Evaluating the technology path of Japanese steelmakers in green steel competition

Nozomu Kawabata

nozomu.kawabata.b1@tohoku.ac.jp

Abstract: This study examines the technological pathway adopted by Japanese steelmakers competing for environmentally friendly or green steel production. The pathway is identified by analyzing documents from the International Energy Agency (IEA), the Japanese government, public institutes, business federations, and steelmakers. The findings suggest that Japanese integrated steelmakers using blast furnace and basic oxygen furnace (BF-BOF) technologies have lagged in technological development and capital investment for green steel. Motivated to maintain the value of fixed capital and reputation as high-grade steel producers, they have persistently adhered to high CO2-emitting BF-BOF technology. Consequently, these firms have slowly transitioned to the lower CO2-emitting electric arc furnace (EAF) method and have been sluggish in developing the direct hydrogen reduction process that promises zero-emission production. However, the Paris Agreement and the Japanese government’s carbon neutrality declaration have pressured these companies to reassess this stance. This case illustrates that theories on the political economy of the environment and the conservative approach of large corporations toward new technologies continue to hold relevance in the era of emerging green technologies.

Keywords: Political economy of the environment, Global warming, Steel industry, Carbon neutrality, Technology path

Subject classification codes: L52, L61, Q55, Q58
Introduction

Decarbonizing the steel industry’s production process is essential as the industry plays a crucial role in mitigating global warming. Assessing the current state of green steel development within the industry and forecasting its future holds significant societal value.¹ This study aims to evaluate the standing of Japanese steelmakers concerning innovations aimed at decarbonization. Given that the outcome of these innovations remains uncertain, the author conducts this assessment by exploring the technological paths pursued by Japanese steelmakers. The examination involves the following two critical research questions.

The first is the relationship between steelmakers’ pursuit of capital accumulation and environmental regulations to prevent global warming. Current international and national policies pressure steelmakers to adopt technologies that reduce CO₂ emissions. In reconciling this with their profit-making endeavors, questions arise: What technologies will Japanese steelmakers opt for, and why? Will these technologies address global warming concerns sufficiently?

The second examines whether substantial fixed capital investments and intangible assets tied to existing technology constrain the strategic behaviors of large Japanese steelmakers. Significant investments in the production facilities of integrated production systems and intangible assets, such as sustained customer satisfaction, may predispose these firms toward a conservative innovation strategy. Are signs of stagnation evident in Japanese manufacturers’ technological development and capital investment decisions aiming for green steel?

Given that the success or failure of green steel innovation remains uncertain, this assessment identifies the technological pathways adopted by these integrated companies.
The author’s understanding of the industry’s policies from the Kyoto Protocol era to the present is grounded in data from three primary sources. The first source comprises the documents of the International Energy Agency (IEA) on steel technologies. The IEA has developed a technology roadmap for the steel industry aiming for zero emissions (IEA 2020). Additionally, they have outlined scenarios for each technology’s adoption toward this goal (IEA 2022). This study uses these roadmaps to place various steel technologies on the technology pathway toward green steel.

The second source comprises the Keidanren (Japan Business Federation) and Japan Iron and Steel Federation (JISF) documents on action plans to prevent global warming. Keidanren orchestrated corporate action plans in response to the Japanese government’s climate change mitigation policies. Meanwhile, the JISF, as the association for the Japanese steel industry, has worked toward implementing government policies and Keidanren’s action plans. It has also compiled steel companies’ views on these policies. As integrated iron and steelmakers account for a significant share of Japan’s production, the JISF policies largely reflect their preferences.

The third source includes documents from the government, government-affiliated agencies, and companies involved in steel technology development projects. Considering that the development of next-generation technologies requires government support, these documents extensively chronicle the evolution of technological pathways.

The remainder of this paper proceeds as follows: Section “Literature review” reviews previous studies. Section “Current and next-generation technologies in the iron and steel industry” presents the nature of existing and next-generation technologies in the steel industry, specifically regarding technology pathways. Section “CO2 emission reduction policies of Japanese BF-BOF makers” identifies the progress made by the JISF, blast furnace and basic oxygen furnace (BF-BOF) makers in implementing global warming prevention policies.
Section “Discussion and conclusion” assesses the Japanese steel industry’s technological pathways and identifies remaining issues.

**Literature review**

_The political economy of the environment_

The behavior of steelmakers concerning CO$_2$ emissions should be understood within the context of a capitalist enterprise. Hikaru Shoji and Kenichi Miyamoto, pioneers in the environmental analysis of the Japanese political economy, witnessed pollution during Japan’s high-growth era owing to the prioritization of direct production processes in capital investments by capitalist firms while neglecting indirect processes, such as pollution control (Shoji and Miyamoto 1975, 13, 1977, 12–13). They observed that this tendency toward capital accumulation is also reflected in the technology of direct production process systems, where technology development prioritizes profit over safety and environmental considerations (Shoji and Miyamoto 1975, 13–14).

Shoji and Miyamoto (1975) identified two firm behavioral principles. First, pollution arises because companies focus on reducing environmental protection costs within a given production technology. Second, firms may employ more polluting technologies if they generate higher profits than cleaner alternatives. The selection of production technology itself is influenced by the tendency to avoid environmental protection costs. This study focuses on the second principle.

Today’s steel industry must decide between innovating production technology or modifying current technology to reduce CO$_2$ emissions. Given the strict global warming regulations in place, capitalist firms can no longer afford to ignore green steel technologies. If new, low-pollution technologies can generate higher profits than older ones, firms will be
incentivized to adopt them. Conversely, if profits decline, firms may resist adopting new technology and instead focus on improving their current methods. This study’s primary research question is set out in this way and taken from the perspective of the political economy of the environment.

**Large steelmakers and innovation**

It is well-documented in political economy that large firms, particularly those in monopolistic or oligopolistic positions, often demonstrate a more passive approach toward new technologies than latecomers and new entrants. There is a debate on whether this attitude is a characteristic of monopoly capitalism (Baran and Sweezy 1966, 97–111) or merely a temporary trait of post-war American monopolies (Brenner 2006, 32–37, 53–56). Nevertheless, these studies highlight the hesitance of well-established firms to invest in new technologies; the United States’ integrated iron and steelmakers from the 1950s–1970s serve as typical examples.

According to industrial organization theory and innovation management research, large United States steelmakers were reluctant to innovate, often relied on protectionist trade, and ultimately lost their international competitiveness (Adams and Dirlam 1966; Baldwin and Clark 1994; Dertouzos et al. 1989, 14–15, 278–287; Scheuerman 1986). Consequently, there was an increase in imports from Japan and Western Europe. Moreover, electric arc furnace (EAF) steelmakers (referred to as mini-mills in the United States) who were willing to invest in equipment expanded their market share (Adams 1995; Lester 1998, 85–107). While EAF steelmakers started to disrupt the industry in the low-end segment, integrated iron and steelmakers narrowed their focus to supplying high-end products to more profitable customers. However, this approach ultimately led to them losing their market share in most segments (Christensen 1997, 87–93). These studies primarily focus on large firms’ reluctance to adopt new technologies as a defense mechanism to preserve the value of two things: their substantial
fixed capital embodied in production equipment and the intangible assets accrued by developing products for their premium customers.

In the post-World War II era, the Japanese steel industry witnessed the aggressive adoption of new technology and significant capital investments in a competitive environment (Hasegawa 1996; Yonekura 1994; Baba and Takai 1997). Japanese steelmakers also reduced pollution by using thermal management and energy conservation technologies (Kobori 2017); however, adopting pollution control measures was not voluntary but in response to pressure from local governments and citizen movements (Kobori 2017; Uezono 1997).

Since the 1980s, the steel industry has experienced intense global competition from developing countries and restructuring in developed countries (D’Costa 1999; Sato 2016). Mini-mills gained predominance in the United States with the emergence of steelmakers from Asian countries, such as South Korea and China (Sato 2009). Japanese steelmakers shifted their focus toward manufacturing high-end steel products (Kawabata 2003, 2012). Moreover, with the advent of global warming, there has been a compelling shift in steel technology. It warrants examination of whether Japanese steelmakers can retain their innovative edge in the competition to produce green steel. The study’s second research question is derived in this way.

Current and next-generation technologies in the iron and steel industry

**BF-BOF, scrap-EAF, and direct reduction-EAF as current technologies**

The steel industry is the primary source of CO₂ emissions in heavy industries worldwide, accounting for 7% of global emissions derived from energy sources. In Japan, the steel industry was responsible for 14% of CO₂ emissions in FY 2019. According to the Intergovernmental Panel on Climate Change (IPCC), CO₂ emissions must be reduced by 99% by 2050 based on 2019 levels to achieve the Paris Agreement’s goal of limiting global average temperature
increase to within 1.5 °C above pre-industrial levels (IPCC 2023). Therefore, the steel industry must also achieve near-zero emissions by 2050.

The predominant existing technologies in steel production, listed according to their global production volume, are the BF-BOF, scrap-EAF, and direct reduction-electric arc furnace (DRI-EAF) methods. The blast furnace-electric arc furnace (BF-EAF) method is also used in China. BF-BOF and DRI-EAF are considered primary production methods, where iron ore serves as the primary material. Scrap-EAF is a secondary production method because its primary material is steel scrap.

The BF-BOF method accounted for 71.7% of global crude steel production in 2019 (World Steel Association [worldsteel] 2020). Contemporary integrated iron and steelmakers have adopted the BF-BOF method. In the BF-BOF process, pig iron is initially produced by reducing the iron ore with coke or coal, using the blast furnace as the primary equipment. Subsequently, during the steelmaking phase, a basic oxygen furnace is predominantly used to adjust the carbon content by injecting oxygen into the molten iron. This process also removes impurities, such as phosphorus, to control the composition. The emission intensity of CO₂ from the production process in the BF-BOF method is 2.95 t/t (IEA 2022, 109). The high-intensity rate is due to carbon consumption as a reducing agent and heat source.

In 2019, the EAF method accounted for 27.8% of global crude steel production. This process primarily uses scrap, directly reduced iron or pig iron. The precise proportion of these materials is unknown; however, given that the production of directly reduced iron is 8.7% of pig iron production (worldsteel 2020), it can be inferred that the DRI-EAF method contributes approximately 6% to worldwide crude steel production. No data is available to clarify the ratio between the use of BF-EAF and scrap-EAF methods in China; however, assuming that half of the EAF methods are BF-EAF in China, the global share of the BF-EAF method is
approximately 3%. Therefore, the scrap-EAF method is estimated to account for approximately 19% of global production.

In the scrap-EAF process, scrap is smelted using arc discharge heat. In this method, the reduction of iron ore is omitted, resulting in a minimal CO₂ emission intensity of 0.29 t/t (IEA 2022, 110). The largest share of these emissions comes from imported electricity, which accounts for 0.22 t/t of indirect emissions.

Similar to the BF-BOF method, the DRI-EAF process also reduces iron ore; however, it does so in a solid state at relatively low temperatures. Solid reduced iron contains impurities; therefore, it must be smelted in an EAF. When natural gas is used for reduction and as a heat source, the CO₂ emission intensity of the DRI-EAF method is 1.49 t/t, lower than that of the BF-BOF method (IEA, 2022, 109).

Determining the most advantageous production method can be complex as costs, excluding those associated with carbon pricing, depend on the price fluctuations in raw materials and energy. However, the BF-BOF method may lose its advantage as the regulation of CO₂ emissions becomes stringent because it is the most CO₂-intensive.

**Renovated blast furnace and hydrogen DRI methods as next-generation technologies**

The IEA has proposed four key technological groups for the decarbonization of steel production, including carbon capture, utilization, and storage (CCUS), hydrogen reduction, electrolysis of iron ore, and substitution of coke by biomass (IEA 2020, 90–92). The next-generation technologies nearing commercialization suitable for mass production and proving highly effective include the renovation of blast furnaces using hydrogen combined with CCUS and the direct reduction process with hydrogen (hydrogen DRI).

One technique for renovating blast furnaces involves replacing carbon reduction with hydrogen reduction. Although the hydrogen reduction does not emit CO₂, it can only be
partially applied to blast furnaces (IEA 2020, 87–88). Solid coke is indispensable for blast
furnaces, as it supports falling iron ores and provides a pathway for reducing gases.

Another method employs reforming CO₂ discharged from the blast furnace into
methane gas using hydrogen. This process does not eliminate CO₂ emissions. In any case,
renovation of the BF-BOF method cannot reach zero emissions within the scope of steel
technology. Therefore, hydrogen utilization in blast furnaces must be supplemented by CCUS,
which treats the emitted CO₂; however, the CO₂ emission reduction rate in CCUS is capped at
83% (Agora Industry, Wuppertal Institute and Lund University 2021, 11–12).

The other next-generation technology is hydrogen DRI. This method substitutes natural
gas for hydrogen during the direct reduction process. Unlike the blast furnace method, the
hydrogen DRI process utilizes 100% hydrogen as a reductant, eliminating direct CO₂ emissions.
If zero-emission electricity is used for hydrogen production and the operation of the DRI facility
and EAF, indirect emissions could also be reduced to zero (IEA 2020, 93–94). The current DRI-
EAF method, which uses natural gas, partially employs hydrogen reduction. Transitioning to
100% hydrogen reduction is feasible without drastically altering the design of the DRI facility
(Mimura 2023).

Technological pathway to near-zero emissions

Considering the characteristics of various steel technologies, this subsection explores the
technological pathways to achieve near-zero emissions by 2050. The term “near-zero emissions”
is preferred since, with our current technological understanding, it is predicted that the steel
industry’s emissions in 2050 will not be absolute zero. The thresholds for near-zero emissions
used by the IEA (2022) are 0.4 t/t for steel production from iron ore and 0.05 t/t for steel
production from steel scrap.
Among the existing technologies, the scrap-EAF method has the lowest emission intensity and is the only one that can reach zero emissions by 2050. Its predominant contributing factor is power generation decarbonization. Conversely, the emission intensities of the BF-BOF and DRI-EAF methods, given their current technological configurations and reduction agents, will not achieve near-zero emissions or even surpass the 2020 emission levels of the scrap-EAF method (IEA 2022, 114, 130).

While all next-generation technologies harbor the potential to reach near-zero emissions by 2050, their specific conditions and success levels differ. The BF-BOF method, for instance, does not achieve near-zero emissions with hydrogen reduction alone; adding CCUS becomes crucial. However, even in this optimal case, its emission intensity in 2050 will still exceed 0.3 t/t, necessitating larger offsets than other technologies. By contrast, the 100% hydrogen DRI-EAF method is projected to reach near-zero emissions by 2050 with emission intensities below 0.1 t/t, contingent upon power generation decarbonization (IEA 2022, 114).

The paths to near-zero emissions vary based on the starting technology. On the one hand, for the BF-BOF method, due to its high initial emission intensity, there is a need for significant reductions. Implementing partial hydrogen reduction and CCUS is pivotal, and considerable offsets will be necessary in 2050. On the other hand, the scrap-EAF method, with its comparatively lower starting intensity, does not necessitate major technological shifts in steelworks. Decarbonizing electricity is necessary. Meanwhile, the DRI-EAF method, which has an initial intensity positioned between the BF-BOF and scrap-EAF methods, can achieve near-zero emissions by transitioning from natural gas to hydrogen for reductants and focusing on electricity decarbonization.

Therefore, the choice of technological pathways by steelmakers is the focal point of the race toward green steel.
CO₂ emission reduction policies of Japanese BF-BOF makers

Overview of the Japanese steel industry

Figure 1 illustrates the supply-demand balance for steel in Japan. Japan’s apparent consumption of crude steel peaked in 1991 and declined slowly. Despite this, crude steel production continued to expand until 2007. The 2008 global financial crisis marked the onset of a downward trend in production. The divergence between consumption and production

Figure 1: Supply and demand of steel in Japan.

Note: Imports and exports are presented as crude steel equivalents. Apparent consumption = production + imports − exports.

trends can be attributed to increased exports, which continued until 2014. However, exports began to decrease during the latter half of the 2010s. Domestic consumption did not recover to pre-global financial crisis levels and further declined due to the COVID-19 pandemic.

Consequently, the Japanese steel industry faces a contracting domestic market and diminishing international competitiveness. Japan, the world’s top steel producer until 1995 and second only to China from 1996 to 2017, has been superseded by India since 2018, relegating it to the third-largest steel producer. The average crude steel output from 2017 to 2019, preceding the COVID-19 pandemic, was 102.75 million tons, constituting 5.6% of global production.

The primary steel production technology used in Japan is the BF-BOF method. In 1990, when the Kyoto Protocol established CO2 emission reduction benchmarks, BOF accounted for 68.6% of crude steel production, with EAF accounting for 31.4%. By 2017–2019, these proportions shifted to 75.4% for BOF and 24.6% for EAF, thereby extending the dominance of the BOF method. Interestingly, Japan’s 2017–2019 share exceeded the global BOF share of 70.0% (worldsteel 2019, 2020).

In the 1990s, Japan had six integrated BF-BOF steelmakers. After several consolidations, Nippon Steel, JFE Steel, and Kobe Steel remained. Of the approximately 40 EAF makers, roughly 30 produce ordinary steel, and approximately 10 produce specialty steel products. In 2019, the industry had 4015 establishments employing 223,524 people (METI 2020).

Japanese BF-BOF steelmakers have predominantly focused on high-grade steel products, maintaining long-term trading, and jointly developing products; key customers include automobile manufacturers (Baba and Takai 1997; Kawabata 2003, 2012; Kipping 1998). In FY 2019, the construction sector accounted for 26% of Japan’s steel demand, mainly for
medium- and low-grade products, while the automotive sector, which largely requires high-grade products, contributed to 30% of the demand.\textsuperscript{8} Although not strictly comparable, global steel consumption in 2008 was 55% for construction and 10% for automobiles, while in China in 2018, these figures stood at 57% and 8%, respectively.\textsuperscript{9} These figures suggest a propensity for high-end products in the Japanese market, aligning with Japanese steelmakers’ focus on manufacturing high-grade steel products.

The CO\textsubscript{2} emission reduction policy in the steel industry can be categorized into three periods, aligning with Keidanren’s response to the global warming prevention framework in international politics. The three periods include the “Voluntary Action Plan on the Environment” (FY 1997–2012) implemented during the Kyoto Protocol, the “Commitment to a Low Carbon Society” (FY 2013–2020) launched in the absence of a post-Kyoto framework, and the “Carbon Neutrality Action Plan” (FY 2021 onward) targeting the implementation of the Paris Agreement. The subsequent sections provide a period-wise analysis of those policies.

\textit{Kyoto protocol and the “Voluntary Action Plan on the Environment:” intensity reduction and sectoral approach}

In December 1997, Japan hosted the Third Conference of the Parties to the United Nations Framework Convention on Climate Change (COP3), establishing the Kyoto Protocol. Under this agreement, Japan committed to reducing its greenhouse gas (GHG) emissions by 6% between 2008 and 2012 based on the 1990 level. Anticipating this, Keidanren announced the “Voluntary Action Plan on the Environment” in June 1997.\textsuperscript{10} The JISF, which represents the steel industry under this plan, aimed for a 10% reduction in energy consumption for 2008–2012 relative to 1990 levels. The energy-saving target was equivalent to a 9% reduction in CO\textsubscript{2} emissions.
This initiative led to a 10.7% reduction in energy consumption and a 10.5% decrease in CO₂ emissions, meeting the target. Although the period witnessed a 3.8% decrease in production activity (crude steel production) relative to the base year, a more significant reduction in emission intensity was achieved (Figure 2). The steel industry has managed to lower CO₂ emissions by enhancing waste heat recovery and facility efficiency, establishing

![Figure 2: CO₂ emissions, emission intensity, and production activity index of the Japanese steel industry during the Voluntary Action Plan period.](image)

clean coal utilization technologies, improving energy efficiency by recovering and utilizing by-product gases and waste energy from plants, and recycling waste plastics, tires, and other resources. Importantly, these accomplishments did not rely on the Kyoto Mechanism credits.

However, the JISF expressed dissatisfaction with the Kyoto Protocol’s approach. They contended that the Japanese steel industry, already making significant strides in energy conservation, was unfairly obligated to reduce emissions while competing countries such as China, India, Korea, and the United States were not subject to such constraints. The JISF advocated a sectoral approach, focusing on industry-level targets rather than overall country emissions.

The Asia-Pacific Partnership on Clean Development and Climate (APP) adopted the sectoral approach in 2005 and sought to promote energy conservation and GHG emission reduction through the industrial sector’s international transfer of Best Available Technologies (BATs). Based on research by the IEA and the Research Institute of Innovative Technology for the Earth in Japan (RITE), the JISF asserted that Japanese steelmakers are leading in global energy efficiency. They suggested that transferring Japanese BATs would be an effective strategy as CO₂ emission reduction potential in other countries surpasses Japan’s.

However, it is worth noting that the IEA and RITE evaluations of CO₂ emission reduction potential and energy efficiency were country-by-country comparisons for the same technologies. These findings only revealed the reduction potential for the same technology (within BF-BOF and EAF methods). Despite the apparent efficiency of Japanese steelmakers in the BF-BOF method, there was potential to transition from the BF-BOF to the EAF method. However, the JISF did not consider this possibility.
Technology development aimed at blast furnace process renovation: COURSE 50 and ferro-coke

In 2008, the JISF embarked on the “Development of Environmentally Harmonious Ironmaking Process Technology” initiative, supported by the New Energy and Industrial Technology Development Organization (NEDO). This project’s pivotal technology was COURSE 50, incorporating two significant technologies. The first involves reforming coke oven gas to produce hydrogen for partial reduction in the blast furnace. The second method involves CO2 capture and storage (CCS) from blast furnace gas. The aim is to reduce CO2 emissions by 10% using the former technology and by 20% using the latter. Commercialization is anticipated by 2030.

Concurrently, the development of a material known as ferro-coke began in 2008. Ferro-coke is a composite substance produced by grinding, blending, and shaping coal and iron ore, followed by heating. It is expected to improve the efficiency of the iron ore reduction reaction occurring in the blast furnace. The application of ferro-coke was targeted to reduce energy consumption in the ironmaking process by 10%. Commercialization is planned for 2030, similar to COURSE 50.

Both COURSE 50 and ferro-coke are technologies centered on the BF-BOF method. Through these developments, the Japanese steel industry aimed to renovate the BF-BOF method as a next-generation technology while preserving existing integrated iron and steel mills.

Post-Kyoto period ambiguity and the “Commitment to a Low Carbon Society:” the rejection of total emission control

In the early 2010s, the international framework to replace the Kyoto Protocol remained uncertain, resulting in ambiguous GHG emission reduction targets for Japan. During this period, Keidanren established the “Commitment to a Low Carbon Society” in January 2013, set to
continue through 2020. This plan allowed each industry to set its emission reduction targets voluntarily.\(^1\)

In the absence of a post-Kyoto framework, the steel industry rejected total CO\(\text{2}\) emission targets, opting instead for targets relative to a business-as-usual (BAU) scenario. Specifically, the JISF anticipated varying levels of crude steel production for FY 2020, setting CO\(\text{2}\) emissions estimates for each predicted production volume as BAU. The goal was to reduce emissions by 3 million tons from the BAU level by 2020 through energy saving. However, even if the reductions relative to the BAU were achieved, increasing crude steel production would not ensure a decrease in total CO\(\text{2}\) emissions.

Using the BAU scenario meant that the JISF set an easy target to achieve while maintaining or increasing the volume of crude steel production. The JISF also asserted that globally, disseminating the Japanese steel industry’s advanced energy-saving technologies would contribute more to CO\(\text{2}\) emission reductions overseas than in Japan. This strategy did not anticipate technological transitions from BF-BOF to EAF within Japan.

By 2020, the unintended consequences of this approach became evident. During the COVID-19 pandemic, the rational calculation of BAU production became impossible owing to discontinuous operations, including temporary blast furnace closures. Nevertheless, total CO\(\text{2}\) emissions, which were not part of the target, fell (Figure 3). The contraction in domestic demand and the subsequent decline in exports owing to competition from emerging economies after 2014 resulted in reduced production volumes despite the absence of explicit restrictions. Moreover, emission intensity has hardly improved since FY 2013. Emission reductions during this period were solely because of lower production.
Figure 3: CO₂ emissions index, emission intensity, and production activity index of the Japanese steel industry during the Commitment to a Low Carbon Society period.

Source: See Figure 2.

*The Paris Agreement and the “Carbon Neutral Action Plan:” acceptance of total emission reductions and technology shift*

In December 2015, COP21 concluded the Paris Agreement, which came into effect in 2016. This agreement established a global goal to maintain the rise in global average temperature well below 2 °C above pre-industrial levels and to strive to limit the increase to 1.5 °C. Initially, Japan aimed to reduce GHG emissions by 26% in FY 2030 compared with FY 2013. However, this target was revised upwards during 2020–2021. First, Prime Minister Yoshihide Suga declared Japan’s intention to achieve carbon neutrality by 2050. Subsequently, the GHG emission reduction target for FY 2030 was revised to a 46% reduction from FY 2013 levels, with a further effort to achieve a 50% reduction.

In response to the Paris Agreement, the JISF announced its long-term vision for climate change mitigation, “A Challenge towards Zero-Carbon Steel,” in November 2018 (JISF 2018). This vision made it clear that COURSE 50 alone would not be sufficient to meet the Paris Agreement requirements. Hence, the necessity of Super COURSE 50 which requires external
hydrogen supplies as a reducing agent, hydrogen DRI technology, and CCUS were emphasized. For the first time, the JISF predicted a global decline in the proportional use of the BF-BOF method. However, the need for Japan to transition to the EAF method was not addressed.

The government’s declaration of carbon neutrality, which pressed for a reduction in total GHG emissions in Japan, made a policy change inevitable for Keidanren and JISF. Accordingly, the JISF announced its basic policy toward carbon neutrality in February 2021. The target for FY 2030 was incorporated into Keidanren’s “Carbon Neutral Action Plan” in March 2022. All three BF-BOF steelmakers also committed to achieving carbon neutrality by 2050.

Figure 4: CO₂ emissions of companies participating in the JISF action plan

Note: Target values are set for the fiscal year 2030.

Source: See Figure 2.
The new goal is to reduce energy-derived CO\textsubscript{2} emissions by 30% from the FY 2013 level by FY 2030, expressed in physical terms as a 57.9 million ton reduction. Figure 4 illustrates the CO\textsubscript{2} emission performance from 1990 to 2020 and the target for 2030. The expected reduction in crude steel production by FY 2030 will contribute most to achieving this goal; this alone was estimated to contribute to a 34 million ton reduction in emissions. Additionally, for the first time, a policy was specified to expand the use of cold iron sources (scrap and DRI) in raw materials, which is assumed to contribute to an 8.5 million ton reduction. The commercialization of COURSE 50 and ferro-coke is expected to contribute to the reduction, but its contribution is assumed to be closer to 2.6 million tons, which is lower than the aforementioned contributions.

*Initiating hydrogen DRI technology development and high-grade steel production using EAF*

The Paris Agreement and the carbon neutrality goal have also catalyzed a policy shift in developing next-generation technologies. In addition to renovating the BF-BOF method, the hydrogen DRI and EAF methods were nominated for development.

In December 2021, the Ministry of Economy, Trade, and Industry (METI) established a 2 trillion yen fund through NEDO’s Green Innovation Fund Project to support initiatives contributing to a green growth strategy to achieve carbon neutrality.\textsuperscript{18} The “Hydrogen Utilization in Iron and Steelmaking Processes” project was selected, which included BF-BOF steelmakers’ participation. The project encompassed two R&D components: the first focused on the development of hydrogen reduction technology for use in blast furnaces, aiming to demonstrate the advancement of Super COURSE 50 in a medium-scale test blast furnace by 2030; the second revolved around developing DRI technology to refine low-grade iron ore using only hydrogen. The latter involved hydrogen DRI technology and the development of
impurity removal technology for EAF. The goal for implementing hydrogen DRI was also set for demonstration by 2030.

Approaches to next-generation technologies have begun to diverge among steelmakers. Nippon Steel intends to implement COURSE 50 and Super COURSE 50 directly. In contrast, JFE Steel is developing carbon recycling technology that uses hydrogen to convert exhaust gas into methane for insertion into the blast furnace. CCUS supplementation is required in both cases. In contrast, Kobe Steel is adopting a more distinct approach. Although the company operates BF-BOF-based steelworks in Japan, it also owns MIDREX as a subsidiary, a DRI engineering company in the United States. Kobe Steel is broadening its natural gas DRI engineering business abroad and developing hydrogen DRI technology without public funding.

Corporate investment behavior and international competition

While BF-BOF steelmakers anticipate the commercialization of next-generation technology by 2030, they have already initiated the expansion of EAF applications. Nippon Steel has transitioned its steelmaking furnaces in the Hirohata area to EAF and is considering a similar shift in the Yawata area. These transitions aim to utilize EAF for high-grade steel production. Additionally, as part of its overseas acquisitions, Nippon Steel joined forces with Arcelor Mittal to acquire a steel company in India, primarily using the DRI-EAF method. It also acquired EAF steelmakers in Sweden and Thailand. Moreover, Nippon Steel and Arcelor Mittal established a new EAF in their joint venture rolling company in the United States. JFE Steel announced plans to halt one BF operation in the Kurashiki area by around 2028 to facilitate the installation of a large-scale EAF facility. In the United States, JFE Steel established a joint venture with Nucor, the largest EAF steelmaker, to increase the base metal supply from EAFs. Kobe Steel is also developing technology to produce high-grade steel using electric furnaces and is considering the installation of a DRI facility in Oman.
However, international competitors have already commenced the construction of steel mills employing not just the EAF but also the DRI method. New construction projects amounting to 57.5 million tons for EAF and 66.1 million tons for DRI were announced for 2017–2022 worldwide. Of these, only 4 million tons of EAF are located in Japan. The leading locations for EAF projects are the United States (15 million tons), China and Iran (7 million tons each), and Canada and Japan (4 million tons each). The leading locations for DRI projects are Germany (14 million tons), Sweden (12 million tons), France and Russia (7 million tons each), and Austria, Saudi Arabia, and China (5 million tons each). DRI will initially operate with natural gas, but plans are in place to eventually transition to hydrogen reduction. In contrast, no concrete projects combining the renovated BF-BOF and CCUS technologies are underway. Consequently, Japanese BF-BOF steelmakers are falling behind their global competitors in developing and commercializing next-generation technologies.

Discussion and conclusion

Adherence to the BF-BOF method

Table 1 summarizes the characteristics of CO₂ emission reduction measures in the Japanese steel industry from the Kyoto Protocol to the Paris Agreement periods.

The Japanese steel industry has sought to reduce CO₂ emissions by leveraging existing energy-saving technologies and developing partial hydrogen reduction technologies. This approach was predicated on the belief that Japanese BF-BOF steelmakers were at the forefront of BF-BOF technology and that it was in their best interests to continue using it. Throughout the Kyoto Protocol and subsequent post-protocol periods, Japanese steelmakers striving to produce green steel remained firmly committed to enhancing and renovating BF-BOF technology.
Table 1: Characteristics of CO₂ emission reduction Measures by Japanese steelmakers

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<th>Kyoto Protocol Period</th>
<th>Post-Kyoto Period</th>
<th>Paris Agreement Period</th>
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<td>Total Emission Control</td>
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<tr>
<td>Expansion of EAF method</td>
<td>None</td>
<td>None</td>
<td>Started</td>
</tr>
<tr>
<td>Development of Hydrogen DRI method</td>
<td>None</td>
<td>None</td>
<td>Started</td>
</tr>
</tbody>
</table>

Source: Compiled by the author.

This stance by the Japanese steel industry stemmed from its significant investments in integrated steel mills employing the BF-BOF method and high-grade steel production technology, which had gained a considerable customer reputation. Switching to alternative production methods requires significant capital investment and time to reestablish high-grade steel production technology. Consequently, the BOF ratio in crude steel production increased as steelmakers preferred using the BF-BOF technology rather than transitioning to EAF. Furthermore, the development of next-generation technology has primarily focused on renovating the BF-BOF method. Japanese BF-BOF steelmakers reached their goal of reducing total CO₂ emissions during the Kyoto Protocol period but evaded this goal in the post-Kyoto period, opting to maintain production under the BF-BOF method.

The international political dynamics surrounding global warming and the enactment of the Paris Agreement disrupted this adherence. The Paris Agreement imposed strict total emission limits on the Japanese government and BF-BOF steelmakers to achieve carbon neutrality; it is impossible to achieve this goal by renovating the BF-BOF method. Therefore,
BF-BOF steelmakers have embarked on expanding EAF applications and developing the hydrogen DRI method.

However, another factor is at play. Even during the post-Kyoto period, when CO₂ emission regulations were less stringent, BF-BOF steelmakers suffered market losses owing to sluggish domestic demand and fierce competition from emerging countries’ steelmakers. Consequently, BF-BOF makers had to confront the reality that domestic production would likely decrease. This led them to accept the imposition of total volume restrictions on CO₂ emissions.

**Implications**

The race for green steel remains unresolved. Nevertheless, from the discussions presented in this study, the author can draw theoretical implications, conduct historical assessments, and identify new issues.

First, this study underscores the applicability of theories regarding the political economy of the environment and the conservative stance of large firms toward new technologies in the context of emerging green technologies. Large established firms often resist green innovations that disrupt existing production technologies because of significant investments in fixed capital and intangible assets tied to current technology.

Second, it contributes a new chapter to the history of the Japanese steel industry. Japanese BF-BOF steelmakers, once lauded for their innovative corporate behavior, are no longer leading the pack in technology development and capital investment for green steel. Their steadfast adherence to the BF-BOF technology has placed them on a dead-end path, causing them to fall behind in expanding the application of the EAF method and developing the hydrogen DRI method. Under the Paris Agreement and the Japanese government’s declaration
of carbon neutrality, they are finally veering away from their fixation and are striving to regain their competitive edge.

Third, it became evident that the race toward green steel could coincide with a decline in domestic production. As evidenced by the post-Kyoto period results, the decline in crude steel production was not because of strict emission regulations. With a maturing domestic market and firms in emerging markets catching up, it has become difficult for the Japanese steel industry to maintain its domestic production volume. JISF assumes that this trend will continue until 2030. Lowering domestic production could facilitate the achievement of CO₂ emission reduction targets. Nonetheless, such a contraction in production could also result in job losses and possibly undermine the potential of domestic green production.

**Future considerations**

The potential for the race toward green steel to coincide with a hollowing out of domestic production is a topic that warrants further examination. Both Nippon Steel and JFE Steel are already curtailing their domestic BF-BOF capacity. After 2020, Nippon Steel and JFE Steel announced that they would suspend five and two blast furnaces, respectively. Nippon Steel aims to allocate 60% of its crude steel production overseas.²¹ Kobe Steel, which owns DRI technology through its subsidiary, may shift its focus toward global engineering operations and overseas DRI production.

The promotion of offshoring raises the following issues. First is whether next-generation technologies developed with Japanese government support can be put to practical use in domestic locations. Even if BF-BOF steelmakers successfully develop green production capacities, they may want to install them in the most profitable locations, which may not necessarily be in Japan. However, the offshoring of production by next-generation technologies
may cause political friction because Japanese public funds are being invested in developing these technologies.

The second issue is whether offshoring represents an export of pollution or reflects comparative advantage within the framework of global environmental standards. The answer largely hinges on the stringency of the recipient country’s CO₂ emission regulations. If a BF-BOF steelmaker establishes a blast furnace in a developing nation where CO₂ emission regulations are lenient, it might be perceived as exporting pollution. Conversely, if developing countries are steering toward carbon neutrality by 2050, offshoring with the scrap-EAF and DRI-EAF methods would signify the pursuit of production locales that possess a comparative advantage under eco-friendly regulations.

These concerns will be pivotal areas of investigation in subsequent studies.

Disclosure statement

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Data availability statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

Notes

1. This study addresses the reduction of CO₂ emissions within the steel production process, a concept referred to as “decarbonization” throughout the text. Steel produced with CO₂ emissions curtailed to levels compatible with global warming mitigation is termed “green steel.” The phrase “zero emissions” is used more strictly, denoting a production process that does not emit CO₂.

2. Keidanren’s action plans align with government policies. For instance, the Japanese government’s “Plan for Global Warming Countermeasures,” formulated in 2021, incorporates the promotion of Keidanren’s action plan. However, for Keidanren, industry associations, and their member companies, these targets are voluntary, with no legal mandate for achievement.

3. The English article of Shoji and Miyamoto (1977) is a translation of Chapter 2 of the original Japanese book by Shoji and Miyamoto (1975). The two behavioral principles discussed in this study are outlined in Chapter 1 of the original text.

4. The author calculated the figures using published data from the National Institute for Environmental Studies, Japan.

5. The CO₂ emissions from producing one ton of crude steel are referred to as emission intensity. The IEA’s intensity calculation method includes several processes within this boundary. These processes encompass iron and steelmaking, iron ore agglomeration, production of reducing agents like coke and hydrogen, production of lime fluxes, combustion of off-gases from coke ovens and blast furnaces, and the generation of imported electricity, heat, hydrogen, and supplied fossil fuels. CO₂ emissions from these processes are accounted for in the calculations (IEA 2022, 104–108).
6. The author’s calculations in this paragraph are based on data from worldsteel (2020).
7. Unless otherwise stated, the figures in this subsection are sourced from the JISF (annual).
8. The author calculated the figures based on JISF (2020).
9. The author calculated the figures based on Cullen et al. (2012) and Yang et al. (2023).
10. References for the “Voluntary Action Plan on the Environment” are official Keidanren documents listed below, except where otherwise noted. The JISF reports are also available from this site (https://www.keidanren.or.jp/policy/vape.html#vape).
11. Under the Kyoto Protocol, developing countries were not obligated to reduce GHG emissions. The United States withdrew from the Kyoto Protocol in 2001.
12. APP is an initiative set up in 2005 by Australia, Canada, China, India, Japan, the Republic of Korea, and the United States. Canada became a member in 2007. APP established eight task forces to develop cleaner technologies and practices to mitigate climate change. The partnership was formally terminated in 2011.
15. CCS is a technology for capturing and storing CO₂, and CCUS includes the utilization of the captured CO₂.
16. For the “Commitment to a Low Carbon Society,” refer to the official Keidanren documents listed below, except where otherwise noted. The JISF reports are also available from this site (https://www.keidanren.or.jp/policy/vape.html#lcs).

17. For the “Carbon Neutral Action Plan,” refer to the official Keidanren documents listed below, except where otherwise noted. The JISF reports are also available from this site (https://www.keidanren.or.jp/policy/vape.html#cnap).


“FY 2022 Earnings Summary,” Nippon Steel Corporation, May 10, 2023

*Internet resources were accessed on 20 August, 2023, unless otherwise noted.

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