The Green Transformation in the Chinese Ironmaking Industry

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China's iron and steel industry has advanced significantly, becoming the world's largest iron producer through technological innovations and industrial upgrades. To address economic complexities and meet new low-carbon requirements, technological innovation is essential for cost reduction, efficiency improvement, and developing a sustainable, green industry. The improvements in traditional blast furnace technology and various low-carbon, high-efficiency technologies are introduced to address energy consumption in ironmaking. Key areas such as raw material preparation, blast furnace operation, fuel ratio reduction, environmental protection, and secondary resource utilization are discussed to minimize environmental impact. New iron smelting processes are explored, including global advancements in low-carbon and hydrogen metallurgy, and China's progress in hydrogen-rich blast furnaces and hydrogen-based direct reduction. These innovations are proposed as crucial for the future, demonstrating China's commitment to cutting-edge, sustainable solutions. The future development of China's ironmaking processes emphasizes technological innovation and carbon-neutral technologies for green and sustainable steel production. The industry's efforts towards a green transformation are showcased, highlighting current advancements and future prospects.

KEYWORDS: GREEN TRANSFORMATION, IRONMAKING, BLAST FURNACE, HYDROGEN METALLURGY EFFICIENCY

INTRODUCTION

The ironmaking industry in China has undergone significant growth and development, evolving from a small and weak sector to becoming the world's largest producer of pig iron. This transformation is closely linked to technological innovations, industrial upgrades, and policy support within the Chinese ironmaking industry. Steel production accounts for 7% to 11% of global CO_2 emissions, with more than 70% of these emissions originating from the ironmaking process. Therefore, reducing CO_2 emissions in ironmaking process is crucial. Among the various low-carbon ironmaking processes, hydrogen metallurgy, represented by hydrogen-rich blast furnaces and hydrogen-based direct reduction, has emerged as the most promising short-term pathway for large-scale production with reduced carbon emissions. Additionally, ironmaking processes based on renewable energy electrolysis hold potential for future success. However, evaluating the industrial viability of these processes requires considering numerous complex factors, such as energy consumption intensity, carbon

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emission intensity, investment and production costs, and technological maturity. These considerations lead to varying assessments of different processes from different perspectives.

This paper provides an overview of the main low-carbon ironmaking pathways, with a particular focus on innovations in blast furnace technology and the development of hydrogen metallurgy. By exploring these issues, the paper aims to offer valuable insights for the steel industry as it progresses towards the goal of "carbon neutrality."

Iron and Steel production in China

In 1995, China's pig iron production surpassed 100 million tons, accounting for 20% of the world's total pig iron output. This milestone marked a historic transition for China's steel industry from being "small and scattered" to "large and centralized." Entering the new century, the scale of China's iron smelting industry continued to expand, gradually moving into a phase of independent development. By 2019, China achieved a pig iron production milestone of 800 million tons, representing approximately 64% of the global total (1). In 2023, the Chinese steel industry faced numerous challenges but continued to demonstrate strong resilience. The pig iron production reached 871.01 million tons, marking a 0.7% year-over-year increase. Simultaneously, the annual crude steel production reached 1019.08 million tons, remaining almost flat compared to the previous year (2). These figures reflect the stable production levels of China's steel industry despite a complex and volatile economic environment, showcasing the industry's robust development trend. It is evident from Fig 1 that from 2000 to 2023, the crude steel production in Canada, Europe, Japan, and the United States collectively decreased by 19%, while global production increased by 140%. During this period, China experienced an astounding 722% growth, contributing 81% of the global increase in crude steel production. This shift highlights the significant transition of global production from developed countries to China. By 2023, China accounted for 54% of the world's crude steel production.

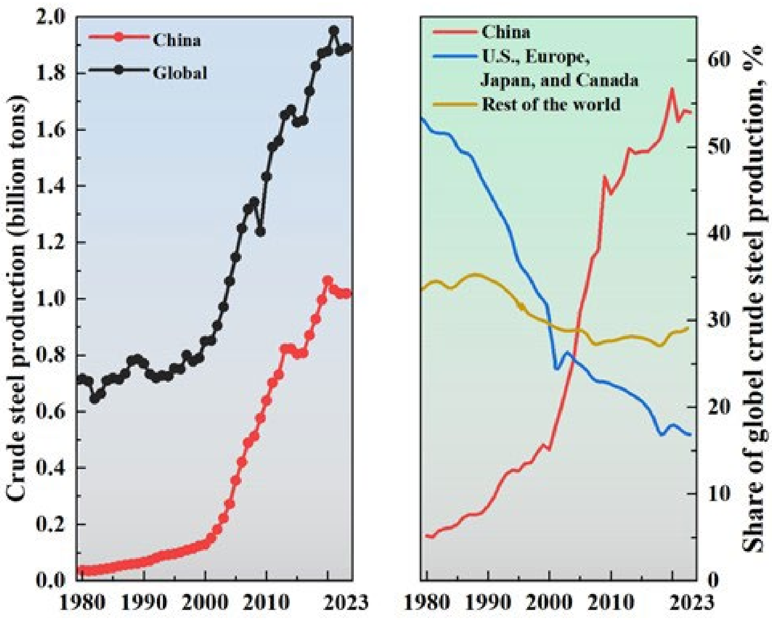

Fig.1 - Evolution of Crude Steel Production.

Improvement of Blast Furnace Ironmaking Process

Due to differences in processing routes, raw material acquisition, and available technologies, the crude steel production capacities and associated carbon intensities vary across different plants. China, Japan, and India primarily use the blast furnace-basic oxygen furnace (BF-BOF) route for ironmaking, accounting for 54%, 6.6%, and 4.7% of the world's crude steel production, respectively (3). The Chinese steel industry remains heavily reliant on blast furnaces, and it is projected that by 2050, 50% of steel production in Asia will still use the blast furnace process. BF Low-carbon ironmaking and efficiency improvement technologies are summarized as Fig. 2 (4), include High Proportion Pellet Technology, Super

Thick Layer Sintering Tech-nology, Ultra-High Oxygen Enrichment and Full Pulverized Coal Injection, Coke quality evaluation technolo-gy, etc. Those technologies have been successfully promoted and applied in China and achieved particular-ly good results.

Thick bed sintering technology is a goal pursued by major steel enterprises to enhance the sintering pro-cess. Increasing the thickness of the sintering machine bed effectively improves the quality of sinter, re-duces fuel consumption, and lowers pollutant emissions. For instance, Ansteel Bayuquan increased the bed thickness from 750mm to 900mm, resulting in a 13.3% increase in output, a 1.4% increase in sinter yield, a reduction of solid fuel consumption by 3kg/t, and a reduction in electricity consumption by 3.6 kWh/t.

Pellets, with their high grade, good strength, and uniform size, are advantageous for ironmaking. Adopt-ing a high-quality pellet-based burden structure is crucial for narrowing the fuel consumption gap between Chinese blast furnaces and the world's advanced levels. It is also a key measure for transitioning Chinese blast furnace ironmaking to green and low-carbon practices. Basicity pellet preparation technology is fun-damental for high-ratio pellet ironmaking in blast furnaces. Steel companies like Shougang, Baosteel Zhan-jiang, Hebei Iron and Steel Group, Baotou Steel, and Taiyuan Iron and Steel Group have actively explored basicity pellet preparation and high-pellet ratio ironmaking technologies, achieving significant results. For example, Shougang successfully produced pellets with a basicity of 1.1, TFe of 65.79, and SiO_2 content of 2.2, maintaining a furnace burden ratio of 55%.

Using renewable, carbon-neutral biomass instead of coal for metallurgical production is vital for reducing global carbon consumption. In December 2023, Shougang Group conducted a biomass injection trial in a 2650 m^3 blast furnace, achieving a maximum injection capacity of 2.4 tons per hour and a total injection volume of 100 tons. Shougang Group also completed full-cycle production verification of the new "bottom-blown CO_2-O_2 steelmaking technology," which increased dephosphorization efficiency by 6.99% and re-duced CO_2 emissions by 0.75%.

Additionally, the rapid development of technologies like computer simulation, artificial intelligence, and big data has greatly benefited the steel industry. Advanced steel enterprises increasingly use big data and intelligent operation technologies, with intelligent ironmaking representing the future direction of the indus-try. By integrating cutting-edge interdisciplinary technologies and practical applications, establishing big da-ta cloud platforms for blast furnaces, and applying data mining and intelligent analysis, the automation and intelligence of blast furnace ironmaking can be significantly enhanced.

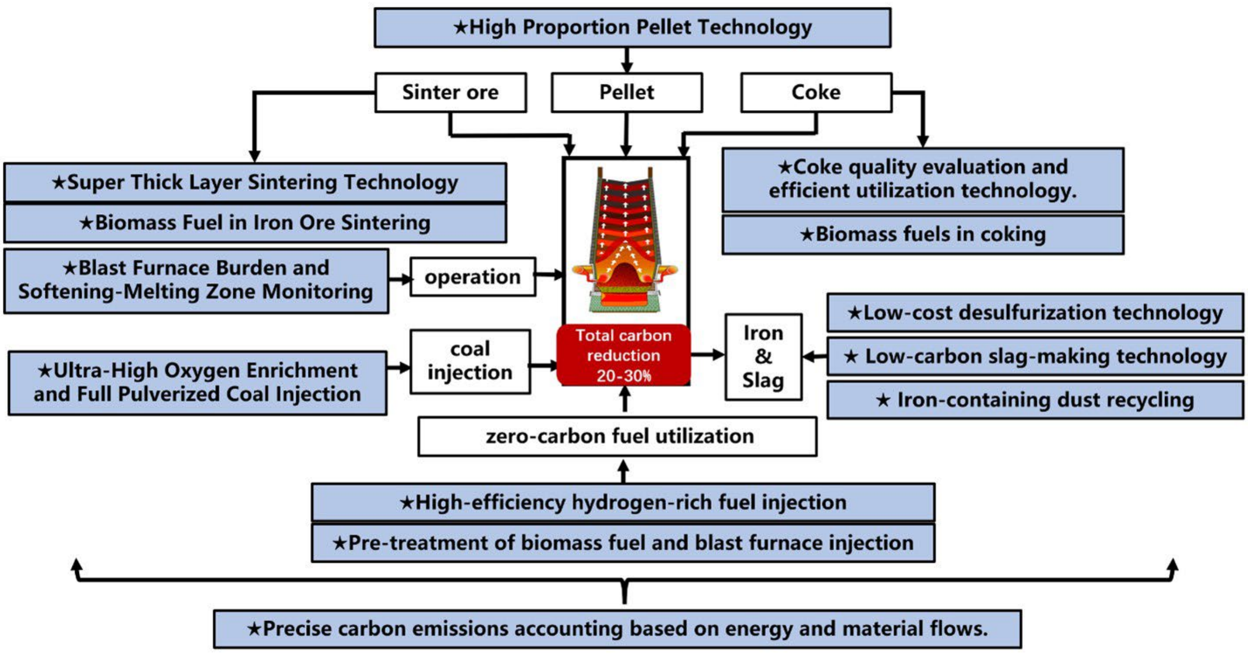

Fig.2 - BF Low-carbon ironmaking and efficiency improvement technologies

Development of Hydrogen-based Ironmaking Processes

The future development of global hydrogen metallurgy technology is expected to follow two main paths: modernizing traditional long process smelting with hydrogen upgrades and advancing hydrogen-based direct reduction methods. Fig. 3 (5)(6) outlines the two main China's Hydrogen-based ironmaking processes.

Hydrogen-rich low-carbon blast furnaces are a key pathway for achieving large-scale low-carbon steel production in China. Baowu Steel's Hydrogen Carbon Recycling Oxygen Blast Furnace (HyCROF, Fig.3 (a)(5)) is a technology that separates CO_2 from blast furnace top gas, recycles the high-reduction potential byproduct gas (CO), and injects green hydrogen into the furnace. This approach maximizes the use of car-bon chemical energy and substitutes green electricity for fossil fuels in heating, further reducing fossil fuel consumption in the blast furnace process. In 2022, Baowu operated a 400-cubic-meter HyCROF, achieving low-carbon operation with significant reductions in carbon emissions (over 20%) and reaching a maximum utilization factor of 5.0 t/m³/d, validating the technical and economic feasibility of the HyCROF process. As of October 26, 2023, Baosteel has initiated the trial operation of a 2500-cubic-meter HyCROF commercial demonstration project. Additionally, Jinnan Steel has reduced fuel consumption, production costs, and CO_2 emissions by injecting hydrogen-rich gas into the blast furnace with minimal modifications.

Chinese steel companies, including HBIS, Baowu, and Zhongjin, are also exploring and experimenting with hydrogen-based direct reduction processes. These new applications and innovative technologies are expected to drive the development of hydrogen metallurgy in China. In December 2020, Zhongjin commis-sioned China's first hydrogen-based vertical direct reduction plant, similar to the PERED process, which uses hydrogen extracted from coke oven gas (COG) with an annual capacity of 300,000 tons of direct re-duced iron (DRI). In May 2023, the world's first "coke oven gas zero-reforming vertical direct reduction" plant, similar to the Energiron process (Fig.3 (b) (6)), began operation at HBIS with an annual capacity of 600,000 tons of DRI. Compared to traditional blast furnace-basic oxygen furnace processes, HBIS's hydro-gen metallurgy demonstration project is expected to reduce CO_2 emissions by over 70% annually, SO_2 emissions by 30%, NOx emissions by 70%, and particulate matter emissions by over 80%. On December 23, 2023, Baosteel's Zhanjiang hydrogen-based vertical furnace was ignited and put into production, mark-ing the start of China's first million-ton-level hydrogen-based vertical furnace in industrial operation. Baowu Steel is also exploring the direct reduction-electric furnace-basic oxygen furnace/electric arc furnace pro-cess.

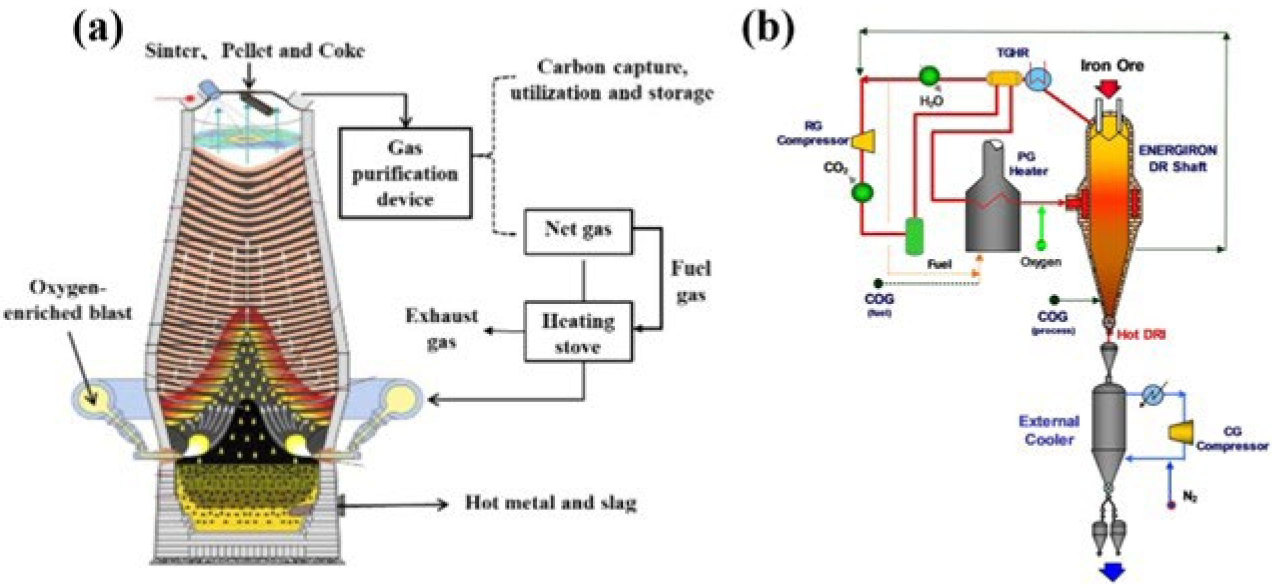

Fig.3 - Processes of (a) oxygen blast furnace with carbon recycling and (b) Hydrogen direct reduction process.

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