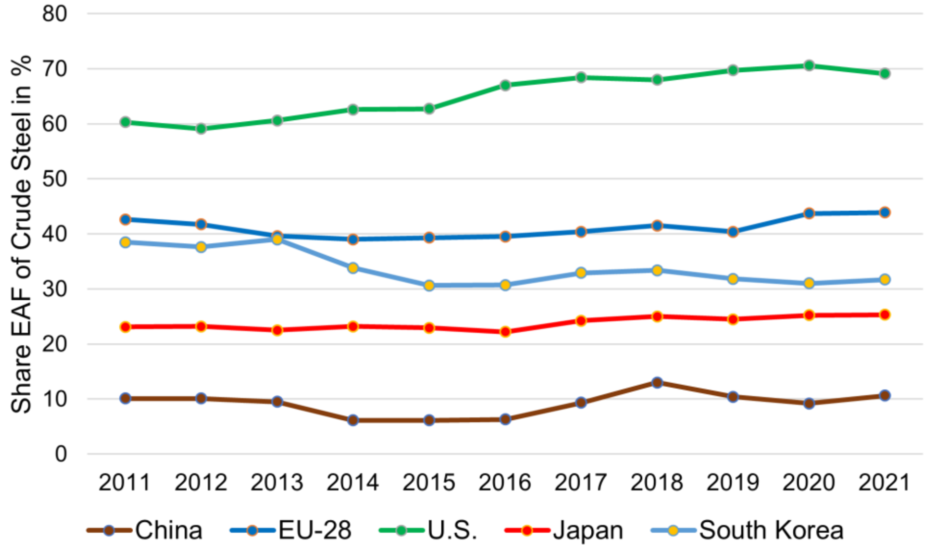
Production process	Crude steel production (by production process)	Iron consumption source	
		Scrap iron consumption	Pig iron consumption
Blast Furnace-Basic Oxygen Furnace (BF-BOF)	74,900 (76%)	8,891	71,006
Electric Arc Furnace (EAF)	23,526 (24%)	23,674	95

(Note) FY 2019 data is referenced here, due to the substantial drop in production in 2020 due to the caused by the COVID-19 pandemic.
(Source) Japan Metal Daily, "Steel Yearbook 2021" (2021)

As Table 1 shows, most of Japan's crude steel (76%) is produced using the blast furnace-basic oxygen furnace (BF-BOF) process. Another feature of Japan is the low rate of EAFs (24%), compared to 69% in the U.S.A. and 43% in the EU. (Fig. 5).

[8] Nippon Steel Research Institute, "Report on Survey Project for Sustainable Development of Japan's Metals Industry Based on Carbon Neutrality" (February 2022). "High" scenario assumes 90.49 million tons (-8%); "Low" 41.9 million tons (-57%).

Figure 5 Share of EAF Process in Major Countries



(Source) Bureau of International Recycling Ferrous Division (2022) World Steel Recycling in Figures 2017-2021 (data prior to 2016 is from earlier reports)

As a result of industry consolidation over recent years, just three BF-BOF steelmakers in Japan are responsible for three-quarters of Japan's total steel production. These are Nippon Steel, JFE Steel, and Kobe Steel, which collectively operate 19 blast furnaces at 11 locations across the country. Japan's total blast furnace capacity of 83 million tonnes per year is the fourth highest in the world.

At the same time, Japan also has substantial electric furnace steelmaking capacity, amounting to 37 million tonnes per year, but this is spread out between 60 or so companies. These EAF steelmakers are very diverse, ranging from small to large producers and handling a wide variety of products. They are also widely dispersed around Japan.

Companies in the steel industry employ a total of around 220,000 people (as of 2019),[9] with about 40,000 working at BF facilities[10] and 27,000 at EAF facilities.[11] EAF plants are more labor intensive than BF plants, employing 11.6 workers per 10,000 tonnes of crude steel production, compared to 5.3 for BF plants. (However, BF producers reportedly make use of many temporary workers from affiliated companies, which may not be reflected in these figures.) There are also other kinds of businesses that engage in wide-ranging activities, such as those involved in rolling and pipe manufacturing without producing their own steel, as well as those involved in casting and forging. Scrap-related businesses also employ around 45,000 employees.

[9] Ministry of Economy, Trade and Industry, "Industrial Statistics Survey 2020 Final Report on Statistics by Industry" (August 2021)

[10] Facilities that manufacture pig iron using a blast furnace and steel products in an integrated blast furnace operation

[11] Facilities that manufacture steel ingots in an electric arc furnace and steel products in an integrated electric furnace operation

1-2 Key Technology Options for Decarbonizing the Steel Industry

All around the world, efforts to decarbonize the steel industry have begun. The steel industry, especially blast furnace (BF) steelmakers, which use large quantities of coal, generate massive amounts of CO_2 emissions. The big question for decarbonization has been how to reduce these emissions. In recent years, however, technical studies on reducing emissions to zero have advanced, yielding some methods that promise to become mainstream.

Current Steelmaking Processes

Table 2 shows current technologies on the left and the main decarbonized steelmaking technology options on the right. Currently, the dominant method of manufacturing steel products from iron ore is the blast furnace-basic oxygen furnace (BF-BOF) process. It became established in the 20th century and is well suited to mass production. It is most widely used method of steelmaking in China, Japan, Germany, and other parts of the world. Coal is used as a reducing agent and fuel, so CO_2 emissions are high. The left side of Fig. 6 shows the BF-BOF process and CO_2 emissions per tonne of crude steel produced. The iron in the iron ore is bonded with oxygen, so it needs to be reduced. The reduction is carried out by feeding coke made from processed coal into the blast furnace, to supply carbon and remove oxygen. CO_2 is emitted not only from the reduction process, but also when making coke and sintering the iron ore as a pretreatment for reduction. Oxygen is then injected into the reduced iron (pig iron) in the basic oxygen furnace and quick lime is added, to remove carbon and impurities from the pig iron. This also generates CO_2.

Another method of producing iron is the direct reduction (DR) method, which currently uses natural gas in most cases. This method is widely used in natural gas-producing countries such as Iran, Russia, and Saudi Arabia. As shown on the right side of Fig. 6, there is no pre-reduction process because the carbon that acts as the reducing agent is supplied directly by the natural gas. In addition, natural gas is also used as a raw material for producing carbon monoxide (CO) and hydrogen, which are necessary for reducing iron ore. Since some of the reduction is accomplished by hydrogen, in addition to the CO, the resulting CO_2 emissions are lower than those from a blast furnace.[12]

In contrast to these primary steelmaking processes, there is secondary (recycled) steelmaking. In electric arc furnace (EAF) plant, scrap iron is melted in the furnace to produce crude steel, which is then used to manufacture steel products. The main energy source is electricity, and although CO_2 emissions are affected by the emission factor of electricity, they are significantly lower than those from primary steelmaking because there are no emissions from the iron ore reduction process.

[12] Chevrier et al., “MIDREX® Process: Bridge to Ultra-low CO2 Ironmaking” (KOBE STEEL ENGINEERING REPORTS/Vol.70 No.1) (July 2020) and Nippon Steel Engineering, “Direct Reduced Iron (DRI) Production Facility” (accessed October 19, 2022)

Table 2 Main Technology Options for Conventional and Decarbonized Steelmaking

	Main conventional technologies/methods			Main decarbonization technologies/methods		
	Primary steelmaking (iron ore as raw material)		Recycled/secondary steelmaking (scrap iron as raw material)	Primary steelmaking		Recycled/ Secondary steelmaking
Technology/ method	Direct reduction -electric arc furnace (NGDR-EAF)	Blast furnace-basic oxygen furnace (BF-BOF)	Electric arc furnace (EAF)	**Hydrogen direct reduction-electric arc furnace** (H_2DR-EAF)	**Blast furnace-basic oxygen furnace+CCS** (carbon capture/storage) (BF-BOF+CCS)	**Electric arc furnace** (EAF)
Energy (partially reduced material)	Natural gas and electricity	Fossil fuel, mainly coal	Electric power	Decarbonized (green) hydrogen/ Decarbonized (green) electricity	Fossil fuel **+CCS+Offset**	**Decarbonized (green) electricity**
GHG emissions	Medium (Low, if NG is converted to H_2)	High	Low	Near Zero	Low if CO_2 capture and offsets are used	Near Zero
Level of maturity	Mature	Mature	Mature	Now demonstrated Commercial by 2030	CCS, offset technology are not mature	Mature

Conditions for decarbonized steelmaking

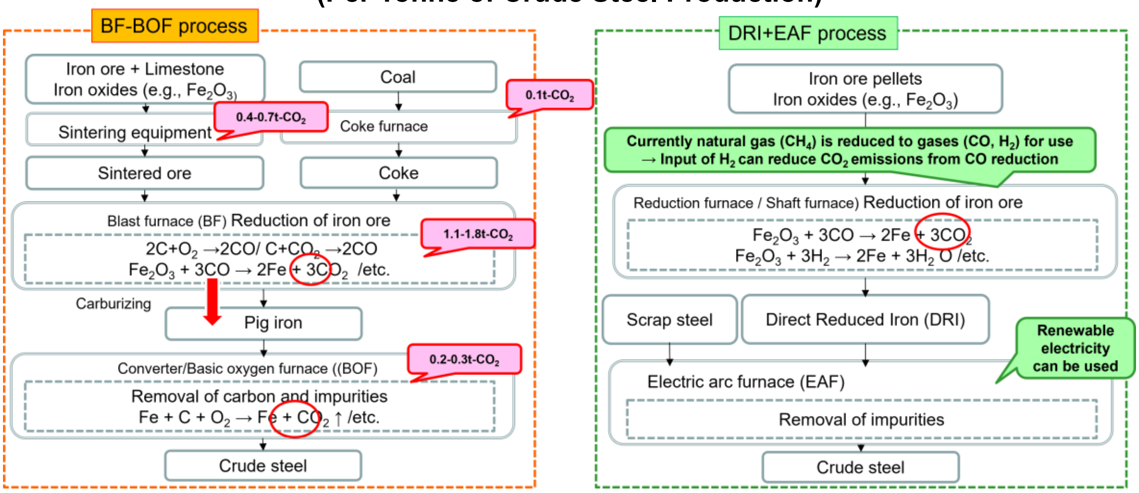
BF-BOF+CCS: Maximize CO_2 emissions capture and ultimately store permanently (CCS). Since 100% capture is difficult, it is necessary to offset the equivalent of residual CO_2

H_2-DRI-EAF: Decarbonized (green) hydrogen and electricity

EAF: Decarbonized (green) electricity

(Source) Created by Renewable Energy Institute from various sources

Figure 6 Comparison of BF-BOF and DRI-EAF Processes and Their CO_2 Emissions (Per Tonne of Crude Steel Production)



(Source) Created by Renewable Energy Institute from various sources; CO_2 emission figures for integrated BF steelmaking from Carbon Trust (2011)

Technology Options for Decarbonization

The right half of Table 2 shows different methods for cutting the CO_2 emissions currently emitted in the steelmaking process to zero. These are the three main steelmaking methods that are now under development.

(1) Blast Furnace-Basic Oxygen Furnace + CCS (primary steelmaking): BF-BOF + CCS

This method uses the BF-BOF steelmaking process together with carbon capture and storage (CCS) to capture and permanently store CO_2 emissions. It has the advantage that long-established steelmaking technology can continue to be used without modification, but there are question marks about the possibilities of capturing all the huge quantities of emitted CO_2 and about transporting and permanently storing captured CO_2. This issue is discussed below. Typically, as the CO_2 capture rate approaches 100%, the cost of capture rises exponentially. For this reason, some other way is needed to deal with the CO_2 that cannot be captured economically, such as offsetting the emissions, e.g., by planting trees. Due to this limitation, the effectiveness of this method in terms of CO_2 emissions is rated “low” in Table 2.

To improve on this approach, in Japan attempts are being made to add hydrogen (H_2) to the blast furnace reduction process, so that both carbon from coal and the hydrogen function as reducing agents. However, since it is considered impossible to convert all the coke to hydrogen, it will still be necessary to rely on CCS to deal with a large proportion of the carbon emissions.

(2) Hydrogen Direct Reduction + Electric Arc Furnace (primary steelmaking): H_2-DR + EAF

Today’s most promising decarbonization method for primary steelmaking is to use direct reduction by replacing the reducing agent with carbon-free hydrogen. Direct reduction technology that uses natural gas for direct-reduction steelmaking in a shaft furnace has been in commercial use for some time. Partial conversion of natural gas to hydrogen has already been implemented too. To achieve 100% hydrogen, further technological improvements are needed, but it is expected that near-zero emissions will eventually be possible. In this case, an electric furnace is needed to convert the direct-reduction iron(DRI) that is produced into crude steel. Consequently, to decarbonize the whole process, a carbon-free source of power for the electric furnace is also needed. In Japan, the main technology used for DRI (accounting for 63% of the world’s DRI production[13]) is MIDREX®, a proprietary technology of a wholly owned subsidiary of major Japanese steelmaker Kobe Steel.[14]

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[13] Kobe Steel website, “World DRI Production by Process” (accessed October 19, 2022) https://www.kobelco.co.jp/products/ironunit/dri/dri02.html

[14] Improvements and advances in MIDREX are expected to enable steelmaking using H_2 with near-zero CO_2 emissions. See [12] for details.

(3) Electric Arc Furnace (recycled scrap-based steelmaking): EAF

Recycled scrap-based steelmaking is still today's least emissions-intensive method, but by combining it with the use of fossil-free electricity takes it even closer to zero emissions.

Another new technology under development is the direct electrolysis of iron ore.[15] However, this technology is not yet mature, and it remains unclear whether it will be commercially implemented on a large scale by 2050.

[15] U.S. company Boston Metal is in the process of commercializing an innovative, patented production technology for zero-emission steel production that electrolyzes iron ore directly by Molten Oxide Electrolysis (MOE) instead of reducing it using coal or hydrogen. It is seen as a groundbreaking technology with the potential to greatly reduce production cost in the future. https://www.bostonmetal.com/

Chapter 2: Why Accelerated Decarbonization is Important for Japan's Steel Industry

2-1 Reduction Needed by 2030 to Achieve the Global Temperature Target of 1.5°C

As mentioned above, the steel industry is a major source of CO_2 emissions, both in Japan and globally, so its decarbonization is highly anticipated. However, alternatives to the use of coal and natural gas in the reduction process have not yet been expanded As the third largest steel producer in the world[16] and the largest crude steel producer among the G7 developed nations, Japan needs to make the transition to decarbonization faster than other countries.

In considering the 2030 target needed to achieve the 1.5°C global warming target, in accordance with the goal of reaching global carbon neutrality by 2050, various studies have looked at the decarbonization pathway that the steel industry must take. Numerous scenario studies have been published, including IEA's NET Zero by 2050, ETC's Mission Possible Project,[17] IDDRI's Net Zero Steel Project,[18] and a study by Agora Industry.[19] The report of the "Glasgow Breakthrough Agenda"[20] (an initiative launched at COP26 to stimulate urgent internationally coordinated action to resolve particularly critical issues) summarizes the findings of these studies in the following points.

- Increase near-zero emission steel (NZS)21 production to 100-500 million tonnes per year by 2030 (5-25% of total global production)
- Reduce average direct emissions intensity of steel production by 30% to less than $1tCO_2$
- Reduce the cost of NZS to approach that of "high emission steel" costs in the most advantageous locations

[16] World Steel in Figures 2022, No. 4 if EU is considered one country

[17] Energy Transitions Commission, "Keeping 1.5 ℃ Alive: Closing the Gap in the 2020s" (September 2021)

[18] Bataille, IDDRI et al., "Global facility level net-zero steel pathways: technical report on the first scenarios of the Net-zero Steel Project" (2021)

[19] Agora Industry, Global Steel at a Crossroads (November 2021)

[20] IEA, IRENA, UN Climate Change High-level Champions "Breakthrough Agenda Report 2022" (September 2020)

[21] Near Zero Emission Steel (NZS) refers to crude steel and steel products that have nearly zero emissions. For definitions, etc., see the end notes.

The scale of NZS capacity needed by 2030 varies widely from one scenario to another, but at a minimum the figure should be 100 million tonnes, equivalent to 40 of today's biggest DRI plants, capable of producing around 2.5 million tonnes of crude steel per year. At the same time, many new projects are also taking shape in developing and emerging countries,[22] but considering that most of them are based on high-emission BF-BOF processes, it's clear that further effort is needed to promote NZS in developed countries. According to the IEA report,[23] which gives milestone values for the G7 countries in 2030, hydrogen-based DR-EAF and other steelmaking with CCS will account for 14% of total steel production. Japan, which produces close to 100 million tonnes of crude steel per year, will therefore need to develop nearly 15 million tonnes worth of new projects by 2030. Clearly, Japan needs to step up its efforts to decarbonize by 2030, as well as to lead and collaborate with the rest of the world.

2-2 Length of Investment Cycle and Size of Investment – Investment Decision to be Made in the 2020s

Capital investments in the steel industry are massive and equipment and facilities are long-lasting, which means that to recover the investment and increase profits, existing facilities need to be kept in operation for as long as possible. Over the whole steelmaking process, the blast furnace emits the greatest quantity of CO_2 emissions, requires the greatest investment, and has the longest service life. Recent blast furnaces have been designed and constructed to last for over 20 years, with a new blast furnace expected to operate for 25 years or more.[24] There is therefore barely one investment cycle left before the carbon neutrality target year of 2050. Thus, any high-emission blast furnace facilities based on existing technology that are repaired or invested into before 2025 are likely to become stranded assets before 2050, without reaching their full-service life.

Investments in blast furnace renovation are very costly and getting more and more expensive in recent years. In the 2010s, the renovation cost per cubic meter was ¥6.5 million, compared to ¥10.2 million in the 2020s.[25] While it is difficult to make precise comparisons due to differences in the scale of expansion and the extent of repairs and improvements, construction costs have been rising substantially, in line with a now well-established trend, due to factors such as a shortage of skilled workers, rising wages, longer construction periods, as well as the inclusion of sophisticated functions based on AI and other advanced technologies.

Of the 21 blast furnaces currently in operation throughout Japan, 10 will have been in operation for over 20 years by 2030, thereby requiring renovation or other kind of reinvestment. In terms of production capacity, these will account for 48% of the total capacity of the 19 furnaces in operation in 2030 (Fig. 7). (Two BFs are scheduled to be idle.) A critical decision needs to be made about these 10 furnaces. What is the best way to avoid the risk of stranded assets and ensure that steelmaking will be compatible with the zero-carbon era of 2050 and beyond? We are forced to make a critical decision.

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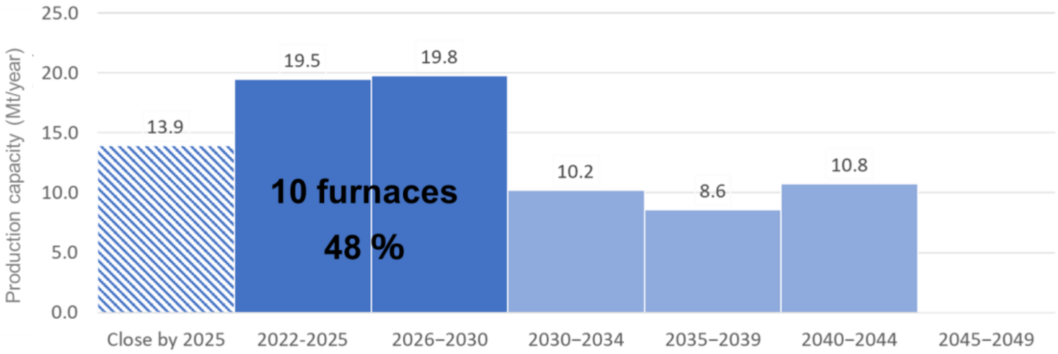
[22] OECD, "Latest developments in steelmaking capacity 2021"

[23] IEA, "Achieving Net Zero Heavy Industry Sectors in G7 Members" (May 2022)

[24] Nakano et al., "Development of Blast Furnace Lifetime Extension Technology" (2019)

[25] Average of five blast furnace renovations in the 2010s and four in the 2020s (based on data from each company's published materials and press reports, excluding one case that is unclear)

Figure 7 Blast Furnaces Reaching End of Life in the Decades Ahead (Production Capacity)

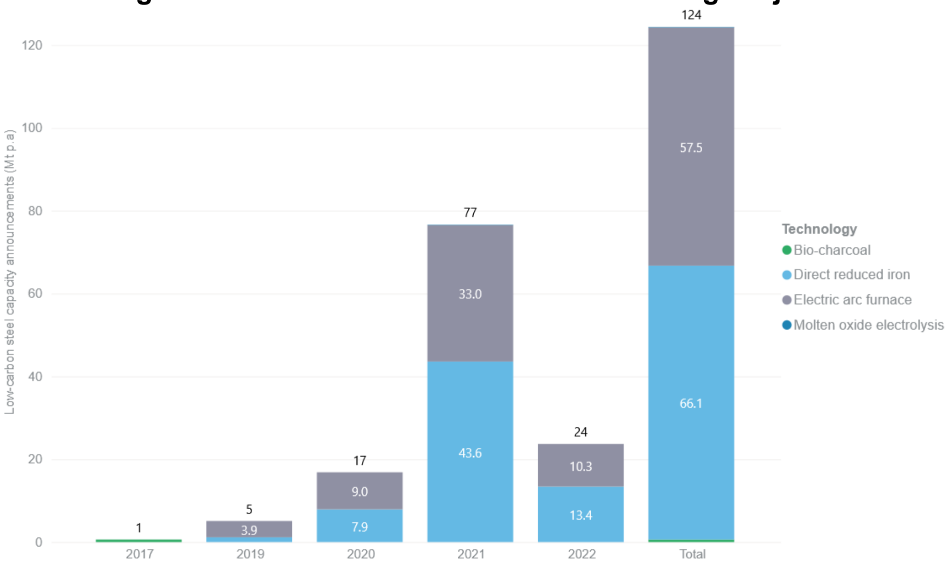


(Source) Created by Renewable Energy Institute from various sources

2-3 Companies and Policies in Europe are Moving Toward Low-Carbon Steelmaking in 2030

A noteworthy trend in steel industry decarbonization is that a variety of low-carbon projects[26] are being launched with good prospects for commercialization, particularly in Europe. As more and more such projects have been announced recent years, total global low-carbon steelmaking capacity is expected to exceed 100 million tonnes globally by 2030 (Fig. 8).

Figure 8 Announced Low-carbon Steelmaking Projects



(Source) Agora Energiewende, "Global Steel Transformation Tracker - Low Carbon Steel Announcements" (latest update August 11, 2022)

[26] In Fig. 8, from Global Steel Transformation Tracker by Agora Industry, low-carbon projects are those that use or plan to use processes that reduce CO_2 emissions by 50% or more compared to conventional BF-BOF ironmaking. (Projects that initially use natural gas in new DRI plants before converting to H_2 DRI are also included in low-carbon projects because they pose little risk of locking-in fossil fuel use.)

The definition of low-carbon steel/green steel, etc. is explained at the beginning of this report, while details of near-zero emission steel are explained at the end of the report.

At the pilot level, in 2016 Swedish steelmaker SSAB joined forces with mining company LKAB and energy company Vattenfall to launch the HYBRIT project aimed at fossil fuel-free primary steelmaking. Test operation has already begun. The project achieves fossil fuel-free steel production using a hydrogen-based direct reduction (H_2-DRI) and an electric arc furnace (EAF), without the use of any fossil fuels from the stage of mining. It also utilizes scrap iron. In the next phase of the project, a 1.3-million-tonne plant is scheduled to start commercial operation by 2026.

Getting such a project to full-scale operation requires a massive investment, however. Even after a project is announced, news of a final investment decision has never been heard in many cases. More recently, though, the situation seems to be changing a little. In July 2022, German steel company Salzgitter AG announced that its supervisory board had approved €723 million of funding to implement the first phase of a project to produce low-carbon steel, under the brand “SALCOS.”[27] Then in September, Thyssenkrupp, another German steel giant, agreed to make a huge investment in a direct reduction plant, which will be one of the largest in Germany.[28] National and regional governments in Europe are pursuing policies and support measures to forge a pathway to decarbonization before 2030. In 2021, the EU toughened its 2030 target, committing itself to reducing emissions to 55% below the 1990 level. Clearly, unless cuts are made in steelmaking and other industrial sectors, which account for a large share of emissions, this target will be difficult to achieve.

At the same time, there is fierce competition in the global steel industry, not only to develop decarbonization technologies before 2050, but also to stay ahead of competitors in the global market. Even China, the biggest player in the global steel industry, has put together a committee to promote low-carbon initiatives. It seems to have created a vision and roadmap to guide its transition to the low-carbon future.[29] Japan lags the rest of the world in the penetration of renewable electricity and the supply of carbon-free hydrogen, so it has no competitive advantage in steel decarbonization. To survive in the era of decarbonization and keep up with Europe, which is a pioneer, and China, which has started its low-carbon transition, Japan needs a strategy that is tailored to its unique situation and fully leverages its accumulated expertise.

[27] Salzgitter AG, “Green light for green steel” (July 2022)

[28] Thyssenkrupp, “Thyssenkrupp is accelerating the green transformation: Decision taken on the construction of Germany's largest direct reduction plant for low-CO2 steel” (September 2022)

[29] China Iron and Steel Association, Steel Industry Low-Carbon Promotion Committee, “2022 annual meeting of the steel low carbon work promotion committee successfully” (August 2022)

2-4 Demand Side Movements for Low-Carbon Steel Products

As well as steel companies and supply side movements to start low-carbon steelmaking projects, there is a growing demand for low-carbon steel products. Sending a clear signal to let steel companies planning to produce low-carbon steel products know that there is a future demand for such products can help to ensure the supply of low-carbon/zero-carbon steel. This can also serve as a demand-side measure to help companies to reduce their emissions in the medium to long term. Signals from end-consumers to reassure companies that there is a future demand are important, especially since low-carbon products are initially expected to cost 15-40% more.[30] Demand-side action is a major factor in the final startup of projects and investment decisions. In this regard, the European auto industry has been particularly active over the past two years.

In the Swedish HYBRIT project mentioned above, Volvo is committed not only to purchase fossil fuel-free steel, but also to do R&D on its use in automobiles and to use the green steel for serial production and commercial products. In this way, it has made a valuable contribution to getting the HYBRIT project off the ground. There are multiple ways in which the auto industry can be seen as a suitable demand-side driver.

1） Automakers consume large quantities of steel[31]
2） Many automakers purchase steel through the terms of purchase contracts that exert significant influence on steelmakers[32]
3） Many large automakers operate very broadly across the market
4） The cost increase per vehicle will be limited even when vehicles are manufactured with low-carbon steel[33]
5） They are close to end-consumers, so they can take initiatives to manufacture and sell low-carbon vehicles with the involvement of environmentally conscious consumers

Like this, the conditions for leading the demand for “green steel” are now in place, with demand-side initiatives leading the way (Table 3). The forms of these agreements are diverse, ranging from “off-take agreements,” whereby a company agrees to purchase green steel when it is commercialized in the future, to equity participation in green steel production, development of products using green steel, and partnership agreements that involve plant development.

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[30] Mission Impossible, “Steeling Demand: Mobilising buyers to bring net-zero steel to market before 2030” (July 2021)

[31] Steel for automobiles accounted for 25% of orders. (The Japan Iron and Steel Federation, “Steel Statistics Handbook 2021”)

[32] Includes so-called “string-attached transactions,” in which the buyer or recipient is already decided at the time of steel production, and centralized purchasing, in which steel to be used by parts and body manufacturers is included in the purchase

[33] Even if the cost of steel increased by 20–30% as a decarbonization premium, assuming that 0.7 tons of steel is used per passenger car, the car price would only increase by about ¥30,000, or 1%. This is a level that can easily be absorbed in product prices.

Table 3
Automotive Industry Moves Toward Offtake Agreements and Equity Participation

Automaker	Steelmaker	Form of cooperation	Details
Volkswagen	Salzgitter AG	2021 offtake agreement	MOU to supply low-carbon steel Supply expected from 2025
Volvo	SSAB	2021 agreement on R&D, serial production and commercialization	Strategic collaboration with affiliated companies on development of “climate neutral” vehicles
Shape Corp. (auto parts)	SSAB	2022 offtake agreement	Development of fossil fuel-free steel crash management system and car body structural system
Gestamp (auto parts)	ArcelorMittal	2021 partnership agreement	Purchase and use of decarbonized steel produced by recycled steel and in EAF with 100% RE power (XCarb® certified green steel)
Daimler (Mercedes Benz Group)	H_2 Green Steel	2021 equity participation	Adoption of green steel for various types of vehicles by 2025
BMW	H_2 Green Steel	2022 offtake agreement	Support of the BMW Group to meet its SBT targets. Technical cooperation agreement for ambitious CO_2 emissions reduction schedule

(Source) Created by Renewable Energy Institute based on materials published by various companies

At the same time, the Science Based Targets initiative (SBTi) to elicit commitments from demand-side companies is starting to bear fruit.[34] Since participating companies are required to reduce not just direct emissions from their own operations (Scope 1) and emissions related to electricity use (Scope 2), but also emissions across their entire supply chains (Scope 3), they are doing more to influence their supply chains, through their procurement of raw materials and in other ways. Daimler AG, for example, has set itself the goal of achieving CO_2 neutrality for new passenger cars across all its value chains and supplier networks by 2039, and it is working with all steel suppliers to build supply chains for green steel.

[34] SBT/SBTi (Science Based Targets initiative) is an initiative that requires participating companies to set GHG emission reduction targets (SBT) consistent with the levels required by the Paris Agreement. 20,761 companies worldwide have committed by FY2021, of which 1,237 companies have had their set targets certified. The following requirements of SBT encourage demand-side companies to take action on green steel.

-Set a target for the next 5 to 10 years to reduce emissions by at least 4.2% each year to help achieve the 1.5°C target.

-In addition to emissions, including supply chain emissions (the enterprise’s own emissions (Scope 1 and 2)), upstream and downstream emissions related to business activities including raw materials (Scope 3) must also be reduced.

Methods, tools, and guidelines for setting targets are currently being developed for the steel industry. (SBT website: https://sciencebasedtargets.org/sectors/steel and Ministry of the Environment “SBT” website: https://www.env.go.jp/earth/ondanka/supply_chain/gvc/intr_trends.html)

Two other new initiatives, Steel ZERO[35] and the First Movers Coalition (FMC),[36] are also beginning to make an impact. By bringing together more and more companies, governments, and other organizations, including those that would otherwise have little influence, these organizations are able to aggregate demand for low-carbon/zero-carbon steel products and send a clearer and more powerful demand signal. The Japanese government is part of the FMC and is expected to be an active member of the coalition. As well as the government, the Japanese auto industry and various other companies and organizations also need to take demand-side action.

[35] SteelZero is a group initiative launched in 2020 by the Climate Group, an international NGO that operates RE100 and EV100 programs, to purchase steel products with zero emissions. The goal is to achieve 100% net-zero steel by 2050 at the latest, with an intermediate goal of at least 50% by 2030. The group aims to realize and increase demand for net-zero steel by inviting companies and organizations to make a public commitment. Currently 27 companies and organizations are participating. Climate Group "STEELZERO" website: https://www.theclimategroup.org/steelzero

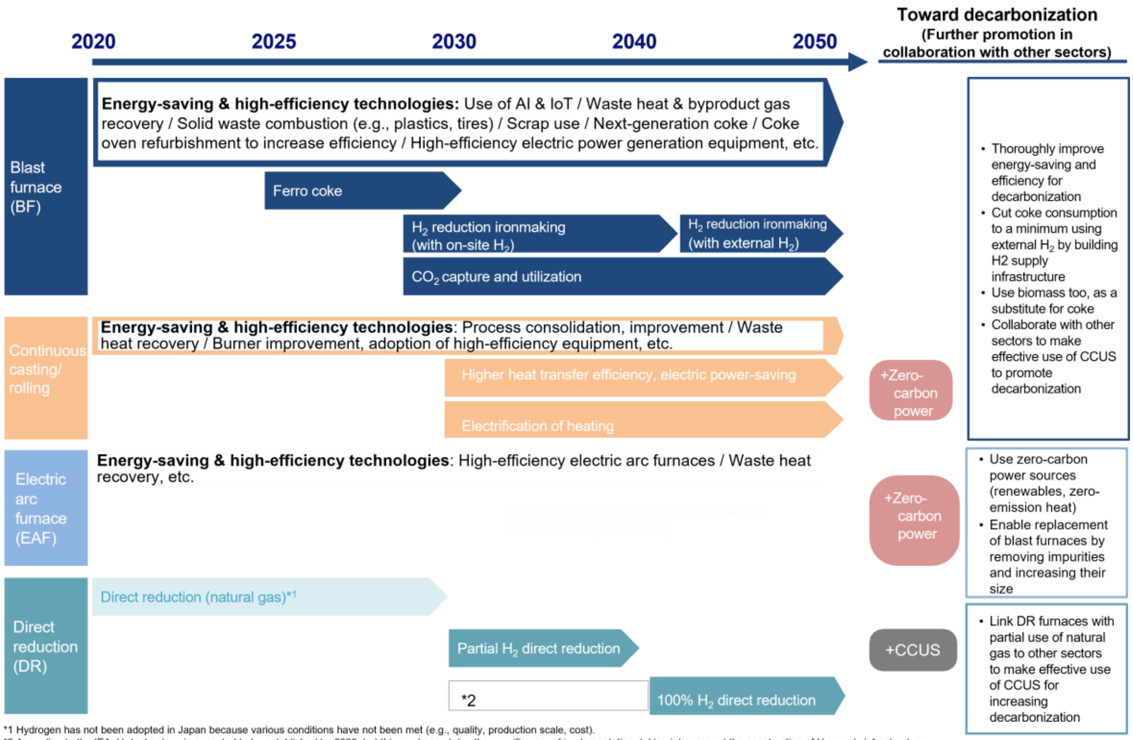
[36] The First Movers Coalition (FMC) is an initiative launched jointly by the World Economic Forum and the U.S. government at COP26 in November 2021. It is a platform designed to formulate purchase commitments by the world's leading global companies for the purpose of creating an early market for the critical technologies needed to achieve net-zero by 2050. Apple, Amazon were initial members of FMC. The initiative focuses on the steel industry and other industries in which countermeasures are difficult to take, as well as Direct Air Capture (DAC), the direct capture of CO_2 from the atmosphere. In the case of steel, the purchasing companies commit to make near-zero emission steel 10% of their annual steel procurement by 2030. FMC website: https://www.weforum.org/first-movers-coalition/about

Chapter 3: Decarbonization Challenge of Steelmaking in Japan

3-1 Japan's Plan for Zero-Carbon Steelmaking

How is Japan's steel industry currently planning for the 2050 carbon-neutral future? While the Japan Iron and Steel Federation and steelmakers (BF operators) have planned and announced a roadmap to decarbonization, the government has reflected this in its Strategic Energy Plan and other long-term plans. An overall picture of the planning is offered by the "Technology Roadmap Formulated for Transition Finance Toward Decarbonization in the Iron and Steel Sector," formulated in October 2021 (Fig. 9).[37] This is an official roadmap created to help financial institutions and investors determine whether a company that is in the process of raising funds to pursue decarbonization or thinking about the transition to decarbonization is a suitable object of investment.

Figure 9 Steel Industry Roadmap for Transition Finance



*1 Hydrogen has not been adopted in Japan because various conditions have not been met (e.g., quality, production scale, cost).
*2 According to the IEA, H_2 technology is expected to be established by 2030, but this roadmap states the specific year of implementation, taking into account the construction of H_2 supply infrastructure.
*3 Products that contribute to decarbonization ("eco-products") like those on page 8 are not covered by this roadmap, which focuses on decarbonization in the steel sector, but they may also be suitable targets for transition finance.

(Source) Ministry of Economy, Trade and Industry, "Technology Roadmap Formulated for Transition Finance Toward Decarbonization in the Iron and Steel Sector" (October 2021)

In March 2021, the launch of the Green Innovation Fund, a new government support system, was announced, pledging up to ¥2 trillion of funds. The announcement stated that "Based on specific goals shared by the public and private sectors, the plan is to continuously provide support for R&D, verification and implementation over the coming 10 years to companies and other organizations that show commitment to working toward this ambitious goal as a business challenge."[38] One of the 14 projects that is being funded is "Hydrogen Use in the

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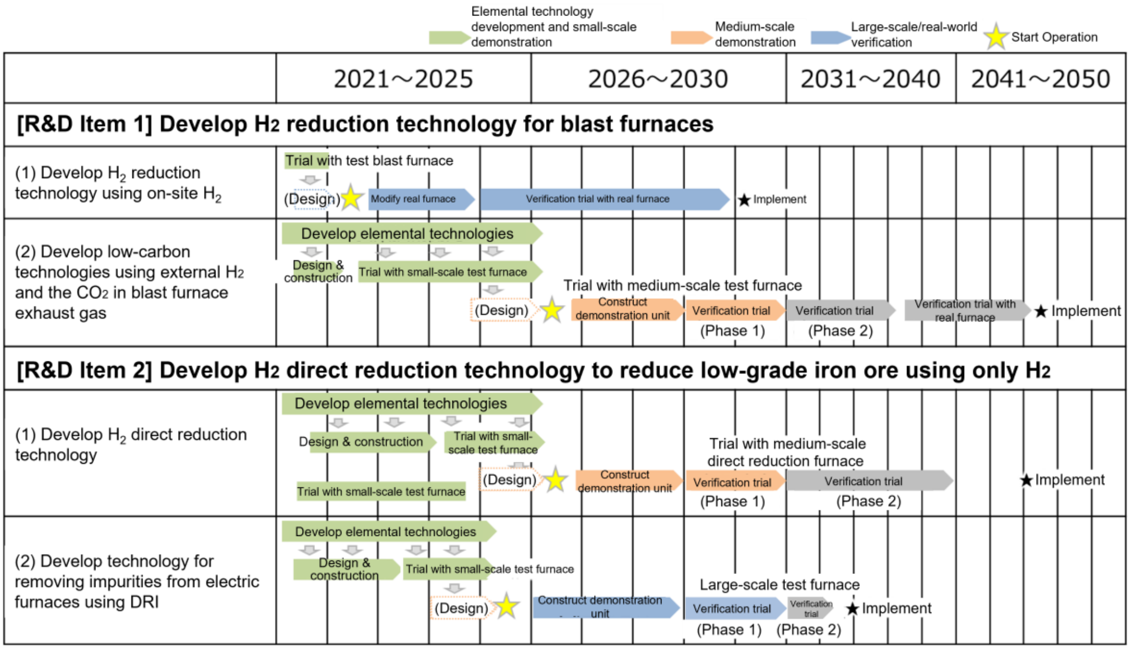
[37] Ministry of Economy, Trade and Industry, "Technology Roadmap for "Transition Finance" in the Iron and Steel Sector" (October 2021)

[38] Ministry of Economy, Trade and Industry, "Basic Policy for Green Innovation Fund Projects" (December 2021)

Steelmaking Process." Thus, solid support for R&D aimed at the decarbonization of the Japanese steel industry has emerged. An R&D and implementation plan for the project was announced in September 2021, including a timeline (Fig. 10).

Figure 10 R&D and Implementation Plan



* One possible timeline is shown.

(Source) Ministry of Economy, Trade and Industry, Manufacturing Industries Bureau, the Project for the Green Innovation Fund, "An R&D and Social Implementation Plan for 'Hydrogen Utilization in Iron and Steelmaking Processes'" (September 2021)

These documents describe three methods that overlap with the technology options for decarbonized steelmaking discussed in Chapter 1.

1) Hydrogen in blast furnace + CCUS[39]

In Fig. 9, hydrogen-based reduction in a blast furnace (on-site and external hydrogen use).

In Fig. 10, [Research Item 1] - (1) Develop H2 reduction technology for blast furnaces and (2) Develop low-carbon technologies using external H2 and the CO2 in blast furnace waste gas

Note: Applies to the COURSE50 and Super COURSE50 projects described below.

[39] CCUS stands for "Carbon dioxide Capture, Utilization and Storage." It is method of reducing CO_2 emissions by separating and capturing CO_2 from emissions and storing or utilizing it. However, there has so far been almost no utilization of captured CO_2. Expected applications are conversion to materials such as synthetic fuels and plastics, but most of these are short-life products that ultimately release CO_2 into the atmosphere, thereby making CO_2 storage meaningless. According to the IEA's "Net Zero by 2050," even in 2050, 95% of captured CO_2 will be stored and only 5% used. As explained in the report, storing CO_2 poses a number of challenges. The term "CCUS" is often used to mask the difficulties of achieving CCS by making it appear that CO_2 can practically be reused. For this reason, this method of emissions reduction is mostly referred to as "CCS" in this report.

2） Hydrogen-based direct reduction (H_2-DRI) + electric arc furnace (EAF)

In Fig. 9, partial hydrogen direct reduction in DRI and 100% hydrogen DRI

In Fig. 10, [Research Item 2] Develop H_2 direct reduction technology to reduce iron ore using only H_2 - (1) Develop H_2 direct reduction technology

3） Direct reduction in electric arc furnace

In Fig. 9, Removal of impurities from electric furnaces and increasing their scale

In Fig. 10, [Research Item 2] - (2) Develop technology for removing impurities from electric furnaces based on direct reduction

A look at the timeline in Fig. 9 shows that even the first project "(1) Develop H_2 reduction technology for blast furnaces" won't reach implementation before around 2030. Just recently, in June 2022, when the steelmakers operating blast furnaces formed the "Hydrogen Steelmaking Consortium," they referenced the above R&D and social implementation plan (Fig 10), but also indicated that they would "consider accelerating the plan as far as possible." It could be inferred that the move to commence full-scale operation of direct reduction ironmaking (DRI) plants in Europe by 2025 has heightened awareness about the need to push faster on decarbonization in Japan.

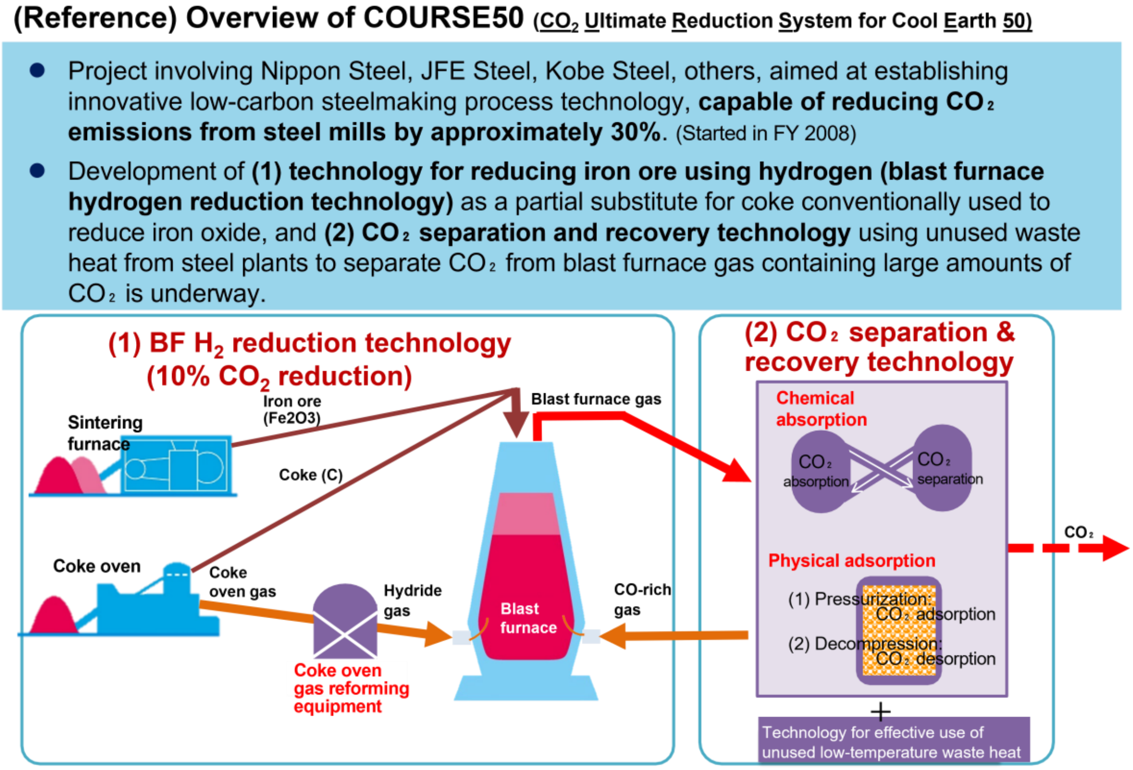
However, the need to accelerate the transition is not the only decarbonization challenge facing Japan's steel industry. The following is an examination of the challenges for the three approaches to decarbonization and the pathways Japan needs to take for each.

3-2 Issues of Blast Furnace + CCS Pathway

The Japanese government and Japan's blast furnace steelmakers have positioned the COURSE50 and SuperCOURSE50 technology development projects jointly undertaken by the three companies at the forefront of their efforts to achieve carbon neutrality by 2050 (Fig. 11). This corresponds to the "hydrogen-based reduction ironmaking in blast furnaces (on-site and external hydrogen use)" referred to in Figs. 9 and 10. The projects were commissioned by The New Energy and Industrial Technology Development Organization (NEDO) to run from 2008 to 2020, with government funding of ¥43.3 billion. Then from FY2021, the projects were run as one of NEDO's Green Innovation Fund Projects, with a further ¥193.5 billion of funding planned through up to FY2030. The basic concept of this technology is to inject hydrogen into the blast furnace ironmaking process to serve as a reducing agent, as a heating energy source, and also for capturing CO_2 emissions. The goal is to reduce CO_2 emissions from the blast furnace by 30%. Pilot trials in a small furnace have shown that the reduction goal can be met. A demonstration project in an actual blast furnace[40] will begin in 2025.

[40] Equipment is set to be introduced to the No. 2 Blast Furnace at the Kimitsu Area of Nippon Steel's East Nippon Works

Figure 11 Overview of COURSE50



(Source) Ministry of Economy, Trade and Industry, Manufacturing Industries Bureau, "Direction of Research and Development and Social Implementation of the 'Hydrogen Utilization in Ironmaking Processes' Project (Draft)" (June 2021).

COURSE50 - A Transitional Measure towards 2050

The first challenge is that COURSE50 initially aimed at a 30% reduction in CO_2 emissions[41] (Fig. 11). Even SuperCOURSE50, an evolved form of COURSE50, aims at a reduction of 50%. These targets and the implementation schedule show clearly that this approach is not aimed at complete decarbonization. This is likely because the plan was conceived before Japan committed to carbon neutrality by 2050 and before The Iron and Steel Federation and steelmakers set themselves the goal of decarbonization by 2050

In COURSE50, the emissions reduction rate from using hydrogen gas in blast furnaces is set at 10%. SuperCOURSE50 aims at further reductions by combining other means, but hydrogen injection in blast furnaces is reportedly limited by the need for coke (coal) to maintain the physical space for chemical reduction to occur. There are studies that suggest that even at optimal theoretical values, the maximum achievable reduction rate is 20 several%.[42] With this approach, the remaining emissions reduction will ultimately have to be achieved with CCS, so the question of whether blast furnaces can be used beyond 2050 for zero-carbon steelmaking depend on the feasibility of CCS (storage more than capture). In the final analysis, if these decarbonization methods are used after 2050, the CO_2 emissions

[41] Based on comparison with emissions from conventional BF-BOF furnaces using coal

[42] Can Yilmaz, et. Al, "Modeling and simulation of hydrogen injection into a blast furnace to reduce carbon dioxide emissions" (2017)

that cannot be met by using hydrogen—90% with COURSE 50 and up to 80% with SuperCOURSE 50—will have to be met by CCS and carbon offsets.

Bottlenecks of CCS, the Essential Tool for the Continued Use of Blast Furnaces

As pointed out above, if blast furnaces continue to be used in the zero-carbon era, it will ultimately be necessary to treat the remaining emissions with CCS. As long as blast furnaces remain in use, the need for and dependence on CCS will grow rapidly from 2030 to 2050. In setting its 2030 target, The Iron and Steel Federation seems to have expressed concern about the extent of CCS dependence when it stated, "A precondition is that public infrastructure, including the selection and securing of CCS storage sites when CCS is carried out under government leadership, must be in place."[43] The realization of the needed CCS, both in terms of recovery and storage, is a serious challenge.

It is instructive to try and estimate how much CCS storage would be needed to decarbonize steel production.

Projected CCS Requirements in 2050

Approx. 47 million tonnes per year

[Rough assumptions]

- CO_2 emissions from blast furnaces: 2.3 tCO2e[44]
- Reduction targets and proportion of CCS
  Course50: 30% reduction, (20% by CCS, 10% by hydrogen injection)
  SuperCourse50: 50% reduction (25% by CCS, etc, 25% reduction by hydrogen)

Other emissions

- Crude steel production with primary steelmaking in 2050: 41 million tonnes
  (Total crude steel production in 2050: 75 million tonnes; 34 million tonnes from EAFs)[45]
- Three primary steelmaking methods in 2050: H_2-DRI, SuperCOURSE50, COURSE50,with each method producing one-third of the total steel
- CO_2 capture is set at 90% of target emissions, with remainder offset

[43] The Japan Iron and Steel Federation, "State of Global Warming Countermeasures: Carbon Neutrality Action Plan (Low Carbon Society Action Plan) Report" (March 2022)

[44] Average value in Carbon Trust, "International Carbon Flows Steel" (May 2011)

[45] Set from the "Moderate" scenario of Nippon Steel Research Institute, "Report on Survey Project for Sustainable Development of Japan's Metals Industry Based on Carbon Neutrality" (February 2022)

If COURSE50, SuperCOURSE50, and 100% H_2-DRI making are achieved under these conditions, the volume of emissions that would need to be captured with CCS to achieve carbon neutrality in 2050 is approximately 47 million tCO_2e per year. On the other hand, according to the Ministry of Economy, Trade and Industry's "CCS Long-term Roadmap Interim Summary," released in May 2022, the study group shared and reached a common understanding that the estimated annual CCS storage volume available in 2050 is from 120 to 240 million tonnes per year.[46] At the same time, under the government's planning power source mix in 2050, 30 to 40% of the total power supply will come from thermal power with CCS or nuclear power.[47] And according to a reference case presented by the Research Institute of Innovative Technology for the Earth (RITE), which was used in the study process, the estimated storage needed to handle the CO_2 emissions from thermal power generation with CCS is 245 million tonnes.[48] On the basis of these assumptions, there would be no CCS capacity left over for steelmaking and other industrial sectors.

The apparent inconsistency between the government CCS goals outlined in the long-term roadmap for the steel industry and other industry and power sector decarbonization scenarios presented by the same government reflects the difficulty of realizing CCS in Japan. In the first place, CCS cannot be considered a sustainable decarbonization technology or approach, because stored CO_2 requires permanent monitoring and management, with risks of long-term impacts that cannot be fully foreseen. If CCS must unavoidably be used to decarbonize Japan, at least the following storage-related should be kept in mind. For more information, see Renewable Energy Institute's report "Bottlenecks and Risks of CCS Thermal Power Policy in Japan." [51]

Japan's CCS Bottlenecks

1) Japan has no existing depleted oil or gas fields suited to CO_2 storage
2) There are no suitable areas of land identified for CO_2 storage in Japan
3) Japan needs to develop unexplored offshore areas where CO_2 storage cost is high
4) Japan has not assessed the risks of earthquakes or other risks on CO_2 storage

CCS does not capture 100% of CO_2 emissions

Looking only at CO_2 capture, the COURSE50 project is reported to be currently at the research and demonstration stage, with the 20% reduction target now in sight for capture from blast furnaces. However, to really achieve zero or near-zero emissions, it is essential to capture most of the remaining CO_2, including emissions from other sources (apart from blast furnace), and finally offset the emissions that cannot be captured. Even if credits can be purchased initially, further in the future it will be necessary to use negative emission methods, such as direct air capture (DAC) of CO_2 from the atmosphere, or Bioenergy with Carbon Capture and Storage (BECCS) to capture and store CO_2 from biomass energy combustion. Finding solutions to these challenges will take time, but above all, it will be expensive.

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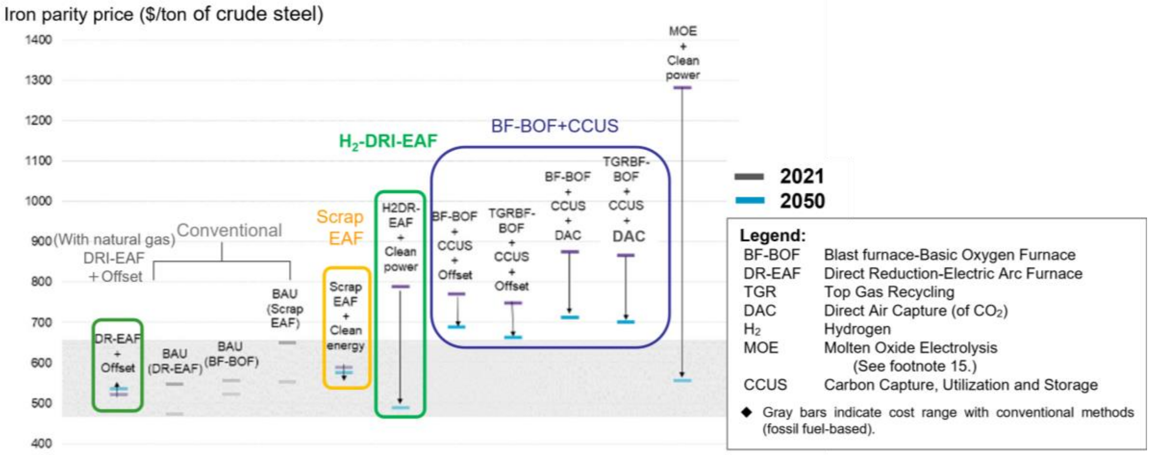
[46] Agency for Natural Resources and Energy, "Interim Summary of the CCS Long-Term Roadmap Study Group" (May 2022)

[47] Committee on the Growth Strategy, Cabinet Secretariat (6th Meeting) Document 1: "Green Growth Strategy Accompanying Carbon Neutrality in 2050" (December 2020)

[48] REI, "Bottlenecks and Risks of CCS Thermal Power Policy" (April 2022)

Figure 12 compares the current costs of decarbonization methods with corresponding 2050 projections based on BloombergNEF data. Calculated forecasts were made for the U.S.A., Germany, and China, with averages taken of these values. The 2050 values show that the cost for BF+CCS is more expensive than the other methods. The cost for the BF+CCS process is even higher if remaining emissions are captured using DAC rather than offset.

Figure 12 Change in Levelized Cost of Net-Zero Steel



(Source) BloombergNEF, “Decarbonizing Steel: Technologies and Costs” (August 2021)
Figures are added to aid understanding by REI

Considering how difficult it is to secure domestic storage sites, the idea of exporting domestic CO_2 emission overseas has recently gained momentum. One example is the CStore1 project, now under development off the coast of Australia. Nippon Steel is examining the economic viability of capturing, liquefying, and shipping 1 to 5 million tonnes of CO_2 per year from its steel mills to CStore1 (Fig. 13).[49] There are numerous challenges to overcome however, involving the capture, liquefaction, transportation, delivery, and storage, as well as associated monitoring. Even the very possibility of transporting CO_2 overseas remains unproven, and the cost hurdle is high, especially given the long distances involved in transporting the CO_2 to Australia. According to the reference materials provided with the “CCS Long-term Roadmap Interim Summary,” released in May 2022, CO_2 transportation necessitates the development of special carriers many times larger than current LNG carriers, with even more stringent low-temperature and low-pressure control requirements compared to those for transportation of LNG and LPG. And such carriers would need to be produced in large numbers. In any case, the costs would be high.

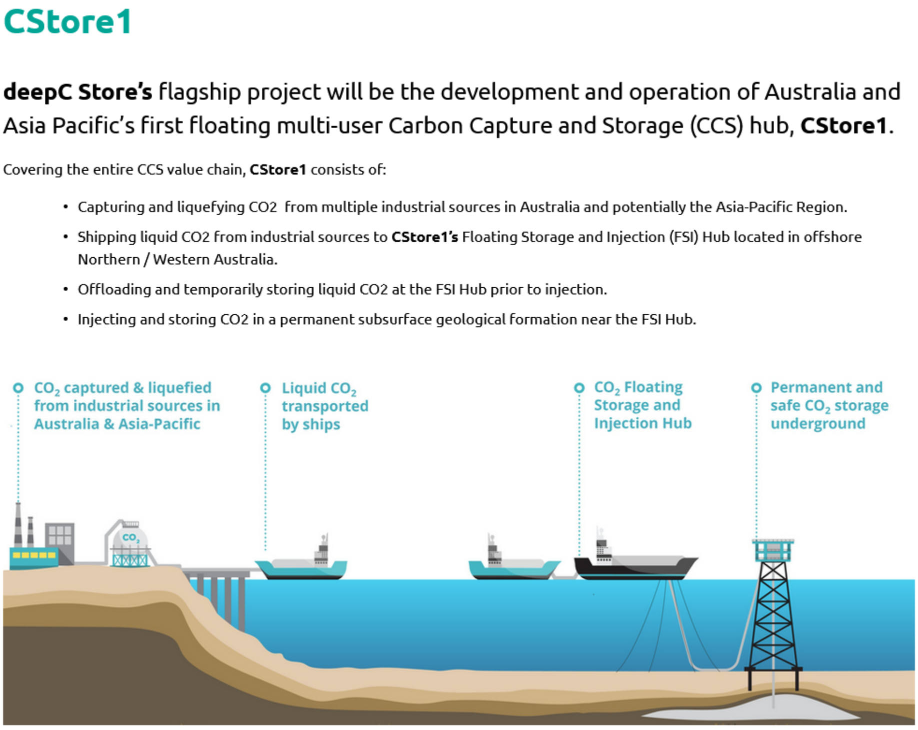
49 CStone1website: https://www.nipponsteel.com/news/20220214_100.html

and Nippon Steel, “Execution of Joint Study Agreement regarding Capturing and Transporting Liquefied Carbon Dioxide (CO2) to Offshore Floating CO2 Capture and Storage Hub Project” (February14 2022)

The Ministry of Economy, Trade and Industry (METI) expects Southeast Asia to accept most of Japan's CO_2 exports. A scheme in which a developed country like Japan exports the CO_2 emissions it cannot process at home to developing countries could be seen as a failure to play a leading role in cutting emissions, as befitting an advanced nation.[50] Moreover, the customers who purchase green steel at an early stage are likely to be environmentally conscious companies and organizations who are prepared to pay a premium to maintain high standards sustainability. There is a real possibility that such future customers would rate CCS-dependent decarbonization projects poorly in terms of sustainability.

Considering the above, the continued use of blast furnaces in Japan beyond 2050, requiring massive amounts of CCS, would not only be very expensive, but also problematic from a sustainability viewpoint. It must be said, therefore, that this a very risky approach to survival in the competitive milieu of the decarbonization era. Even if COURSE50 and SuperCOURSE50 are fully implemented to promote the decarbonization of steelmaking in Japan, the idea of continuing to use of blast furnaces in 2050 seems unrealistic.

Figure 13 CStore1 Project



(Source) CStore1 website

50 See P.24-25 of REI, "Bottlenecks and Risks of CCS Thermal Power Policy" (April 14, 2022)

3-3 Challenges of Hydrogen Direct Reduced Iron in Japan

Now, what about the hydrogen-based direct reduction method of steelmaking? If the risks to Japan of relying on CCS to continue using blast furnaces are taken into account, it becomes vital to enhance this method. As discussed in Chapter 1, the low-carbon steelmaking projects that are now underway, most notably in Europe, employ the H_2-DRI method in most cases. In Japan, this method presents significant challenges, however. Due to the large amount of hydrogen consumed, the key question is whether hydrogen can be supplied in sufficient quantity and at a reasonable cost.

Can Japan's Hydrogen Supply Contribute to Green Steelmaking?

To begin, it is important to confirm that the government’s plans and strategies for hydrogen supply are up to the task of achieving green steelmaking. There are four essential points to check.

1) Are the timelines of hydrogen supply and steel industry decarbonization compatible?
2) Is the hydrogen supply target appropriate (current government targets are > 1 million tonnes of new supply by 2030 and 20 million tonnes by 2050)?
3) What is the impact of the government policy that supports all types of hydrogen even without distinguishing high-CO2 emission hydrogens (i.e., gray and blue hydrogen)?
4) Is the target cost appropriate (¥30/Nm3 in 2030; ¥20/Nm3 by 2050)?

1) Hydrogen supply under the government’s current hydrogen strategy is based on a very limited response to demand in the 2030 phase. The move to decarbonization on the steel side described earlier is currently consistent with the fact that Japan will not significantly expand its hydrogen supply until around 2050. Accordingly, while the timelines appear consistent, they are slow relative to the speed of steel decarbonization required of developed countries by the international community.

2) The Japan Iron and Steel Federation (JSF) has published estimates of the potential demand for hydrogen supply for primary steelmaking. If all the coal currently used as a reducing agent to make pig iron in blast furnaces were replaced with hydrogen, approximately 7 million tonnes (80 billion Nm^3) of H_2 would be needed (this does not include other uses, i.e., use for energy) (Fig. 14). Japan’s total hydrogen supply is expected to grow to 20 million tonnes by 2050,[51] of which steelmaking will account for more than one-third. The government’s supply target is no more than a rough estimate, but it appears that the 7 million tonnes for steelmaking is included in the 20 million tonnes, and there is no mention of other industry sectors. So, it does not seem that the government is examining what applications will use hydrogen or how in any detail. Even at this point, the real issues will not emerge until concrete proposals are presented and reviewed. The questions of when and how hydrogen will be used to meet what kind of demand need to be studied, taking into consideration demand volumes and locations and relationships with hydrogen supply and electricity.

[51] Industrial Science and Technology Policy and Environment Bureau and Agency for Natural Resources and Energy, “Interim Report on Issues of and Measures for Future Hydrogen Policy (draft)” (March 22, 2022)

3) In addition, since current Japanese hydrogen policy does not call into question emissions at the stage of hydrogen production, initial hydrogen supplies are likely to be gray hydrogen derived from fossil fuel. Even if H_2DRI is started through technological innovation or new capital investment, as long as gray hydrogen is used the resulting steel material will not be rated as a “green steel.” Domestically, the government is planning a scheme that rates products as “zero emission” even if they are made using gray hydrogen,[52] but any such classification will not be internationally recognized. As discussed later, discussions on a definition and rating method for green steel is growing around the world. As a fuel, hydrogen is evaluated on a life cycle basis, including emissions during its production. Particularly in the initial stages, most consumers are likely to be environmentally conscious companies and organizations that will demand third-party certified products..

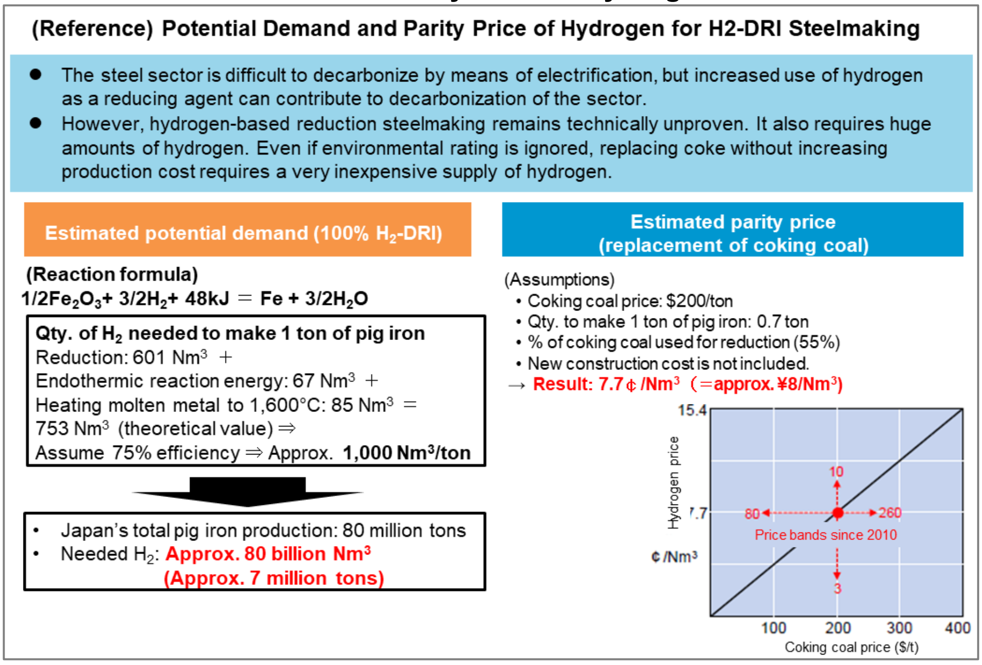
4) Cost is the biggest challenge, so it will be discussed in detail in the next section.

As all the above shows, hydrogen supply in Japan faces many challenges that could become obstacles to the achievement of hydrogen-based direct reduction steelmaking.

Japan's Hydrogen Costs are Highest of Any Countries

The cost targets set as part of Japan’s hydrogen strategy are ¥30/Nm^3 (¥336/kg) in 2030 and ¥20/Nm^3 (¥224/kg) in 2050. The Japan Iron and Steel Federation (JSIF), however, estimates that compared to using coal as a reducing agent, the required parity price of hydrogen is around ¥8 yen/Nm^3 (¥89.6/kg) (Fig. 14). The substantial difference between these estimates is itself a good indicator of the difficulties involved.

Figure 14 Potential Demand and Parity Price of Hydrogen for H_2-DRI Steelmaking



(Source) Agency for Natural Resources and Energy, “Measures to Promote Investment in and Expand Demand for Hydrogen and Ammonia Supply Chains” (April 2022)

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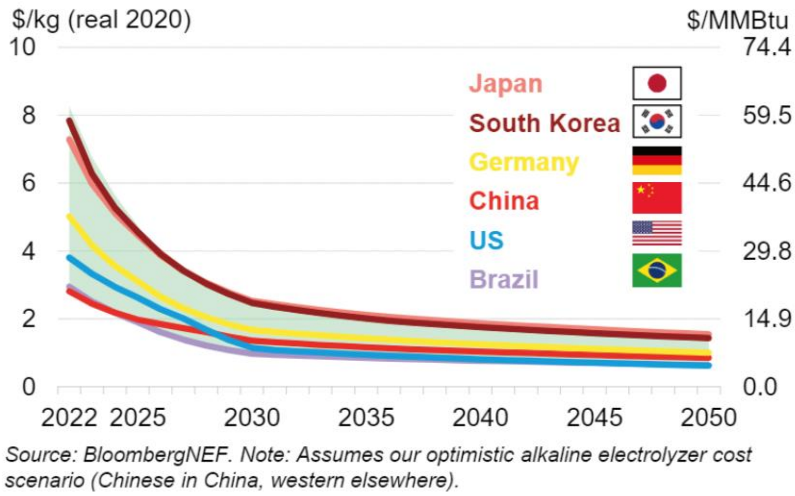
[52] Refer to P.27 of REI, “Re-examining Japan’s Hydrogen Strategy” (September 2022)

The problem is that the level of domestic hydrogen costs in Japan is likely to be considerably higher than in other countries and regions. Figure 15 shows the projected trend in levelized cost of hydrogen production by BloombergNEF, which predicts an extended decline in the global price of green hydrogen. The survey covers 25 countries, with the light green color indicating the spread in cost. Japan has the highest cost of all the countries. According to this projection, Japan's cost of H_2 production will be \$2.53 (¥278)/kg in 2030, and \$1.54 (¥169)/kg in 2050. At these levels, Japan can meet its strategic goal, but the cost remains higher than that of other countries. The International Renewable Energy Agency (IRENA) also estimates that cost will be highest in Japan, though its price estimates are different. [53]

Figure 15 Levelized Cost of Hydrogen Production from Renewable Electricity, 2022-2050



(Source) BloombergNEF, "1H 2022 Hydrogen Levelized Cost Update" (June 2022)

Importing hydrogen will not eliminate the cost difference.

As cost differentials with other countries become apparent, proposals to promote imports from countries with lower costs naturally emerge. In fact, the Japanese government's current hydrogen policy seems more focused on building an international supply chain based on imports than on domestic production.

The import pathway is also fraught with difficulties. Due to its low energy density per unit volume, hydrogen is difficult to transport efficiently. Japan is also very far from regions that enjoy low hydrogen production costs, so it would be forced to transport hydrogen over long distances by sea. However, to ship hydrogen, it is necessary to reduce its volume by liquefaction, compression, or chemical conversion. A variety of studies have identified the three most promising options for shipping as liquefaction, conversion to ammonia, and conversion to liquid organic hydrogen carriers (LOHCs). With support from the government's Green Innovation Fund Projects, Japanese companies are currently pursuing each of these methods, striving to commercialize them and reduce their costs. Table 4 shows a summary of the methods by IRENA.

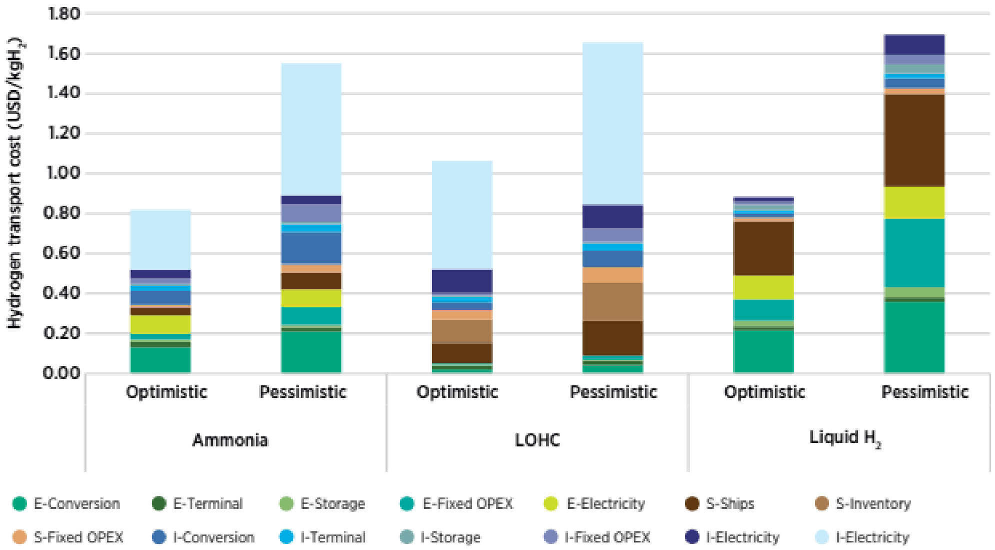
[53] IRENA,"Global Hydrogen Trade to Meet the 1.5°C Climate Goal Part 3: Green Hydrogen Cost and Potential" (May 2022)

Table 4 Advantages and disadvantages of each potential hydrogen carrier

	Pros	Cons
Ammonia	・Already produced on a large scale ・Already globally traded ・High energy density and hydrogen content ・Carbon-free carrier ・Can be used directly in some applications (e.g., fertilizers, power generation, maritime fuel) ・Can be easily liquified (20°C at 7.5 bar or -33°C at 1 bar)	・High (12–26%) energy consumption for ammonia synthesis ・High (13–34%) energy consumption for reconversion (importing region) with high temperatures requirement (up to 900°C but more commonly in the 500–550°C range) ・Ship engines using ammonia as fuel need to be demonstrated ・Might require further purification of the hydrogen produced ・Most applications require compression of hydrogen ・Higher NOx (nitrogen oxides) production during shipping would require flue gas treatment ・Toxic and corrosive ・Flexibility of the ammonia synthesis and cracking still to be proven
Liquid hydrogen	・Limited energy consumption for regasification (most of the energy is consumed in the exporting region, which is expected to have low renewable energy costs) ・No need for a purification system at the destination ・Easier transport at the importing terminal ・Low energy consumption to increase pressure of delivered hydrogen ・Liquefaction is already a commercial technology ・Carbon-free carrier	・High energy losses for liquefaction (30–36% today), which calls for larger energy supply ・Need to expand energy supply ・Boil-off (0.05–0.25% per day) during shipping and storage ・Cryogenic temperatures lead to high equipment cost ・Currently available only on a small scale
Organic hydride	・Can be transported as oil is today using existing infrastructure, making it suitable for multi-modal transport ・Low capital cost for all steps ・Can be easily stored	・High (25–35%) energy consumption for dehydrogenation (importing region) ・Requires high-temperature heat (150–400°C) for dehydrogenation ・Requires further purification of the hydrogen produced ・Hydrogen is produced at 1 bar, requiring compression ・Only 4–7% of the weight of the carrier is hydrogen ・No clear chemical compound that is the most attractive ・All the possible carriers currently have a high cost ・Carrier losses every cycle (0.1% per cycle) ・Carriers would probably contain fossil CO_2 ・Most of the possible carriers require scaling up multiple times from current global production

Figure 16 shows IRENA's cost comparison of different carriers in "a future in which each technology attains its full potential." The scale of production plants is greatly expanded to enjoy better economies of scale and the calculated costs are layered to show different cost components (conversion from hydrogen to carrier, transportation, and reconversion to hydrogen). The conclusion, in short, is that although all the methods have their challenges, ammonia appears to be the best option because there is already a supply chain for it. The weak point of ammonia is that the reconversion to hydrogen is expensive both in terms of energy consumption and cost. When ammonia can be used directly as a fuel, these energy and monetary costs can be avoided. However, since hydrogen itself is needed for steelmaking, the steelmaking sector would have to bear high transportation and storage costs on top of reconversion costs.

Figure 16 Transport Cost Breakdown by Hydrogen Carrier



Notes: Costs are for a 1 MtH$_2$/yr export flow and a distance between ports of 10 000 km. Cost components are divided by part of the value chain: E = exporting country; S = ships; I = importing country. Refer to Figure 1.3 for the scope of these costs.

(Source) IRENA, "Global Hydrogen Trade to Meet the 1.5°C Climate Goal: Technology Review of Hydrogen Carriers" (April 2022)
(Note by REI) "I-Electricity" at the right end of the bottom row of the legend remains the same as in the original, but the original description suggests that it actually refers to "energy for reconversion in the importing country".

Transportation costs in current pilot projects are \$6.5 to \$17.3 per kg of hydrogen, but with bigger plants, economies of scale could bring costs down to somewhere around \$1 to \$2 per kg, as shown in Fig. 16. However, the cost of hydrogen production would also drop significantly over the same time. In the same report, IRENA forecasts that "In 2050, the LCOH from a stand-alone green hydrogen production system will be very low on average; below \$1.5 per kg in most countries when the best renewable resources are used." BloombergNEF predicts that the price of H_2 in 25 countries worldwide will range from \$0.7 to \$1.5 per kg.[54] It is therefore likely that the transportation cost, estimated to be \$1 per kg or higher, will be the bigger burden, in the sense that this cost will be paid by Japan but not by green hydrogen production areas. It is also important not to underestimate the additional cost to Japan compared to Europe and other regions where hydrogen can be imported from production areas via pipeline by simply compressing the gas.

These projections suggest that it will be difficult for Japan to access the inexpensive hydrogen needed to enable internationally competitive hydrogen-based steelmaking, whether by means of domestic production or imports. Therefore, any large-scale domestic development of H_2-DRI steelmaking, requiring large quantities of hydrogen, is likely to entail considerable difficulties.

[54] BloombergNEF, "1H 2022 Hydrogen Levelized Cost Update" (June 2022)

[BOX 1] Quality of iron ore required for direct reduction ironmaking + electric furnace method

It is fair to say that for now, the most promising technology for decarbonizing primary steelmaking is hydrogen-based direct reduction iron(H_2-DRI) process. The technical issues have been largely overcome and Sweden's SAAB has already commenced production of zero-emission steel in a pilot plant. In fact, according to the Global Steel Transition Tracker, nearly all the low-carbon steelmaking projects planned for implementation by 2030 are based on the H_2-DRI process (Fig. 8). Two key challenges remain—hydrogen supply and iron ore quality. Currently, H_2-DRI plants need to use the highest quality (DR grade) iron ore, containing 67% iron on average, which only accounts for 4% of current global iron ore shipments. Given that the overall quality of iron ore has reportedly declined in recent years, it is impossible to expect increased production of DR-grade steel or expanded mining of magnetite ore, which is easier to concentrate, in the years ahead. Steelmakers are working on various technological innovations to address this issue. As well as trying to create DR-grade iron ore in the pelletizing process, they are also pursuing various technological developments in the steelmaking process to improve performance with low-quality iron ores.[55]

Direct Reduction-Melter-Basic Oxygen Furnace

This method adds a melting process after direct reduction[56] and then utilizes an existing converter (basic oxygen furnace) instead of an electric furnace. This reportedly allows the use of blast furnace-grade iron ore pellets with an iron content of 65% or less. Thyssenkrupp of Germany and BlueScope of Australia are engaged in R&D on this method.

Fluidized Bed Furnace

Reportedly, a fluidized bed furnace in which fine iron ore powder is reduced by reaction with 100% hydrogen gas, without the need for pelleting the iron ore, does not require DR-grade ore. Both Korean company Posco and Japanese company Primetals Technologies are doing R&D on this method.

The results of NEDO Green Innovation Fund Projects in Japan are also promising, with some projects announcing aims to launch production before 2030. Like this, it seems that the issue of iron ore quality in H2-DRI is gradually being resolved.

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[55] Details are in IEEFA, "Iron Ore Quality a Potential Headwind to Green Steelmaking" (June 2022) and "Solving Iron Ore Quality Issues for Low-carbon Steel" (August 2022)

[56] An electric arc furnace for melting is attached to the shaft furnace for direct reduction (sub-merged arc furnace) (DRI-SAF-BOF), or melting process is added in which DRI is fed into a melting furnace after direct reduction (DRI-Melter-BOF)

3-4 Challenges and Developments of the Electric Furnace (Recycled Iron Manufacturing)

Two methods, (1) BF-BOF+CCS and (2) H_2-DRI, have been mentioned as pathways to steel industry decarbonization, but in both cases, domestic deployment is fraught with various difficulties. Then what about the other pathway, method (3) Electric arc furnace (EAF)with recycled steel? Steelmaking that uses iron scrap in electric arc furnaces (EAFs) is still practiced today, accounting for 24% of Japan's total crude steel production (Table 1). Compared to the other two methods, which require technological innovations, there are no significant technical hurdles to the feasibility of this method. CO_2-based reduction could also be used in the future to produce carbon-free EAF crude steel, provided that suitable zero-carbon power sources are available. Thus, if the shift to using electricity as an energy source for downstream processes continues to advance, it will become increasingly viable to produce steel products with near-zero emissions.

Nippon Steel has announced that it will construct a new EAF facility at its Setouchi Works (Hirohata Area), with commercial operation set to start in October 2022.[57] This will be the largest EAF in Japan, with a capacity of 4 million tonnes per year by 2030. Meanwhile JFE Steel has announced that it is shutting down the No. 2 Blast Furnace at its Kurashiki Works, to replace it with an EAF. It also has plans to expand the EAF plant at its Sendai Works.[58] The move to EAFs by steelmakers that operate blast furnaces merits attention as a highly feasible approach to decarbonization.

However, even electric furnaces have some issues.

1） Is sufficient scrap iron available to provide enough iron to meet all demand?
2） Can the electric furnace satisfy all quality requirements using scrap iron?
3） What is the impact of the higher cost of electricity in Japan (compared to other countries)?

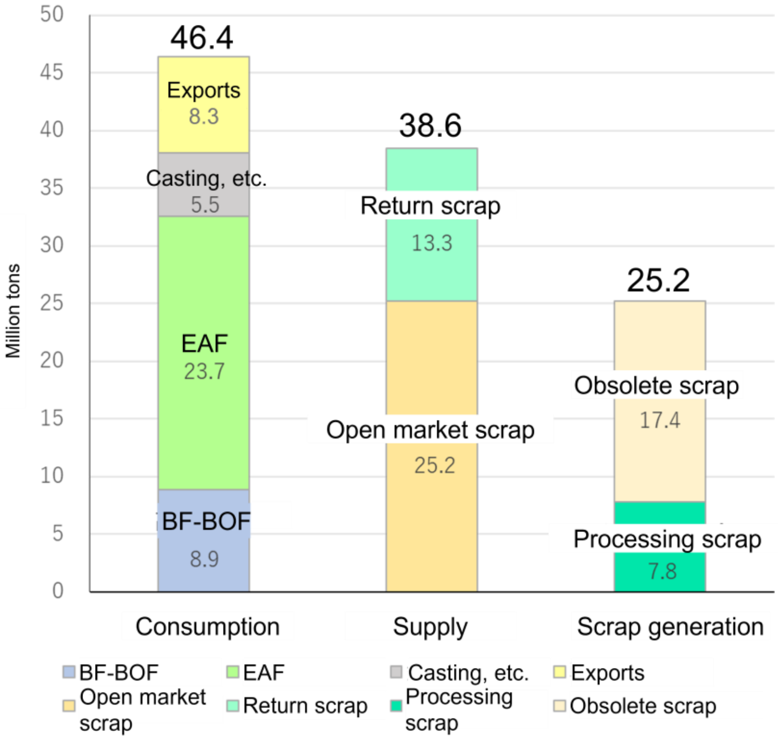
Can the Electric Arc Furnace Method Meet All Iron Demand?

The value of scrap iron will increase as a low-carbon iron source that is available domestically at low cost. The current supply-demand situation of scrap iron is shown in Fig. 17. Total consumption is approximately 46 million tonnes, including BF-BOF, EAF, castings, etc., plus exports. Exports are around 8 million tonnes, or nearly 20% of consumption. Exports have served as a buffer between domestic supply and demand, so when domestic scrap demand increases, exports may decline. However, even if all current exports were redirected to domestic crude steel production, they would still fall far short of the 71 million tonnes (Table 1) of iron source (pig iron) currently produced in blast furnaces for conversion in BOF furnaces. Furthermore, exports of steel scrap from Japan are important for developing countries that lack sufficient iron and steel reserves of their own. It is therefore essential to pursue new approaches, such as importing DRI as a new source of iron and using EAFs to produce that quantity of steel that has been produced up to now in BFs.

[57] Nippon Steel News Release, "Commercial Operation Begins at Hirohata Area Electric Furnace of Setouchi Works: Steady development of high-grade steel production technology, a carbon-neutral technology, in a large electric furnace" (November 1, 2022)

[58] JFE Steel, "Environmental Vision 2050" (September 1, 2022)

Figure 17 Steel Scrap Consumption (FY2019)



(Source) Japan Ferrous Raw Materials Association, "Annual Report of Iron Sources No. 31" (2020)
See Table 6 for an explanation of various kinds of scrap.

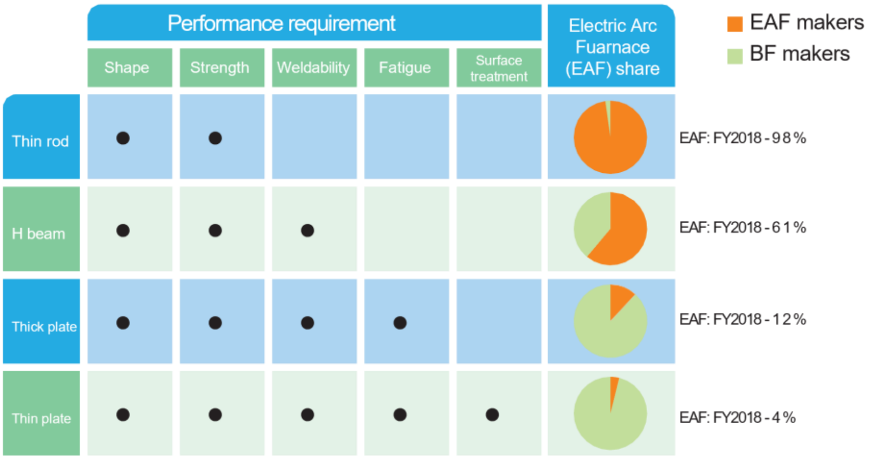
Can the Electric Arc Furnace Method of Scrap Utilization Cover All Demand?

Electric furnace steel mills currently use scrap iron for almost all their iron raw material (Table 1). At the same time, their product lines are wider than in the past. However, there are still some steel products they cannot produce from scrap iron. As a result, BF steelmaking and EAF steelmaking are now almost "segregated" (Fig. 18). There are also some kinds of steel products that cannot be made solely from scrap iron, though this also depends on the quality and condition of the scrap.

On the other hand, JFE Steel is moving forward with technological development and investment to begin production of high-grade steel for automobiles using an electric furnace at its Sendai Works in FY2024. Nippon Steel Corporation has also announced a plan to start production of electromagnetic steel sheets at its new EAF plant in Hirohata.[59] Other companies are also moving to produce high-grade steel using EAF processes. Some EAF steelmakers are even producing automotive steel sheet, though this requires further effort and technological development. Work needs to be done not only on EAF processes, but also on the iron raw materials and product design, to figure out how to control the composition of the iron source in order to produce steel products with the optimal properties for specific products.

[59] Nippon Steel, "Briefing Material for Energy Structure Transformation Field Working Group of Green Innovation Project Subcommittee, Industrial Structure Council" (September 12, 2022)

Figure 18 Required Performance of Steel Products and Share of Production from Electric Arc Furnaces

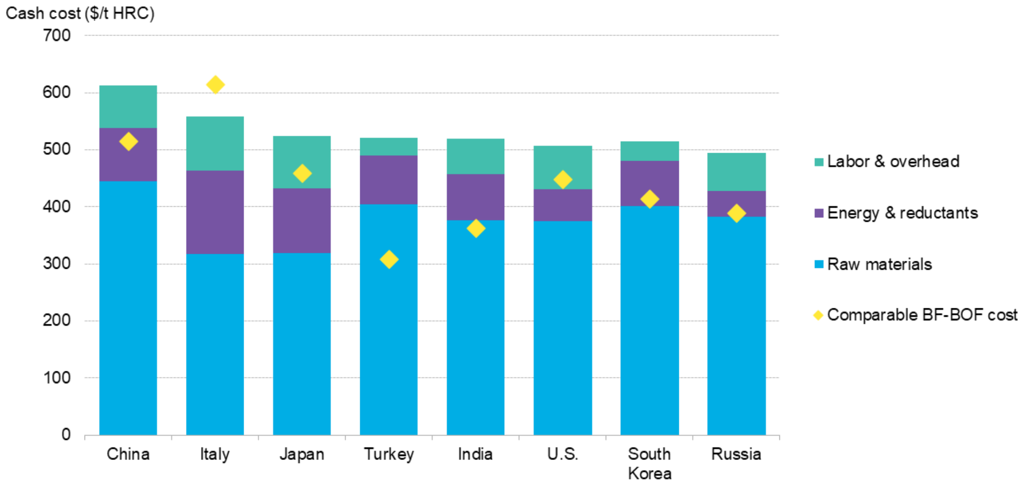


(Source) Tokyo Steel website, https://www.tokyosteel.co.jp/pdf/q1-1-2.pdf

Japan's Electricity Costs are Higher Compared to Other Countries

The economics of EAF steelmaking is influenced by the cost of electricity, which is consumed in large quantities. It is well-known that the cost of electric power in Japan is currently higher than in other countries. On the other hand, the cost of scrap iron is relatively low in Japan, so the overall cost of making steel from recycled iron is aboutthe same as in the U.S.A., which enjoys low electricity costs (Fig. 19). While instability in fossil fuel prices will continue to affect electricity costs across the world for the time being, policies and economies of scale could eventually lower the cost of renewable electricity. Japan also needs to expand its deployment renewable energy (including the development of independent power producer), upgrade its power transmission infrastructure, and operate its electric power plants more flexibly, giving consideration to supply-demand balance. Such measures can help to reduce the cost of the power used by EAF steel mills.

Figure 19 Scrap-based EAF Cash Costs for Hot-rolled Coils[60] in Major Countries)



(Source) BloombergNEF, "Decarbonizing Steel-Technologies and Costs" (August 2021)

[60] Hot coil (hot-rolled wide strip steel) is a steel product made by heating and rolling steel billets that are made in a BF-BOF or EAF process, before coiling

3-5 Summary of Issues for Steel Decarbonization Approach in Japan

Finally, Table 5 offers a summary of Japan's planned approach to decarbonization.

Table 5 Approach to Decarbonization Approach: Pros and Cons of Steel Industry Decarbonization Methods in Japan

Method	Pros	Cons
BF-BOF + H_2-DRI + CCS ▪ Renovate existing BFs and add H_2 as a reducing agent to cut coal use ▪ Capture and store residual CO_2 emissions	▪ Can take advantage of the technological advantages of current BFs and BOFs ▪ Existing BF-BOF plants can be renovated and utilized, thereby containing infrastructure costs to some extent ▪ Makes use of zero-carbon H_2	**Difficult to achieve near-zero emissions. Rather a transitional approach** ▪ Only a 20-30% reduction, even with zero-carbon H_2 ▪ CCS cannot capture 100% of CO_2 emissions ▪ Residual CO_2 emissions must be offset using DAC or other means of negative emissions solution
		Lack of storage sites for large volumes of captured CO_2 ▪ There is no prospect of securing permanent storage sites for the large volumes of captured CO_2 (deep-sea storage costs more than land storage) ▪ Risks of CCS need to be assessed
		Not yet technically mature, but outlook is good (COURSE50 is on track for 30% reduction)
		High infrastructure costs, for facility renovation and installation of ancillary equipment
H2-DRI + EAF ▪ Construction of new H_2-DRI plants ▪ 100% H_2 reduction	**Can be made near-zero emission** ▪ Makes use of zero-carbon H_2 and electricity	▪ High cost of H_2 supply (even if imported) ▪ H_2 production needs large quantities of zero-carbon electricity
		Not technically mature, but outlook is good (Proven in pilot plants around the world)
		Need to secure high-quality iron ore OR Need to develop new technology to enable use of low-grade iron ore (Technology is under development in Japan and other parts of the world)
		New capital investment, high cost of H_2 supply infrastructure
EAF (Recycled steelmaking) ▪ Crude steel production in EAFs using scrap iron and DRI	**Can be made with near-zero emission** ▪ Makes use of zero-carbon electricity ▪ Makes use of scrap iron or zero-carbon iron source (H_2-DRI) ▪ Existing EAFs and other infrastructure can be used, allowing infrastructure costs to be contained to some extent ▪ Enables use of existing technology	▪ Need more decarbonized electricity ▪ Cost of electricity is higher than in other countries
		To expand use of EAFs ▪ It is necessary to increase supply of scrap iron and/or import DRI iron
		To expand the range of steel products made in EAFs ▪ Need to improve scrap iron quality ▪ Need to secure zero-carbon iron source (H_2-DRI) ▪ Need to develop new technology (on both production and product sides)

(Source) Created by Renewable Energy Institute from various sources

In conclusion, it does not make sense for Japan to continue using the BF-BOF process as a means of advancing the goal of decarbonization, even if combined with partial use of hydrogen for reduction, or CO_2 capture, especially due to the limitations of CO_2 storage. On the other hand, the supply of hydrogen is a major challenge for the large-scale deployment of H_2-DRI in Japan, particularly in terms of cost. Ultimately, the most rational pathway toward zero-carbon steelmaking for Japan is to make maximum use of the EAF process while also using H_2-DRI on a limited basis where conditions can be optimized.

Chapter 4: Japan's Zero-Carbon Steelmaking in the Carbon-Neutral Era

As already shown, continuing to operate blast furnaces (BF-BOF), relying on CCS to reduce CO_2 emissions, and importing large quantities of hydrogen to commit fully to H_2-DRI domestically are both unrealistic approaches to decarbonizing the Japanese steel industry by 2050. Considering Japan's unique circumstances and taking advantage of its strengths, the three pillars of Japanese steelmaking in the age of carbon neutrality are likely to be the following.

Pillar 1	Maximum utilization of recycled iron making by electric furnace to meet the era of circular economy
Pillar 2	Utilization of H_2-DRI imports
Pillar 3	Introduction of H_2-DRI making utilizing domestic hydrogen at optimal locations in Japan

Crude steel production in Japan will shift from conventional blast furnace (BF) steelmaking to electric arc furnace (EAF) steelmaking. The most rational choice to suit Japan's circumstances is to take full advantage of scrap iron available domestically, as well as to import or domestically produce H2-DRI, and to combine these two sources of iron raw material in various ways to produce steel in EAF plants.

It could be said that up to now, BF and EAF steelmakers have largely operated in different markets, producing different products. From now on, though, they will both have to tackle decarbonized steelmaking with no real boundaries between them. BF steelmakers will adopt EAFs and actively use scrap iron, and work to master a new kind of iron raw material—H_2-DRI. Taking advantage of downstream process technologies, they will work to preserve and even enhance their international advantage using "integrated electric furnace" production processes. At the same time, EAF steelmakers will also procure H_2-DRI as an iron source to produce a more diverse range of products. They will be able to take advantage of the technology of EAF steelmakers to control the content of various substances according to the steel product they wish to produce.

Several scenarios have been presented for crude steel production in Japan in 2050. It is quite possible that Japan could manage to supply about half of its iron resource needs by making maximum use of its available scrap iron, which is the country's largest domestic iron resource. Another rational choice would be to import most of its H_2-DRI needs, while producing some H_2-DRI domestically too, on a limited basis in areas that offer high renewable energy potential. This is discussed further below.

Supported by these three pillars, the transition to steel production in the decarbonization era will require a series of actions on the steelmaking side, including technology development and penetration, and capital investment, as well as a transition strategy that takes into account impacts on local economies and employment, expansion of green steel demand, transition to a circular economy, and acceleration of renewable power source development. These strategies are outlined in Chapter 5. The following sections will make clear the importance of each of these three pillars of steel industry decarbonization.

[Pillar 1] Maximum Utilization of Recycled Iron by Electric Arc Furnaces in Response to the Age of Circular Economy

A transition to the zero-carbon era cannot be achieved without the backing of a circular economy. Even many of the decarbonization scenarios presented at the beginning of Chapter 2 anticipate significant use of recycling. As a basic strategy for decarbonization, it is vital to put in place measures to ensure the maximum possible scrap iron utilization, giving it precedence over iron sources made by primary steelmaking.

In the future, it will be necessary to develop technologies and invest in facilities to manufacture products from scrap iron that have been impossible to make with conventional EAF processes up to now. BF steelmakers have begun working to produce electromagnetic steel sheet in EAFs. The efforts of one of these companies, Nippon Steel, to establish an integrated EAF steelmaking process at Hirohata[61] is an important model initiative for Japan's steel industry in the era of decarbonization. Efforts to overcome the weakness of domestic operations in Japan, which tends to be high in cost by leveraging the advantage of making steel and manufacturing products within Japan to enhance product differentiation and create added value need to be undertaken in collaboration with local communities.

Aside from this, Tokyo Steel is moving to begin mass production of steel sheet for automobiles in 2025,[62] while U.S. Steel announced that its new EAF steel sheet plant, set to begin operating in 2024, will produce leading-edge, high-strength steel sheet from source iron consisting of 90% scrap.[63] Like this, globally steelmakers are accelerating their decarbonization efforts utilizing scrap steel. It is important to keep strengthening and promoting this line of action.

Measures on the scrap iron side are necessary too. Table 6 provides a breakdown of the current scrap iron supply in Japan along with some explanations. Scrap iron can be classified as (1) return scrap, generated at steel mills, (2) process scrap, generated by processing steel into a variety of products, and (3) obsolete scrap, recovered after steel products or structural materials have been consumed or used. Naturally, return scrap and process scrap need to be recovered in a way that ensures they are free of impurities. It will also be necessary to improve the quality of obsolete scrap and to recover and use it efficiently and effectively. Comprehensive measures that take into consideration everything from product and building design to intermediate treatment and recovery, involving both the private sector and government, will be needed.

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[61] Nippon Steel News Release, "Commercial Operation Begins at Hirohata Area Electric Furnace of Setouchi Works: Steady development of high-grade steel production technology, a carbon-neutral technology, in a large electric furnace" (November 1, 2022)

[62] NIKKEI BUSINESS DAILY, "Tokyo Steel to mass-produce steel sheets for automobiles in electric furnaces in 2025, demand for de-carbonization" (May 26, 2022)

[63] U. S. Steel website: https://www.ussteel.com/next-generation-steel-mill, https://www.ussteel.com/prereleases/-/blogs/u-s-steel-confirms-major-near-term-expansion-of-sustainability-commitments-at-ceres-2021

Table 6 Types of Scrap, Their Properties and Future Directions (FY2019)

Type of scrap	Qty. (ktonnes)	%	Description/quality	Remarks
(1) Return scrap	13,320	35%	Scrap from iron and steel production processes; of high quality	Linked to steel production, so availability will not significantly increase. Availability tends to be decreasing as production becomes less wasteful.
(2) Process scrap	7,808	20%	Commercially available scrap generated from steel processing; of relatively high quality	Linked to the quantity of steel consumption, so availability will not significantly increase. Availability tends to be decreasing as processing becomes less wasteful.
(3) Obsolete scrap	17,384	45%	Scrap iron and steel recovered from obsolete products, structures, etc.; of variable quality	Linked to past consumption and demand for various products and structures. Even if quantity does not increase, it can be exhaustively utilized by increasing quality.
Total	38,512	100%		
(4) Exports	8,286		Scrap exported abroad. Supplements the domestic supply-demand balance.	Decreasing in accordance with domestic demand increases

(Source) Created by Renewable Energy Institute based on Japan Ferrous Raw Materials Association, "Annual Report of Iron Sources No. 31" (2020)

Cooperation between companies on the demand side, especially in the automotive industry will be even more important. It is widely recognized that the strength of the Japanese steel industry lies in the quality of its steel products, which are in large part produced for the automotive industry. However, as the blast furnaces that served as the foundation of Japanese steelmaking come into disuse, the challenge of making steel products that meet stringent performance requirements using electric furnaces must be tackled in cooperation with companies on the demand side. A noteworthy example is the Volvo Group's commitment to SSAB's fossil fuel-free steel production and its development of products that will use the steel. Japanese automakers and other large steel consumers in Japan should also make a positive commitment to decarbonized steel production and review their product manufacturing with a clear understanding of the pros and cons of new steel materials produced in the decarbonized process, so that they can offer feedback on their requirements to the steelmakers. It is only through this kind of cooperation and collaboration that Japanese industry will be able to wield its traditional strengths in the decarbonization era.

[BOX 2] Demand Response by Electric Furnaces - Tokyo Steel's Contribution to the Power Grid

Electric furnaces have started to get involved in demand response efforts. Since electric furnaces consume such large amounts of electricity, they can play a valuable role in adjusting the electricity supply-demand balance by coordinating their operation according to times of electric power surplus or shortage. Demand response behavior by large power consumers such as electric furnaces will be very important for electric power systems in the era of decarbonization, when renewable sources, which are subject to output fluctuations, will account for the bulk of the power supply.

Although electric furnaces have traditionally operated at full capacity overnight and on holidays to take advantage of low off-peak power prices, as the power supply-demand balance has become more complex in recent years they are now operating even more smartly and nimbly. For example, on the request of power companies, they may operate during the day in spring and fall, when solar power generation is high, thereby boosting power demand and absorbing surplus power to help balance supply with demand. Such so-called “raise DR” demand response programs (DRPs) are also seen as an effective way to ease local output suppression of photovoltaic (PV) power generation. In cooperation with Kyushu Electric Power, Tokyo Steel has run a trial of “raise DR” since 2018, with a total of 26 implementations in spring and fall by 2021. The opposite kind of DRP (“lower DR”) is being tested in a collaboration with TEPCO Energy Partner, for the purpose of reducing peak demand by flexibly adjusting furnace operations on request when power supply is tight in winter.

Together with various other companies and organizations, Tokyo Steel is also participating in the “Renewable Energy Aggregation Demonstration Experiment” with Chubu Electric Power Miraiz. This project aims to verify the magnitude of output adjustment and response time that is possible with electric furnaces, as part of a system of various adjustable resources, including storage batteries, EVs, and air-conditioning equipment.[64]

Thus, even though electric furnaces consume huge amounts of electricity, they can be operated in ways that contribute importantly to power systems, by serving as “**flexible demand**” to balance power supply and demand.

[64] Kyushu Electric Power, “About the “Raise DR” Initiative” (November 2021); Tokyo Steel website: https://www.tokyosteel.co.jp/eco/achievement/; Nara, “Examples of Demand Response” (August, 2022); Nihon Keizai Shimbun, “Tokyo Steel to support power saving with the use of electric furnaces: Temporarily suspending the use of electricity when supply and demand are tight to help prevent blackouts in the entire region” (September 2022)

[Pillar 2] Utilization of Hydrogen Direct Reduced Iron (H_2 -DRI) Imports

Making steel by direct reduction with hydrogen requires both a large amount of hydrogen and a large amount of renewable energy and power to produce the hydrogen. Even if hydrogen can be produced at low cost somewhere overseas, importing hydrogen for H_2-DRI making would be very expensive, due to the huge cost of transporting hydrogen over long distances, as discussed in 3-3. Hydrogen could be converted to ammonia, which is relatively easy to transport by sea, but the ammonia would need to be reconverted to hydrogen before use. Whichever way it is done, the cost of H_2-DRI in Japan will inevitably be high.

Increasing the use of recycled iron and reducing the demand for steel by promoting a circular economy will reduce the amount of iron that needs to be reduced from iron ore. However, some new H_2-DRI will need to be supplied for products that are difficult to produce with 100% scrap, to ensure the quality..

Given this situation, a reasonable approach to securing a supply of the necessary H_2-DRI domestically is to produce it in regions (overseas) that enjoy low renewable power generation costs and abundant iron and steel resources and then import it to Japan in the form of hot briquetted iron (HBI).[65] The idea of producing H_2-DRI in areas of the world where it is possible to produce green hydrogen inexpensively on a large scale and creating a global market for trading the commodity is beginning to gain traction internationally.[66] The positive aspects of this approach, particularly for Japan, are outlined below.

1) It reduces the total cost of decarbonizing the steel industry in Japan and helps to ensure international competitiveness
2) It avoids the need to make excessive investments in the infrastructure needed to import large quantities of hydrogen, which is difficult and costly to transport and store
3) It enables stronger collaboration with iron ore/hydrogen producing regions (by not only importing iron ore and hydrogen but also setting up H_2-DRI plants locally, the result is a win-win situation that contributes positively to the local economy and community)

To compare different approaches to steelmaking, a case study was conducted assuming the use of a H_2-DRI process to produce iron using Australian iron ore and green hydrogen. The study compared the relative energy and cost advantages of locating a H_2-DRI plant and electric arc furnace (EAF) plant in Japan versus Australia.[67] The following three cases (Fig. 20) are compared in terms of energy consumption and cost.

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[65] Reduced iron is not stable in its original form (sponge-like state); it ignites easily, for example. It is therefore solidified into masses called “briquettes,” which are suitable for transportation and storage. This material is called “hot briquetted iron” (HBI).

[66] For example, Recharge, “Hydrogen-derived sponge iron could become a globally traded commodity: ETC chair” (June 29, 2022)

67 Devlin et al., “Regional supply chains for decarbonising steel: Energy efficiency and green premium mitigation” Energy Conversion and Management 254 (2022)

SC1) Iron ore and green hydrogen are imported from Australia and used in H_2-DRI and EAF plants in Japan to produce iron and steel products

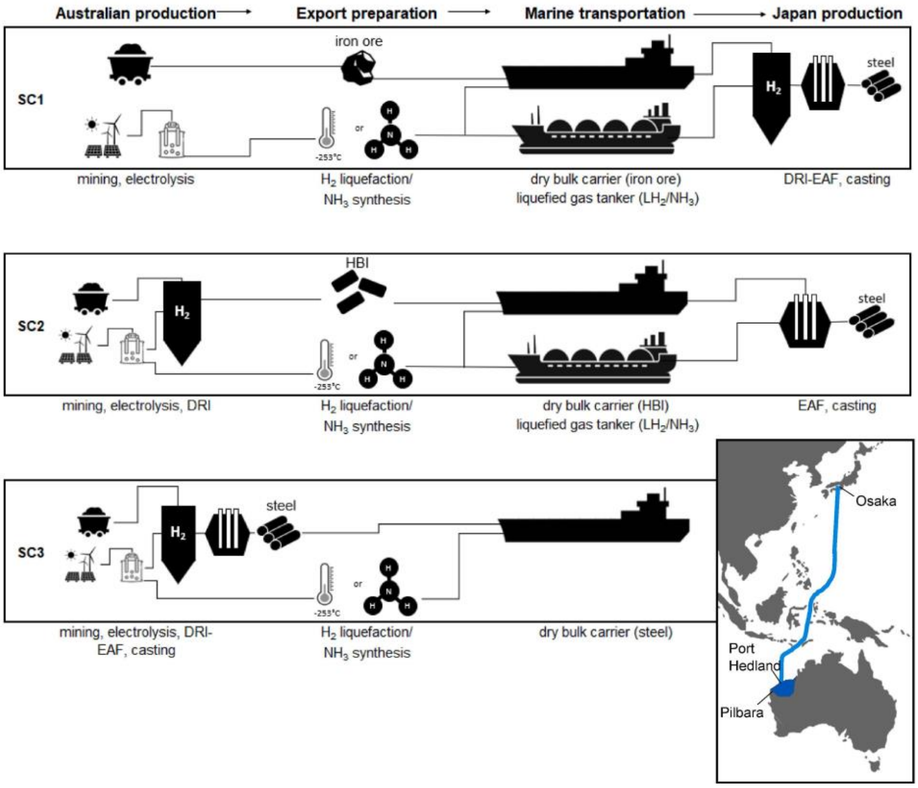
SC2) Iron is produced in Australia by direct reduction in a H_2-DRI plant and then imported to Japan in the form of hot briquetted iron (HBI), to be used to make steel in an EAF plant

SC3) Iron and steel are produced in Australia in H_2-DRI and EAF plants, after which the crude steel is imported to Japan

The results of the study show that regardless of whether liquid hydrogen or ammonia is used as fuel for marine transportation, in both 2030 and 2050, the first scenario (SC1) of importing hydrogen and iron ore and performing all the iron and steel production in Japan entails the highest energy consumption and cost. The second scenario (SC2) of importing iron (HBI) to Japan has lower energy consumption and cost than (SC1). And the third scenario (SC3), in which all the iron and steel production is done in Australia, has the lowest energy consumption and cost of all (Fig. 21).

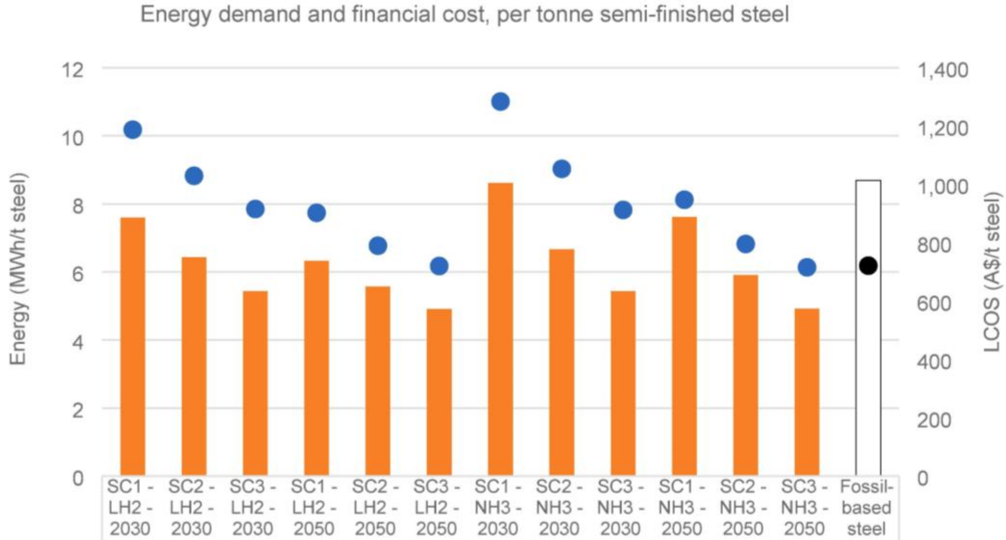
The results of this study suggest that the best approach is to produce crude steel in Australia. However, for reasons of industrial competitiveness and regional employment, it is important for Japan to maintain and revitalize the steelmaking industry in Japan, by manufacturing semi-finished steel products in EAF facilities using H_2-DRI as the iron raw material, and then, processing them into final steel products. This point will be revisited in Chapter 5, but importing H_2-DRI as a raw material is considered an appropriate approach to steelmaking for Japan in the decarbonization era.

Figure 20
Comparison of Energy and Costs of Iron and Steel Production in Australia and Japan



(Source) Devlin, et al., “Regional supply chains for decarbonising steel: Energy efficiency and green premium mitigation,” Energy Conversion and Management 254 (2022)

Figure 21
Energy Demand and Cost by Study Case (Per Tonne of Semmi-finished Steel)



	SC1 - LH2 - 2030	SC2 - LH2 - 2030	SC3 - LH2 - 2030	SC1 - LH2 - 2050	SC2 - LH2 - 2050	SC3 - LH2 - 2050	SC1 - NH3 - 2030	SC2 - NH3 - 2030	SC3 - NH3 - 2030	SC1 - NH3 - 2050	SC2 - NH3 - 2050	SC3 - NH3 - 2050	Fossil-based steel
Energy (MWh/t)	7.6	6.4	5.4	6.3	5.6	4.9	8.6	6.7	5.4	7.6	5.9	4.9	8.7
LCOS (A$/t)	1,188	1,030	916	903	790	720	1,284	1,054	913	948	796	716	722

(Source) Devlin, et al., "Regional supply chains for decarbonising steel: Energy efficiency and green premium mitigation," Energy Conversion and Management 254 (2022)

[Pillar 3] H_2-DRI by Domestically Produced Hydrogen in Optimal Domestic Locations

The third option for decarbonized steelmaking in Japan is to produce hydrogen at optimal domestic locations, rather than importing it, and using it for H2-DRImaking. Although the costs of renewable power generation and hydrogen production will go down in Japan, they are expected to remain relatively high by international standards, which means that the cost of H2-DRI making will be comparatively high too. However, by various means, the Japanese steel industry has always managed to produce internationally competitive products, even with the handicap of high energy costs and other adverse conditions. In view of this, even allowing that costs may be comparatively high, the deployment of H2-DRI plants that can take advantage of the various benefits of domestic production should be pursued as an option to help in the decarbonization of iron and steel production.

To constrain production costs despite unfavorable international conditions, it makes sense for Japan to concentrate its hydrogen production and H_2-DRI plants together in locations that are well suited to renewable power generation. Locating the sites where power is generated close to the sites where power is consumed (hydrogen production plants) reduces the cost of power transmission facilities. Hydrogen transportation is generally very expensive, even by methods other than vessels (as mentioned above), but if the location of consumption (steel plant) is close, the hydrogen can be transported cost-effectively by pipeline or truck.

Here is an estimate of the quantity of electricity required to produce H_2-DRI in a 2.5 million tonne-capacity plant.[68] At least 1.6 billion Nm^3 of hydrogen per year is required for iron reduction. The hydrogen electrolyzers to produce this much hydrogen would require 930 MW of power at full load, corresponding to more than 90 units of large 10 MW-class electrolyzers. If the power used by the electric furnace to produce steel from reduced iron is included, the total power requirement would be over 10 TWh.[69]

The electricity used to produce decarbonized steel must, of course, be decarbonized. There is a view that nuclear power can serve this purpose, but according to the estimates of the International Energy Agency and other organizations, nuclear power is expensive to generate, so it would drive up the price of hydrogen. On top of this, there is little real prospect that new nuclear reactors will be built in Japan. In any case, their construction would take a very long time. It is therefore difficult to see their use in steelmaking.

Consequently, H_2-DRI will need to rely on renewable energy sources. The most likely candidate is offshore wind power, which is well suited to supplying a large quantity of energy. 1 GW of offshore wind power capacity can generate around 3 TWh of energy per year (at a capacity factor of 35%). So, to supply the required 10 TWh of electricity, more than 3 GW of offshore wind power capacity is required. The ideal places for supplying such a large amount of decarbonized power are areas with high potential for offshore wind power. This is discussed further in the next chapter under Strategy 3.

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[68] Although small compared to recent blast furnace plants, which have capacities of more than 4 million tonnes, this is the largest DRI making plant in the world today.

[69] According to Chevrier et al., “MIDREX® Process: Bridge to Ultra-low CO2 Ironmaking” (KOBE STEEL ENGINEERING REPORTS/Vol.70 No.1) (July 2020), MIDREX’s H2-DRI making process requires 650 Nm^3 of hydrogen for reduction and 150 Nm^3 of hydrogen (or electricity) for heating per tonne of product. The conversion efficiency of the hydrogen electrolyzer is 5 kWh/Nm3. Calculations assume electricity is used as the energy source for heating.

Chapter 5: Transition Strategies for Decarbonizing Steelmaking in Japan

To leverage its strengths and develop a competitive steelmaking industry in the era of carbon neutrality, Japan needs to turn away from its current decarbonization strategy, which relies heavily on CCS. The following five transition strategies can help Japan to realize the three forms of decarbonized steelmaking presented in Chapter 4: (1) Maximum utilization of recycled iron making by electric furnace to meet the era of circular economy, (2) Utilization of hydrogen direct reduced iron (H2-DRI) imports, and (3) Introduction of hydrogen direct-reduced ironmaking utilizing domestic hydrogen at optimal locations in Japan.

Strategy 1	"Electric Arc Furnace Phase-in / Blast Furnace Phase-out Plan" to develop the local economy
Strategy 2	Lead the world in the international hydrogen direct reduced iron (H2-DRI) market and supply chain
Strategy 3	Selection of optimal sites for direct hydrogen reduction ironmaking in Japan in conjunction with offshore wind power development
Strategy 4	Promote reduction of domestic demand and maximum utilization of scrap iron by shifting to a circular economy
Strategy 5	Develop policies to expand demand for green steel

Strategy 1: "Electric Arc Furnace Phase-in / Blast Furnace Phase-out Plan" to develop the local economy

To decarbonize steelmaking, blast furnaces, which emit large quantities of CO_2 and are not amenable to effective emission reduction measures, will be phased out. However, Japanese technologies that have been cultivated through conventional steelmaking and steel manufacturing processes, as well as the local industries and work forces that have supported the industry, should be passed on and even developed in the decarbonization era, both for steelmaking and other new industries. One essential strategy for achieving this is an "electric arc furnace phase-in/blast furnace phase-out plan," to guide the adoption of electric furnaces to coincide with the closure of blast furnaces.

Large numbers of people are employed at integrated steel plants in regional Japan.[70] Steel mills with blast furnaces typically employ over 1,000 people, but their closure would impact not only employees, who could be reassigned to other jobs, but also various related businesses, including subcontractors and employee services, thereby disrupting the local economy. In the transition to decarbonization, the shutdown of a blast furnaces would put local employment and economic well-being at risk. For this reason, a strategy that aims at preserving local jobs and economic activity is needed. One example would be to try and shift seamlessly to electric furnaces for steelmaking in step with the phase-out of blast furnaces.

[70] For example, JFE Steel has decided to shut down the blast furnace in the Keihin Area of its East Japan Works by 2023. The company claims that approximately 1,200 employees will be affected by the shutdown of facilities related to integrated steelmaking, including basic oxygen furnaces, coke ovens, shaft furnaces, continuous casting machines, and electric furnaces. Some 2,000 employees of group companies and partner companies will also be affected. (It also stated that it would secure employment for the 1,200 employees through job reassignments and other measures and address the needs of group companies and subcontractors in good faith. The Kure Area of Nippon Steel's Setouchi Works shut down its blast furnace in 2021, affecting 1,500 workers (500 employees and 1,000 subcontractors). The entire area will close in 2023, with a total loss of 3,000 jobs. The economic impact on subcontractors and affiliated companies will also be significant.

Moves to phase in electric furnaces at the same time as phasing out blast furnaces has already begun in the Japanese steel industry. On September 1, 2022, JFE Steel announced plans to convert a blast furnace at its West Japan Works in Okayama Prefecture to a large electric furnace by 2027.[71]

Preserving steelmaking and product manufacturing processes in Japan, using electric furnaces, makes it possible to utilize established human resources and existing facilities, as well as processing technologies of excellence that offer significant technological and cost benefits. Since the advanced technologies of the Japanese steel industry have been honed through collaborative relationships with supply chains and customers, it is important to maintain production sites that can take advantage of these relationships. For example, the use of high-tensile steels in automobiles and their increasing sophistication over the years are seen as the fruit of the long collaboration between Japanese automakers and steelmakers. This collaboration has focused not only on improving steel performance, but also on material structure and design optimization, and joining technology to ensure that the requirements for energy efficiency and crash safety are both met.[72] To fully utilize recycled iron and H_2-DRI for decarbonization, it is vital that steelmakers, as well as the various manufacturers that use steel products, work together on product development.

To ensure a smooth transition to the era of decarbonization, a phase-out plan for all blast furnaces should be formulated as soon as possible, for example to guide the shift to electric furnaces. The plan should be jointly promoted by national and local governments and a dialogue with local stakeholders should be opened. It is important to establish a common understanding that a transition plan, focused on shifting from blast furnaces to electric furnaces, is a positive plan that helps to ensure a sustainable local economy and environment for the future. If Japan continues to rely on blast furnaces without any transition policy, it will end up losing the international decarbonization race, and the local economy will eventually die out, along with the blast furnaces. It is therefore essential to create a system in which the national and local governments play leading role.

Strategy 2: Lead the world in the international hydrogen direct reduced iron (H2-DRI) market and supply chain

There is currently a growing movement in Japan to build supply chains for international trade in hydrogen, but whereas in Europe imports are transported by pipelines, Japan must rely on shipping by sea. Furthermore, to use hydrogen for direct-reduction ironmakingH_2-DRI, Japan needs to either import hydrogen in the form of liquefied H_2 or as ammonia (or other carriers) that can be transported less expensively. On top of this, it is necessary to reconvert the ammonia back to hydrogen in Japan. In either case, the cost is very high.

Consequently, rather than importing hydrogen for steel production, a more rational approach for Japan would be to produce H_2-DRI in areas outside the country that are optimally suited to hydrogen production, with access to abundant renewable energy, and then import the green iron to Japan.

[71]JFE Steel, Carbon Neutral Strategy Briefing Material (September 1, 2022)

[72] Manabu Takahashi, “Sheet Steel Technology for the Last 100 Years: Progress in Sheet Steels in Hand with the Automotive Industry” (2014)

This kind of international trading of H_2-DRI is expected to play a big role as a decarbonization solution, both in Japan and many other countries around the world that lack the conditions or technology to develop their own H_2-DRI plants. It is important for Japan to lead the world in establishing an international market for H_2-DRI—an “international green DRI market”—and to build a framework for collaboration that supports the construction of H_2-DRI plants and contributes to local economies and societies at an early stage, with the aim of accelerating global decarbonization.

If the cost of hydrogen production in Australia, South Africa, and other regions blessed with the potential to produce green hydrogen thanks to abundant renewable electricity and iron ore resources, can be sufficiently lowered, the export of DRI iron could end up replacing the export of iron ore. This could lead to a global-scale shift in ironmaking to the H_2-DRI process in the regions of the world with the most favorable conditions.[73] Imports of H_2-DRI could also enable a shift from blast furnaces to electric furnaces in many parts of the world. It is likely that all regions except those with optimal conditions for hydrogen production would sooner or later become incorporated into the global “green DRI” market.

If Japan were to accept the clear disadvantages it faces in securing hydrogen supplies, such as the fact that hydrogen would need to be imported by vessels, it could quickly decide to work on building new supply chains, based on the premise that H_2-DRI will become a highly traded international commodity. It is essential to quickly establish a forward-looking collaborative framework with the regions (and companies) best suited to producing H_2-DRI.

In a move that leads to this kind of international trading in DRI, Nippon Steel has already concluded a memorandum regarding “the utilization of raw materials that contribute to carbon-neutral ironmaking processes” with Vale S.A., a Brazilian mineral resources company. The memorandum includes engagement of joint research on the utilization of raw materials which contribute to carbon neutral steelmaking processes.[74] By cooperating to create zero-emission processes with comprehensive consideration to sustainability, from iron ore extraction to DRI iron production, the two companies are expected to make significant progress toward the establishment of an international supply chain for H_2-DRI in the future.

Strategy 3: Selection of optimal sites for direct hydrogen reduction ironmaking in Japan in conjunction with offshore wind power development

To implement H_2-DRImaking in Japan, it is necessary to examine optimal locations from a cost perspective. As explained, hydrogen costs in Japan are projected to be relatively high by international standards. To make H_2-DRI production competitive under such disadvantageous conditions, it is desirable to locate hydrogen production plants and H_2-DRI plants close to areas where there is a high potential for renewable electricity development. This would reduce the costs for power infrastructure including power grids, as well as infrastructure needed for hydrogen transportation.

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73 Australia: Gielen et al., “Renewables-based decarbonization and relocation of iron and steel making” (2020); South Africa: Trollip et al., “How green primary iron production in South Africa could help global decarbonization” (January 2022)

74 Nippon Steel, “Nippon Steel Corporation and Vale Sign Memorandum regarding Decarbonization Solutions” (April 2022)

The most favorable locations for H_2-DRI production plants are in areas with high potential for offshore wind power generator farms capable of delivering the massive quantities of renewable electrical power and energy needed for this process. So far (as of May 2022), a total of 80 environmental assessments of offshore wind power generation development projects have been conducted in 32 coastal regions of Japan. These projects are most concentrated in Hokkaido and Tohoku, but some are located on the Pacific coast near Tokyo and in Kyushu. There are also other areas known to have excellent wind conditions, despite not being assessed yet. These are being studied for potential future developments. The government is aiming to have 45 GW of offshore wind power generation capacity in place by 2040, so projects are likely to emerge in many parts of Japan eventually.

In some cases, areas where offshore wind power projects are currently planned coincide with areas with operating blast furnace ironmaking facilities. And other such cases may emerge in the coming years. With the goal of establishing H_2-DRI making in Japan, the government needs to select the most suitable candidate sites for these facilities with reference to the locations of the latest plans for offshore wind development projects.

A look at the leading companies in Europe reveals that some steelmakers are trying to set up hydrogen production plants on their own, or else in partnership with others. In Japan as well, it is necessary to devise ways of collaborating that enable hydrogen production facilities to be established in step with H_2-DRI making. At the same time, it is also necessary to locate such plants close to locations with access to renewable electric power projects capable of supplying the large quantities of necessary green energy at low cost. Another essential requirement is to make strategic efforts to form collaborations between the three parties handling renewable energy development, domestic hydrogen production, and H_2-DRI making.

Strategy 4: Promote reduction of domestic demand and maximum utilization of scrap iron by shifting to a circular economy

The shift to a circular economy must not be forgotten, because it is fundamental and important perspective on the decarbonization of steelmaking. Even scenario studies for the decarbonization of the whole world assume a significant evolution of the circular economy, accompanied by increasing efficiency of resource utilization and a scaling back of demand itself.

As Fig. 3 shows, there is a gradual and long-term decline in domestic steel demand in Japan. Given the country's irreversibly diminishing population, it is necessary to consider a decarbonization strategy for the steel industry based on a clear recognition that domestic demand, at least, will inevitably shrink. It is also vital to consider GHG emissions and resource balance and recycling from a life cycle perspective, and to strive to increase usable product life and reduce the weight of products (to reduce the quantity of steel per product).

The sharing economy will also gradually change the ways that people use things, live, and work. The patterns and cycles of demand of Japan's cars and buildings will also have to change from the current norm, which is characterized by private car ownership, frequent car replacement, and construction of new buildings. As a result of these shifts, the demand for steel will decline.

In terms of policy, the best way to start is by reconsidering the design of products and buildings, to make them as durable and long-lasting as possible. In the face of shrinking demand, it is important for the steel industry to pursue ways to add value to its products, and to collaborate with communities in the transition to a circular business model.

The shift to a circular economy is also important in terms of maximizing the use of recycled iron sources. As shown in the previous chapter, as steelmakers venture into the era of decarbonization, they will be using some amount of scrap iron in almost all their products. Japan's current iron recycling rate is reportedly high. Further measures and policies are needed, however, to ensure that this valuable recycled resource is utilized to its full potential without degrading its quality as much as possible.

Some important points to keep in mind for maximizing the use of scrap iron are as follows.

1) Incentives to Increase Demand for Scrap Use

Assuming that there will be policies to stimulate green steel demand, it is necessary to objectively assess the decarbonization of primary steelmaking and recycled steelmaking, and to explore incentives to promote the use of recycled steel, especially steel products made from obsolete scrap. Examples of measures that should be considered are incentives based on defining recycled steel as "green steel," preferential use of recycled steel in public procurement, and even quotas (to mandate minimum consumption) further in the future.

At the same time, it is important for companies on the demand side to actively cooperate with steelmakers on effective ways of promoting the use of recycled steel, even in products not previously made with any recycled materials. They need to elicit responses not only from steel producers, but also from the demand side in areas like product design. These kinds of incentives need to be implemented in line with policies to encourage such cooperation and collaboration between steel end-consumers and steel producers.

2) Ensure the Design Suitable for Recycling

In the design of products (and buildings), it is essential to carefully ensure that they can be disassembled or demolished to recover valuable resources as easily as possible, without impurities, in order to fully incorporate their life cycle emissions into consideration. To begin, design guidelines can be established, but at the same time studies should be conducted with a view to eventually setting standards and introducing regulations.

3) Formation of Closed Loop

Forming a closed loop from production to recovery by identifying automobiles, home appliances, and IT devices, and other products individually is an effective and indispensable means of promoting recycling. To complete the loop, producers, vendors, consumers, and intermediate processors all need to work together on introducing recycling and life cycle perspectives into product design, on ensuring that producers take responsibility for product recovery, and on establishing recovery mechanisms. Meanwhile, national and local government bodies need to take the lead in pushing this process forward by collaborating with industry and the various other stakeholders.

4) Support for Upgrading Intermediate Treatment

To promote greater recovery and reuse, both in terms of quality and quantity, it is necessary to implement re-sorting before disassembly and to improve disassembly and sorting/collection processes. It is also vital to invest sufficiently in facilities, equipment, and technological development for this purpose. A business model for intermediate processes is required, to establish a tangible service demand and set collection and recovery routes. This obviously requires government policies and support.

Strategy 5: Develop policies to expand demand for green steel

In Europe and the U.S.A., companies, NGOs, and other parties are already moving strongly to expand demand for green steel (such as “net-zero steel”). Uncertainty about future demand presents a risk, because green steel will initially have to be sold at a premium, i.e., at a higher price than conventional steel. For this reason, clearly showing that there is a demand in the future has the effect of spurring decisions to invest in green steel production. Any actions by companies or other initiatives that serve to increase demand and make it more evident, or that reduce investment risk and encourage others to make the leap to decarbonized steel production, will be effective.

Obviously, “pull” policies to stimulate demand are also important. At the least, Japan should adopt the following policies at the earliest opportunity.

1) Clarify the Definition of Green Steel

Clearly defining “green steel” is an important precondition for expanding demand for the product. Already the G7 worked out a process for reaching agreement on a definition of “near-zero emission steel” as proposed by the IEA. Japan should actively lead the discussion, addressing the issues with this definition. It should also work to achieve a common understanding of a desirable definition, in way that incorporates promotion of recycled steel production. Then, based on the clear definition, targets should be set and policies to expand demand expansion should be formulated. It is also necessary to rank and standardize low-emission steels that are next grade to near-zero emission steels, and to develop policies for guidance to raise grades.

2) Action Initiatives from the Private Sector

As noted in Chapter 2, the automotive industry holds the key to generating the initial demand for green steel, and some players in the European auto industry have already signed agreements to purchase green steel in the future, invested in green steel-related projects, or taken other pioneering initiatives. It is now up to Japan’s auto industry to take similar positive action.

Some companies seem to have started acting on an individual basis, by taking part in Science Based Targets (SBT) or similar programs and reaching out to their supply chains. The important thing, however, is to send out demand signals in a way that is recognized by stakeholders across the world. It would be good to see companies signing off-take agreements to purchase green steel directly and actively participating in initiatives like "SteelZero." In Japan, it is especially important that the auto industry and other demand-side companies make a commitment to using recycled steel, including technological development. Technology development partnerships are also indispensable because they are an essential factor in determining the success of auto industry decarbonization.

It is significant that the move to establish the First Movers Coalition (FMC) was led by the U.S. government with business leaders Japan's national and local governments too need to communicate the importance of this kind of action far and wide, to the auto industry, consumer electronics makers, the construction industry, and other private-sector stakeholders. At the same time, they need to develop and promote mechanisms and initiatives, rather than leaving this task to private-sector interests.

3) Promotion of Public Procurement

In the field of construction and civil engineering, there is a huge demand for public works projects. So, using green steel to meet some of this demand can help to establish stable and steady growth in green steel demand. In September 2022, the U.S.A. announced the Buy Clean Initiative, a federal public procurement policy that will divert $650 billion of federal government spending—the most massive purchasing power in the world—to the purchase of U.S.-made low-carbon construction materials, including steel. The policy has been well received. California had previously established its own Buy Clean California Act (BCCA) in January 2022, setting a cap on embodied carbon emissions for four kinds of materials used in public works projects: (1) structural steel, (2) steel for reinforced concrete, (3) sheet glass, and (4) rock wool insulation. The index used to rate the materials is global warming potential (GWP, over 100 years). Like this, policies to mobilize public purchasing power to help form a green steel market are already in place.

[BOX 3] U.S. Federal Buy Clean Initiative

In September 2022, the U.S. Secretary of Transportation, Senior Procurement Executive and others visited the direct-reduction plant of steelmaker Cleveland-Cliffs (Ohio), to announce the Buy Clean Initiative, a federal government public procurement policy. In accordance with President Biden's 2021 Executive Order and the Federal Sustainability Plan, the U.S. government channeled over $650 billion of federal procurement funds (the largest single purchasing power in the world) to the purchase of American-made, low-carbon construction materials. Priority will be given to acquiring domestically produced construction materials and products that boast low embodied GHG emissions over their life cycle, for use in infrastructure construction by various agencies. This is reportedly the first policy of its kind by the U.S. federal government.

Already, a budget allocation of $4.5 billion has been decided, and the Departments of Transportation, State, and Energy have set up task forces, published road maps, and launched their commitments.

Aim: To generate employment and increase competitiveness of domestic manufacturing industry and promote sales of low-carbon products, while substantially cutting GHG emissions

Target procurement items: Steel, concrete, asphalt, and flat glass. More items and specifications are planned to be covered

Certification of products: Type III Environmental Product Declaration (EPD)[75] for each product, based on best practices

In Japan, there are mechanisms that promote environmental consideration in public works and public procurement including the "Green Procurement Act" and the "Green Contract Act". However, to promote public procurement of green steel, it is necessary to revise these and put in place other mechanisms.

For items purchased directly by the government such as automobiles and ships, it is institutionally feasible to set minimum standards based on life cycle criteria. In the case of automobiles, for example, there is currently an issue that is under investigation relating to the emissions of batteries from a life cycle assessment (LCA) perspective. It should similarly be possible to adopt an LCA-based assessment system for steel and other materials. It is necessary to promptly undertake studies to establish performance assessment methods and LCA criteria for all kinds of products. However, to establish such criteria (recommendation criteria, "Criterion 1," or minimum criteria, "Criterion 2," under the "Green Procurement Act"), the products must be readily and commercially procurable. For this reason, this provision is not applicable to products in the early stages of distribution, such as green steel. In light of this, it is necessary to consider revising the existing system or else establishing a separate system. In the case of recycled steel, some criteria have already been adopted, but they need to be expanded and enhanced.

[75] Type III environmental labels: Labels that indicate the life-cycle environmental impact of a product in a quantitative matter, requiring internal or external independent verification. Type I labels, expressed by a symbol mark, are certified by a third-party organization based on their criteria, while Type II labels show self-declarations.

For construction work, on the other hand, environmentally friendly contracts can be used. Currently, the proposal method is applied to make new zero-energy buildings (ZEBs), so it should be possible to use the same approach to adopt LCA standards. Another possibility is to specify the use of important building materials such as green steel in contract documents, by prescribing minimum standards of "environmental conservation performance requirements." However, it is still necessary to create standards from scratch. And the issue of steel materials and products in the early stages of adoption remain.

In any case, facilitating the purchase of green steel in public projects needs to be examined as soon as possible, along with the introduction of LCA standards. Until national systems are reformed, local governments will need to take the initiative in forming policies.

4) Emission Reduction from LCA Perspective - Creating a Mechanism for Embodied Carbon[76] Reduction

A challenge that needs to be tackled urgently is the labeling of embodied carbon in buildings and products, along with efforts to reduce such emissions, as a mechanism for supporting the growth of green steel demand. In the building sector, particularly, energy consumption during operation or service and associated GHG emissions have been more significant than other LCA-based emissions until recently, which is why saving building energy for operation have been the focus of emission reduction measures. Consequently, although ways to address measures at the time of operation have been progressed, not much progress has been made in addressing the embodied carbon emissions from the use of steel products, cement, and other building materials. There is therefore a glaring need to address this issue.

In France[77] and other countries in Europe, regulations on life cycle emissions, including embodied carbon, have been introduced for new buildings. The proposed revisions of the EU's Energy Performance of Buildings Directive (EPBD) in 2021 call for mandatory calculation and labeling of life cycle emissions from 2030 (from 2027 for large-scale buildings). Japan should promptly move to mandate the calculation and labeling of LCA-based embodied carbon emissions too, starting with new construction but eventually moving to examine policies to require emission reductions. To further this goal, Japan should move swiftly to promote EPDs for building materials and other construction products, create publicly accessible reference databases of LCA information on building materials, and establish suitable calculation methods.

For other products such as automobiles, in addition to the construction sector, it is also vital to require the calculation and labeling of emissions for the whole product life cycle and to establish standards. Examination should be started to build such systems.

[76] The embodied carbon of a building is the total quantity of CO_2 emissions from all processes including raw material procurement, processing, transportation, construction, improvement, and disposal, calculated using manufacturing data on the materials used in the construction based on LCA (Life Cycle Assessment), which assesses the environmental impact throughout the life cycle of the material, as accumulated and contained in the building.

[77] RE2020 Law: Requires a 15% reduction in LCA emissions per m^2 by 2024 and 25% reduction by 2027

Reviewing the entire decarbonization strategy to achieve carbon neutrality in 2050

These are the five strategies needed for decarbonizing Japan's steel industry. The current strategy, which is heavily dependent on the use of CCS, needs to be fundamentally revised. At the same time, all strategies related to electric power and energy, and hydrogen need to be reviewed with a view to achieving carbon neutrality by 2050.

In the electric power sector, even if steel production in 2050 is reviewed on the assumption of a shift to a circular economy, and it is assumed that there will be recycled steelmaking and imports of H_2-DRI, the total amount of renewable electric power required for decarbonized steel production in 2050 is estimated to be more than 30 TWh. Therefore, to achieve carbon neutrality, it will be essential to promote the electrification of entire industrial sectors including steelmaking, and to supply them with electricity generated from renewable sources. Electrification will be promoted in the transportation sector too, using electric vehicles and other technologies.

Under current government plans, Japan is aiming to supply only 36–38% of its electrical energy requirements from renewables by 2030. This target will only rise to 50 to 60% by 2050. Given that it has become the norm for many countries around the world to strive for 90% of electricity from renewables by 2050, the Japanese government plan seems inadequate. It is also unclear how much the demand for electricity is likely to increase, especially by 2050, due to the electrification of more and more industrial sectors.

To ensure the progressive decarbonization of the steel industry, Japan needs to aim at deploying more renewable electricity than the government has so far planned for. Considering the momentum with which international competitors are pushing to realize carbon-free steelmaking, Japan clearly needs to accelerate the pace of deployment and reduce prices further.

As for hydrogen strategy, if the current government policy of treating gray and blue hydrogen with high CO_2 emissions the same as green hydrogen is not changed, even if H_2-DRI steelmaking is implemented, steel Japan manages to produce will not be accepted as "green steel."

Carbon pricing is another essential policy tool for steel industry decarbonization, although no carbon pricing has yet been adopted in Japan, unfortunately. Under the EU Emissions Trading System (EU ETS) that was introduced in Europe in 2005, the free ETS allowances granted to the steel industry will be phased out from 2026. The early adoption and progressive strengthening of this carbon pricing schemed has boosted the process of decarbonizing the European steel industry. Japan's current policy of starting with voluntary credit trading under the GX League, a "green transformation" framework, before introducing an effective level of carbon tax and mandatory emissions trading at a later stage is too little, too late.

It is therefore necessary to create a new roadmap to decarbonization that is more specific and allows numerous stakeholders to work together. This would allow more stakeholders to get involved in the process of redesigning not only the overall plans and goals for Japan, but also the plans and goals of individual regions, industries, and companies, including the formulation of new strategies.

Reference: Near Zero Emission Steel Definition

Formulating a definition of steel suitable for the decarbonization era, using it develop detailed standards and criteria, and getting international agreement on the definition and standards is a vital and important step for the decarbonization of steelmaking, because it enables stakeholders to move forward with a common understanding. It serves as a basis for policies to drive demand and boost supply, and it facilitates international cooperation. A move is now underway to set definitions for "near-zero emission steel" (steel with almost no emissions) or the production of such products. So far, steel companies (e.g., ArcelorMittal), and other companies that participate in the steel supply chain (ResponsibleSteel[78]), as well as demand-side actors (First Movers Coalition) have proposed definitions and standards. The IEA is referring to these to propose a common definition for G7 countries.[79] The G7 Climate, Energy and Environment Ministers' Communiqué of May 2022 calls the IEA's proposed definition "a robust starting point for a common understanding of ambitious general definitions for near-zero- emission steel." The ministers also asserted that they "will work to align definitions in future projects for industry decarbonization."

Nevertheless, this definition is not without its issues. The threshold value for primary steelmaking using 100% iron ore raw material is 400 $kgCO_2$ of emissions per tonne of crude steel, and 50 $kgCO_2$ for recycled steel made in electric arc furnaces from 100% scrap iron. These are stringent criteria if compared to the current emissions of over 2 tonnes per tonne of crude steel for BF-BOF processes (not including emissions from raw material supply). Additionally the criterion for steel made in EAF process requires higher level compared with the current status. The standard is certainly ambitious, for both methods. However, these definitions do not cover the process of conversion from primary to secondary steelmaking, which already generates less than 400 kg of emissions. While scrap iron is currently available and used worldwide, these definitions may unfortunately end up discouraging effective measures that are already in place. In addition, rather than the scrap iron generated at ironworks and steelworks, it is the use of obsolete scrap recovered from the market after consumption that most needs to be encouraged (see Chapter 4).

For this reason, these criteria need to be modified too, but at least the threshold for primary steelmaking and the concept behind the boundary of analysis is worth referencing. These would be good starting points for an international definition and standard.

[78] ResponsibleSteel has launched a global standard and certification system with the participation of diverse stakeholders to promote the responsible sourcing, production, use, and recycling of steel. https://www.responsiblesteel.org/

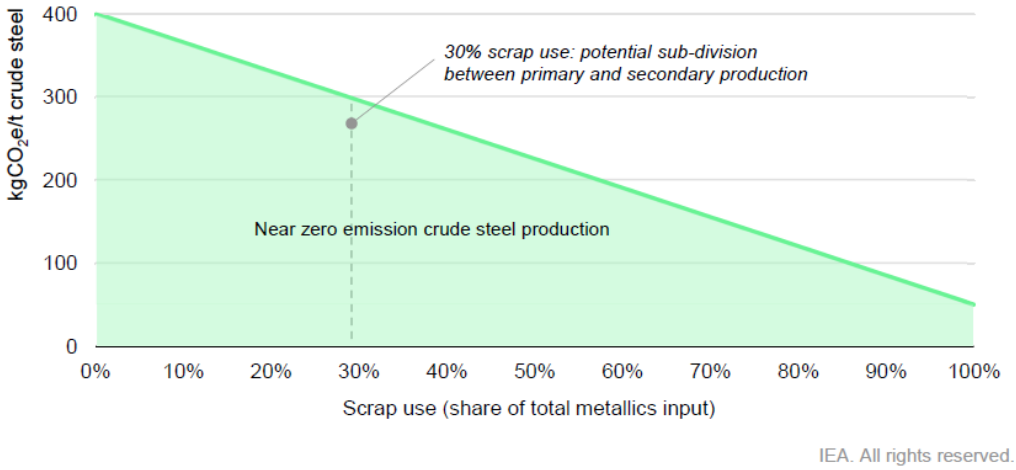
[79]IEA, "Achieving Net Zero Heavy Industry Sectors in G7 Members" (May 2022)

Definition of Near Zero Emission Steel in IEA's Report to the G7

[Definition]　　　　CO2 emissions per tonne of crude steel: 50 to 400 kgCO2e

- Near-zero emission steel (NZS)
  Steel produced with emissions 85% or more less than the emissions of steel produced in a conventional blast furnace (BF-BOF) process, i.e., with emissions below a threshold level of 400 $kgCO_2$ per tonne of crude steel
- Criterion when using scrap iron as raw material
  The threshold emissions value is 400 $kgCO_2e$ per tonne of crude steel when no scrap iron (0%) is used and 50 $kgCO_2e$ when 100% scrap is used. The threshold therefore varies on a sliding scale between these two values based on the scrap ratio (Fig. 22)

Figure 22
Near Zero Emission Crude Production Threshold as a Function of Scrap Use

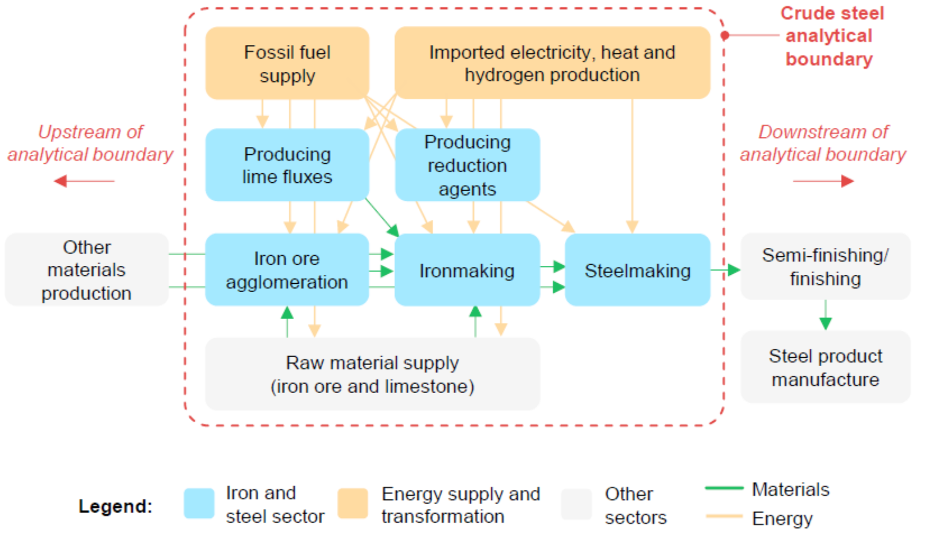


Notes: See the Technical Annex for the specific function used to formulate the series on the graph.
(Source) IEA, "Achieving Net Zero Heavy Industry Sectors in G7 Members" (May 2022)

[Scope of analysis for definition]

- Supply and processing of raw materials (mining, transportation, concentration, agglomeration, etc.) are included in the scope of analysis (for calculation of emissions). However, sorting and transportation of scrap iron are not included.
- Production of crude steel (including casting) used as a basis material for steel products (Fig. 23)

Figure 23 Analytical Boundary for Defining Near Zero Emission Steel Production



Notes: "Other materials production" refers to the production of material inputs to the iron and steel sector besides iron ore and limestone, including electrodes, alloying elements and refractory linings.

(Source) IEA, "Achieving Net Zero Heavy Industry Sectors in G7 Members" (May 2022)

Together with this initiative, the IEA proposes a way to encourage all steel production to approach near-zero emissions, by using the reduction level required to qualify as NZS as standard targets, and by ranking the emission level of all low-emission steel (produced with lower emissions than conventional steel) into standardized grades.

The FMC has already begun working to establish procurement standards along the lines of this definition. Meanwhile ResponsibleSteel has launched a certification program that makes use of similar criteria. More than 50 companies operating in steel supply chains are participating in the scheme and moving toward certification.

Steel companies are also using mass balance methods[80] to market line-ups of zero/near-zero emission steel products. Even Japanese companies have gotten into the act. After Kobe Steel announced the release of its "Kobenable Premier" zero-emission steel in May 2022, Nippon Steel and JFE Steel announced that they would begin producing and selling carbon-neutral steel in 2023.

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80 Low-emission steel products based on the mass balance method means that when emission reduction measures, such as scrap iron use or H_2-DRI result in emission reductions compared to conventional product manufacturing, the proportion of the emissions reduction can be transferred to the product, such that the same proportion of the production output can be considered a low/zero-emission product. For example, if a 10% emission reduction measure is achieved when 100 tonnes of product is manufactured, 10 tonnes of the product can be considered zero-emission steel.

This method has the advantage of allowing low-emission products to be marketed without the risky and massive investment involved in replacing an entire production process, thereby bringing low-emission products into the spotlight sooner and helping to build the market for green products. As an essential precondition for this approach, a certification system that accurately verifies emissions and their proper allocation is needed, and the system needs to have broad penetration. On the downside, such an approach can encourage companies to stick with transitional measures, so measures that encourage more radical change are also needed.

The Path to Green Steel

Pursuing Zero-Carbon Steelmaking in Japan

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