China and Global Steel Demand Forecast Through 2050

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This article presents an innovative enhancement to the traditional S-curve demand forecasting model by incorporating multidimensional factors such as global socioeconomic dynamics, geopolitical risks, climate change and technological advancements. It offers forward-looking projections of steel demand for both the global market and China up to 2050. Additionally, the study estimates the availability of scrap resources globally and in China through 2050 using an in-use steel stock model. Furthermore, based on the principle of ferrous element balance, it derives medium- to long-term forecasts for iron ore demand on both global and Chinese scales. In response to the urgent need for low-carbon development, the article also provides estimates for the global demand of direct reduced iron. These comprehensive forecasts serve as valuable references for nations in formulating their strategic plans regarding iron ore resources. The integrated approach and multifaceted analysis presented in this study offer a more nuanced and robust framework for understanding future trends in the steel industry, considering both economic and environmental factors.

Introduction

Steel, the most widely used metal globally, serves as a critical structural material across diverse sectors including construction, automotive, shipbuilding, machinery, home appliances and energy. The complexity of forecasting steel demand stems from its derivative nature and significant variations across different stages of industrialization. Current international methodologies include econometric approaches, Intensity of Use (IU) method, Steel Weighted Industrial Production (SWIP) calculation, and per capita in-use steel stock models. Chinese scholars have identified an S-shaped demand curve for mineral resource consumption based on the two-inflection-point theory, elucidating the relationship between mineral resource consumption and socioeconomic development during industrialization.

This study analyzes crude steel and steel product production and consumption data from the World Steel Association and national steel associations, examining the economic and steel development histories of different countries. The research reveals significant differences in industrialization periods, industrial policy orientations and economic development models among these nations. Notably, after accounting for improvements in steel yield rates, the study found that only a few countries or regions exhibit steel consumption patterns that align with the S-shaped curve in relation to economic development. Most countries demonstrate diverse trajectories in per capita steel consumption relative to economic development due to variations in industrialization levels, industrial policies and development models.

The author has optimized and improved upon traditional S-curve demand forecasting methods, incorporating multidimensional factors such as global and Chinese economic trends, demographic changes, geopolitical risks, climate change, and technological advancements to provide forward-looking projections of steel demand up to 2050 for both China and the global market.

Furthermore, the steel industry relies on iron-containing raw materials, primarily iron ore and scrap. While the blast furnace-basic oxygen furnace (BF-BOF) process, which mainly uses iron ore, currently dominates, electric arc furnace (EAF) technology and hydrogen metallurgy are gaining attention due to their emission reduction advantages. The composition of iron-containing raw materials in the steel industry is expected to undergo significant changes in response to low carbon emission requirements.

Utilizing an in-use steel stock model, the author has estimated the availability of scrap resources globally and in China through 2050. Based on the principle of iron element balance, medium- to long-term forecasts for iron ore demand on both global and Chinese scales have been derived. Additionally, in response to the urgent need for low-carbon development, the global demand for direct reduced iron (DRI) has been estimated.

The projections indicate that by 2050, global crude steel demand will reach 2.63 billion tons, with an average annual growth of 1.1% (see Table 1 and Fig. 1). This includes pig iron production of 960 million tons, DRI consumption of 510 million tons, and scrap consumption of 1.42 billion tons, representing 33%, 18%, and 49% of the iron element composition, respectively, with average annual growth rates through 2050 of –1.2%, +5.0%, and +3.1%. China's crude steel demand is expected to reach 840 million tons by 2050, with a production of 870 million tons.

The study forecasts global in-use steel stock to reach 71.1 billion tons by 2050, with China accounting for 23.1 billion tons. Global and Chinese scrap resources are projected to reach 1.43 billion tons and 460 million tons, respectively, by 2050.

Table 1

Forecast of Global Crude Steel Demand 2024–2050

	Global			China			Global ex-China			China	
	Crude steel demand	Per capita crude steel demand	Population	Crude steel demand	Per capita crude steel demand	Population	Crude steel demand	Per capita crude steel demand	Population	Steel demand share	Population share
Year	mmt	kg	billion	mmt	kg	billion	mmt	kg	billion	%	%
2000	846	138	6.15	138	110	1.26	708	145	4.88	16	21
2010	1,420	203	6.99	610	453	1.35	809	144	5.64	43	19
2020	1,897	242	7.84	1,048	736	1.42	849	132	6.42	55	18
2023	1,935	241	8.05	982	694	1.41	954	144	6.63	51	18
2025F	1,984	242	8.19	969	687	1.41	1,015	150	6.78	49	17
2030F	2,093	245	8.55	911	653	1.39	1,182	165	7.15	44	16
2035F	2,231	251	8.88	861	628	1.37	1,370	182	7.51	38	15
2040F	2,424	264	9.19	844	628	1.35	1,580	201	7.84	35	15
2050F	2,625	270	9.71	839	660	1.27	1,787	212	8.44	32	13
2023–2035F CAGR	1.2%	0.4%	0.8%	–1.1%	–0.8%	–0.3%	3.1%	2.0%	1.0%	–	–
2035–2050F CAGR	1.1%	0.5%	0.6%	–0.2%	0.3%	–0.5%	1.8%	1.0%	0.8%	–	–
2023–2050F CAGR	1.1%	0.4%	0.7%	–0.6%	–0.2%	–0.4%	2.4%	1.4%	0.9%	–	–

By 2050, global iron ore demand is expected to stabilize at 2.34 billion tons, comparable to 2021 levels. DRI demand is projected to reach 510 million tons, with its contribution to iron element composition increasing from 6.5% in 2023 to 18% by 2050.

These comprehensive forecasts provide crucial references for national iron ore resource strategies, industry policy formulation and sector development.

Figure 1

Global crude steel demand forecast 2024–2050.

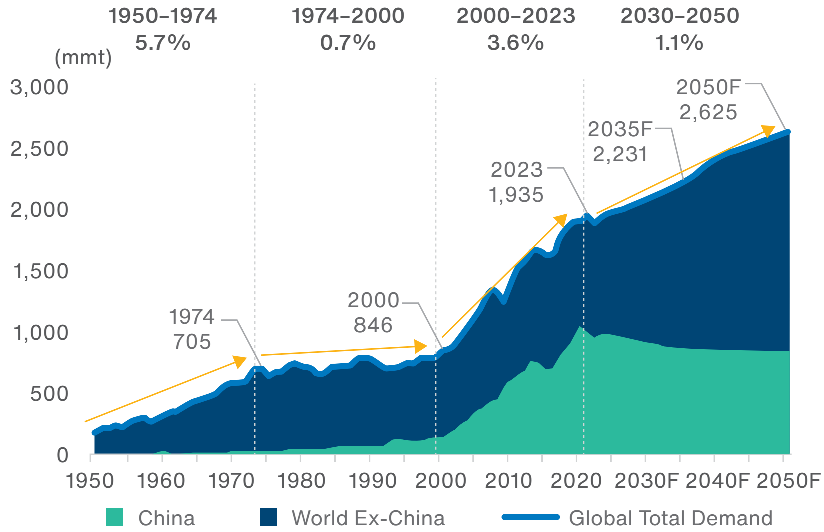
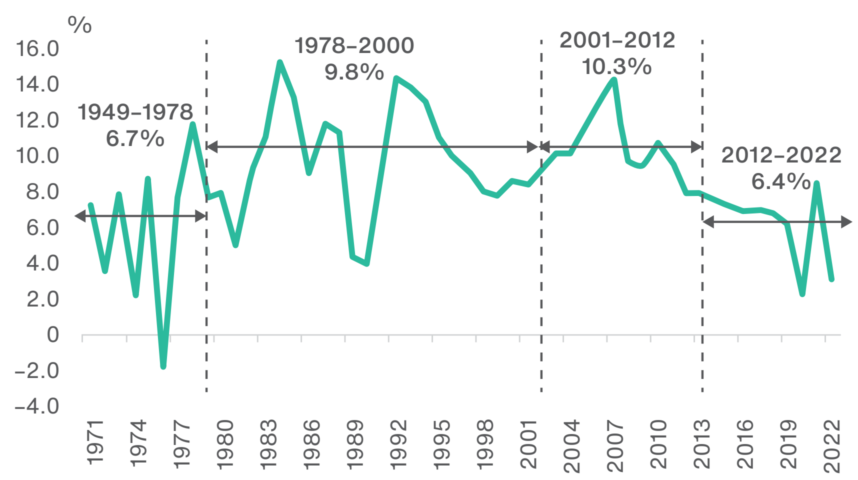


Figure 2

China gross domestic product (GDP) growth rate.



China's Crude Steel Demand Forecast

Review of Steel Supply and Demand in China

Since the founding of the People's Republic of China, the country's economy has undergone four stages of development (see Fig. 2 and Table 2):

- 1949–1978: Low Growth Period. In the early years following the founding of the People's Republic of China, heavy industry was prioritized, resulting in rapid growth in infrastructure investment. The consumption of crude steel rose from nonexistence to over 40 million tons by 1978.
- 1978–2001: Rapid Growth Period. After the reform and opening up, light industry initially took the lead, followed by a resurgence of heavy industry in the mid-1980s. By 1996, China's crude steel production exceeded 100 million tons, making it the world's largest steel producer.
- 2001–2012: High-Speed Growth Period. Following its accession to the World Trade Organization, China became the world's factory, with crude steel consumption escalating from 170 million tons to 680 million tons, and by 2005, it became a net exporter of steel.
- 2012–2020: Stable Growth Period. Economic growth began to slow, with the tertiary sector's share increasing. In 2020, crude steel consumption peaked at 1.048 billion tons before declining, with per capita consumption at 736 kg that year.
- 2020 Onward: High Plateau Period. China entered a stage of high-quality development, with steel demand experiencing high-level fluctuations (see Fig. 3).

Forecast of China's Crude Steel Demand

Population Forecast for China: Predictions regarding China's population by different organizations for

Table 2

Four Stages of China's Economic Development

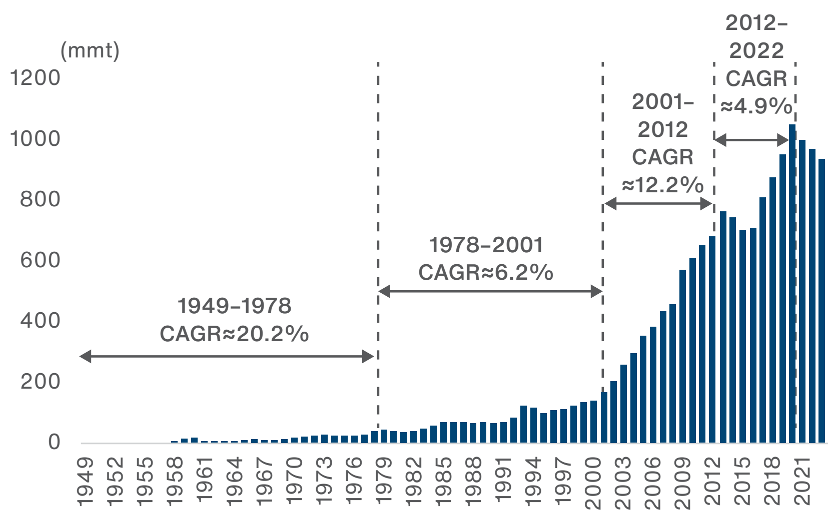
Development stage	Low-speed growth	Rapid growth	High-speed growth	Stable growth
Period	1949–1978	1978–2000	2001–2012	2012–present
Economic background	Planned economy	Market economy	Globalization	High-quality development
Real GDP growth rate	6.7%	9.8%	10.3%	6.4%
Working population (15 to 64 years old)	↑	↑	↑	↓
Elderly population ratio (65 years old and above)	5.0% → 4.1%	4.1% → 6.9%	6.9% → 9.0%	9.0% → 13.7%
Policy orientation	Single public ownership	Reform and opening up	World Trade Organization accession	Supply-side reform
	Planned economy system	Introduction of foreign capital	Integration into globalization	Dual circulation
Crude steel production CAGR	19.3%	6.7%	13.9%	3.1%
Crude steel demand CAGR	20.3%	6.2%	12.2%	3.2%
Steel exports CAGR	–	11.7%	22.8%	1.7%
Steel imports CAGR	–	2.9%	–1.9%	–2.3%

the year 2050 vary significantly, directly impacting forecasts for steel demand. The United Nations (UN) presents the most optimistic estimate of 1.317 billion, while the predictions from the National Development Research Center of China, Guosheng Xiong Yuan, and Liang Jianzhang[1] hover around 1.2 billion. This article adopts the mean of the UN and Liang Jianzhang's population predictions as the baseline assumption for steel demand forecasting, with optimistic and pessimistic scenarios respectively.

New Challenges and Opportunities Facing China: Currently, China is confronting new challenges brought about by the wave of deglobalization, pressures from climate change, shifts in population structure and advancements in technology, while also encountering opportunities arising

Figure 3

Crude steel apparent consumption in China from 1949 to 2023.



from urbanization. Experts believe that China has the capability to avoid falling into the middle-income trap, citing factors such as increased R&D expenditure and productivity, leadership in industrial automation, a sufficient labor supply and the ongoing urbanization process. By tapping into the potential of demographic changes and expanding consumer spending through various reform measures, China can seize development opportunities offered by economies of scale. In the future, China is expected to develop global competitiveness in sectors such as automotive, electrical equipment and telecommunications electronics, while also leveraging scale advantages in emerging industries like the green economy. Overall, China is moving toward the high end of the value chain, with the added value of its manufacturing sector consistently increasing its share of the global total, positioning itself as a key player in leading a new round of industrial revolution.

Table 3

Forecast of China's Potential Economic Growth Rate Under Baseline Scenario

Year	Potential economic growth rate (%)	GDP per capita (US$)	Year	Potential economic growth rate (%)	GDP per capita (US$)
2021	5.38	12,556	2036F	3.89	25,292
2022	5.32	13,192	2037F	3.77	26,342
2023F	5.27	13,860	2038F	3.67	27,416
2024F	5.21	14,561	2039F	3.56	28,515
2025F	5.16	15,297	2040F	3.46	29,637
2026F	4.96	16,046	2041F	3.26	30,755
2027F	4.90	16,829	2042F	3.18	31,899
2028F	4.84	17,648	2043F	3.12	33,077
2029F	4.77	18,504	2044F	3.07	34,294
2030F	4.71	19,397	2045F	3.04	35,555
2031F	4.53	20,305	2046F	2.96	36,844
2032F	4.45	21,248	2047F	2.93	38,181
2033F	4.36	22,223	2048F	2.91	39,568
2034F	4.26	23,229	2049F	2.89	41,008
2035F	4.16	24,267	2050F	2.87	42,501

China Economic Growth Forecast: China's economic growth forecast was calculated according to the 2023 analysis and forecast by Zhang Xiaojing of the Chinese Academy of Social Sciences.[2]

Baseline scenario: China's average annual GDP growth rate will be above 5% during the 14th Five-Year Plan period, and by 2035, China's per capita GDP will reach US$24,300, matching the level of moderately developed countries at US$24,200.

Pessimistic scenario: Considers adverse impacts of accelerating population aging and China-U.S. tech decoupling, the potential growth rate during the 14th Five-Year Plan period will decrease by 1 percentage point annually compared with the baseline scenario, and by 2035, China's per capita GDP will reach US$22,800, US$1,500 less than the baseline scenario, and lower than the level of moderately developed countries.

Optimistic scenario: China will be able to effectively hedge against the adverse impacts of accelerating population aging and China-U.S. tech decoupling, through supply-side structural reforms such as tax cuts, improvement of total factor productivity, improvement of human capital, and increase of labor participation rate. The potential economic growth rate will increase by about 1% annually in the next 30 years, and by 2035, China's per capita GDP will reach US$26,300, exceeding the standard of moderately developed countries.

Although China's future potential economic growth rate will gradually slow down, it will remain above 3% for a long time (see Table 3).

China Crude Steel Demand Forecast: Since the publication of research on the S-shaped demand curve in 2010, nearly all studies have followed this principle, using Japan or the United States as comparative countries to predict China's future steel demand. However, based on the research in the next section, it has been found that, when considering factors such as technological advancements in the steel industry and improvements in yield rates, there are significant differences among countries in terms of industrialization stages, industrial policies and economic development models. Per capita steel product consumption exhibits different evolutionary paths, with only a small number of countries' steel product consumption aligning with the S-shaped pattern of economic development.

In fully industrialized Western countries, such as the United States, the United Kingdom and France, the share of the tertiary sector has increased significantly during the post-industrialization period, leading to a decrease in manufacturing's share and a substantial reduction in per capita steel product consumption. In contrast, countries like Germany, Italy and Austria, which continue to prioritize manufacturing exports, show a fluctuating upward trend in per capita steel product consumption. Rapidly industrialized regions such as Japan have a peak per capita steel product consumption that exceeds that of Western countries; however, a subsequent decline in indirect export demand results in a significant reduction.

The evolution of steel demand in various countries exhibits the following characteristics: due to the differing stages and processes of industrialization, there are notable disparities in peak per capita steel product consumption among nations. Countries that vigorously develop their manufacturing sectors experience a temporary setback followed by a continuous rise in steel product consumption. Changes in economic structure determine the extent of the decline after reaching the peak; typically, the steel consumption in various countries continues to decline for about 8–9 years after reaching its peak. The rebound in steel product consumption during the second peak usually exceeds 40%.

Comparative analysis of China and Germany's development trajectories suggests that China's future steel demand pattern may mirror Germany's experience. This alignment is supported by several structural similarities: both nations maintain manufacturing-centric post-industrialization strategies, emphasize export-oriented economics, possess extensive market access advantages, implement supportive industrial policies, and lead in technological innovation. These parallels indicate that China's per capita steel consumption may maintain relatively high levels post-peak, rather than following a simple declining trajectory.

China's unique position, characterized by its substantial market scale and robust industrial chain integration, suggests an enhanced leadership role across multiple industrial sectors. In the context of deglobalization, China's scale advantages may emerge as a new growth

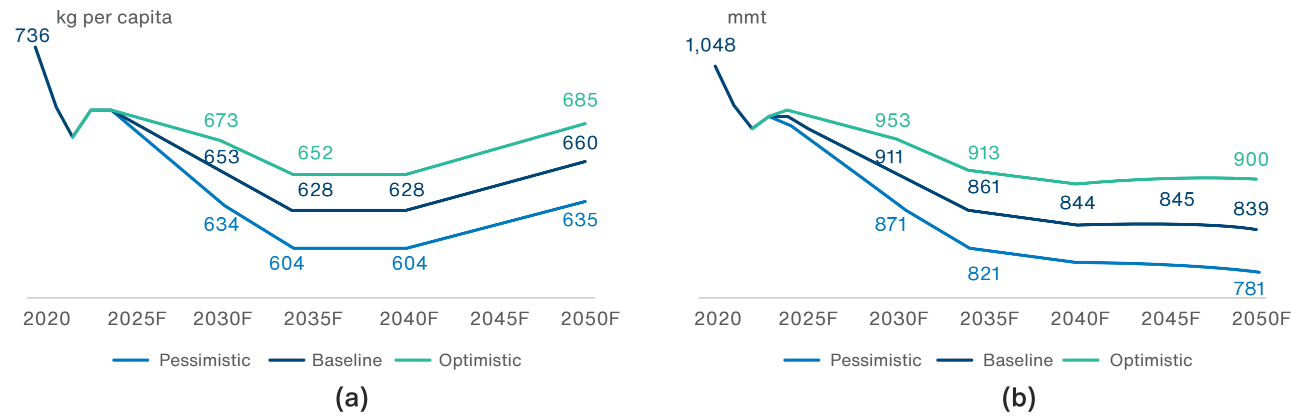
Table 4

Forecast of China's Crude Steel Demand and Production 2024–2050 (O = Optimistic; B = Baseline; P = Pessimistic)

	Crude steel demand (mmt)				Crude steel production (mmt)				Per capita crude steel demand (kg)		
Year	O	B	P	Year	O	B	P	Year	O	B	P
2010	610	610	610	2010	637	637	637	2010	453	453	453
2015	700	700	700	2015	804	804	804	2015	502	502	502
2020	1,048	1,048	1,048	2020	1,065	1,065	1,065	2020	736	736	736
2023	982	982	982	2023	1,068	1,068	1,068	2023	694	694	694
2030F	953	911	871	2030F	993	951	911	2030F	673	653	634
2035F	913	861	812	2035F	948	896	847	2035F	652	628	604
2040F	898	844	793	2040F	933	879	828	2040F	652	628	604
2050F	900	839	781	2050F	930	869	811	2050F	685	660	635
2023–2035F CAGR	–0.6%	–1.1%	–1.6%	2023–2035F CAGR	–1.0%	–1.5%	–1.9%	2023–2035F CAGR	–0.5%	–0.8%	–1.2%
2035–2050F CAGR	–0.1%	–0.2%	–0.3%	2035–2050F CAGR	–0.1%	–0.2%	–0.3%	2035–2050F CAGR	–0.3%	0.3%	0.3%
2023–2050F CAGR	–0.3%	–0.6%	–0.8%	2023–2050F CAGR	–0.5%	–0.8%	–1.0%	2023–2050F CAGR	0%	–0.2%	–0.3%

Figure 4

Forecast of China's crude steel demand 2024–2050 Crude steel demand per capita (a) and total crude steel demand (b). Both graphs present three scenarios: optimistic, pessimistic and baseline cases.



driver. Furthermore, continued investment in supply chain security, green development and energy transition is likely to sustain high levels of steel consumption. This combination of factors suggests that China's steel demand will likely follow patterns similar to those observed in Germany and Italy, with per capita steel consumption maintaining relatively stable levels in the medium to long term.

Based on long-term economic development forecasts, population projections and the preceding analysis, estimates for China's steel demand up to 2050 have been calculated. The baseline population assumption utilizes an average of United Nations and Liang Jianzhang's population projections. In this baseline scenario, the model predicts that from 2025 onward, per capita crude steel consumption will decline at an annual rate of 1.0%, stabilizing by 2035, before experiencing a slight rebound with a 0.5% annual growth rate after 2040. Net crude steel exports are assumed to decrease gradually, reaching 40 million tons by 2030, 35 million tons by 2035, and 30 million tons from 2040 onward. Based on these projections, China's crude steel consumption and production are estimated to be 910 million tons and 950 million tons respectively in 2030, 860 million tons and 900 million tons in 2035, and 840 million tons and 870 million tons in 2050.

For the optimistic and pessimistic scenarios, different assumptions are applied. The optimistic scenario follows UN population forecasts, with per capita crude steel consumption declining at a moderate annual rate of 0.6% until 2035. Conversely, the pessimistic scenario employs Liang Jianzhang's population projections, with per capita crude steel consumption decreasing more rapidly at an annual rate of 1.4% until 2035 (see Table 4, Fig. 4). These figures provide a comprehensive outlook for China's steel industry, reflecting the interplay between economic development, demographic changes and industrial trends over the coming decades.

Global Crude Steel Demand Forecast

Review of Global Steel Supply and Demand

Examining historical data reveals that global crude steel production and consumption have undergone four distinct phases: slow growth (1900–1945), steady growth (1945–1970), decelerated growth (1970–2000) and rapid growth (since 2000), as illustrated in Fig. 5.

It's important to note that using crude steel production as a proxy for steel demand does not account for the impact of the early steel industry's technological limitations and low steel yield rates. Between the 1950s and 1990s, steel yield rates improved at an average annual rate of 0.5%. Taking this into consideration, it is estimated that the global steel demand growth rate from 1970 to 2000 was approximately 1.2%. It underscores the importance of considering technological progress when interpreting historical trends in steel production and consumption.

Global Steel Demand Forecast

In traditional methods of steel demand forecasting, the primary factors determining resource consumption are changes in population, economic growth and the pursuit of improved living standards. Over the past 70 years, international relations have gradually moved toward a state of relaxation, evolving through phases of peace, cooperation and harmony. Coupled with advancements in information and communication technologies, this has significantly reduced transaction costs associated with horizontal international division of labor and vertical disintegration of industrial chains, thereby promoting globalization.

However, the world is currently experiencing several significant mega-trends that are reshaping economies, societies and industries globally (see Fig. 6).

First, the rising geopolitical risks and trends of deglobalization have heightened the focus on supply chain security, leading to a global restructuring of supply chains, fragmentation of production capacity, and intensified supply constraints. Additionally, trade restrictions on critical materials and enhanced strategic reserves by various countries have resulted in increased investment demand for new production capacities and a rise in commodity demand.

At the same time, climate change presents both challenges and opportunities for the steel sector within the green energy domain, as the demand for new low-carbon energies such as wind, hydro and solar power significantly surpasses that of traditional energy sources. Furthermore, the development of low-carbon technologies heavily relies on the support of steel.

The impact of technological advancements on steel demand varies; while lightweight automotive designs reduce the demand for steel, high-strength steel expands its applications. Overall, the influence of technological progress on steel demand is considered positive.

In the context of unprecedented global changes, the restructuring of global supply chains, the rebuilding of safety stock in industrial chains, investments in energy transition and military preparedness are expected to drive the demand for global commodities, including steel, to grow at a pace exceeding potential growth rates.

The global demand forecast for crude steel utilizes the population projections provided by the United Nations.[3] For China's demand forecast, a baseline conclusion of the section titled China Crude Steel Demand Forecast has been adopted, assuming that per capita crude steel consumption outside of China will grow at a rate of 2.0% until 2040. After 2040, the growth rate of per capita crude steel consumption is expected to decline to 0.5%. Based on this, the forecasted crude steel consumption outside of China for 2050 is projected to be 1.79 billion tons, with an average annual growth rate of 2.1% (Table 1). The global crude steel consumption by 2050 is expected to reach 2.63 billion tons, with an average annual growth rate of 1.1% (Fig. 1).

Figure 5

Global crude steel production/consumption.

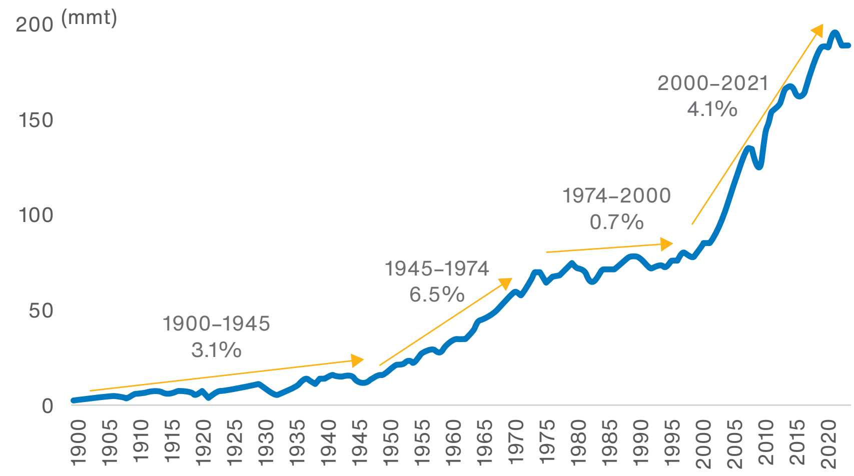


Figure 6

Global mega-trends.

Global Demand Forecast for Ferrous Raw Materials

The steel industry is characterized by high carbon emissions, with significant carbon footprints present from iron ore mining to steel production. This section explores the substantial changes expected in the demand and structure of iron ore, scrap and DRI to achieve carbon reduction targets. Global steel production is anticipated to reach 2.63 billion tons by 2050, corresponding to a global demand for iron ore of 2.34 billion tons, scrap consumption of 1.42 billion tons, and DRI demand of 510 million tons.

Given the lower carbon dioxide emissions associated with scrap, it is projected to become the preferred source of iron elements, though its consumption will be influenced by the availability of other iron-bearing resources. The total demand for iron ore can be estimated based on crude steel production and scrap consumption. In the context of future carbon reduction efforts, the structure of iron ore demand is expected to undergo significant changes, with DRI demand projected to grow rapidly from current levels. Due to the scarcity of high-quality iron ore, the supply of DRI may be constrained, leading to a significant supply-demand gap for DRI.

Review of the Composition of Global Ferrous Raw Materials

In 2023, global crude steel production reached 1.89 billion tons, with pig iron at 1.31 billion tons and DRI at 142 million tons, implying a consumption of 632 million tons of scrap. Pig iron constituted 63% of the iron elements, while DRI accounted for 7% and scrap for 30%. Compared to the year 2000, the proportion of pig iron increased by 2%, DRI increased by 2% and scrap decreased by 4% (see Fig. 7).

In China, crude steel production in 2023 was 1.019 billion tons, with pig iron at 871 million tons and an estimated consumption of 250 million tons of scrap. Pig iron's share of the iron elements was 78%, while scrap accounted for 22%. Compared to 2000, pig iron increased by 17%, and scrap decreased by 17%.

Globally, excluding China, crude steel production reached 869 million tons in 2023, with pig iron at 438 million tons and DRI at 136 million tons, resulting in an estimated consumption of 382 million tons of scrap. In this context, pig iron made up 46% of the iron elements, DRI accounted for 14% and scrap 40%. Compared to 2000, pig iron saw a decline of 10%, DRI increased by 9% and scrap rose by 1%.

From 2000 to 2023, the average annual growth rates for global crude steel, pig iron, DRI, and scrap were 3.5%, 3.6%, 5.1% and 3.6%, respectively. China contributed 86% of the global increase in crude steel, 101% of the pig iron increase, 76% of the scrap increase, while all DRI growth was contributed by overseas sources.

Scrap Supply and Demand Forecast

Scrap metal is currently the most recycled bulk commodity in the world and an important renewable resource. Properly recycling and utilizing scrap can not only reduce energy and raw material consumption for steel enterprises and decrease the emission of environmental pollutants, but also positively contribute to the green development process of the entire industry and the country.

Compared to using iron ore, for every ton of scrap used, steel enterprises can save 1.6 tons of iron ore, reduce coke consumption by 0.35 tons and lower carbon dioxide emissions by 1.6 tons and solid waste emissions by 3 tons. Increasing the usage ratio of scrap is beneficial for energy conservation, emissions reduction, circular economy and low-carbon development.

As the first step in reducing carbon dioxide emissions, steel producers can maximize the use of scrap in existing factories and implement electric arc furnace steelmaking processes that utilize mainly scrap as raw material, which is known to have the lowest carbon dioxide emissions among all existing steelmaking routes.

Methods for Predicting In-Use Steel Stock and Scrap Resource Volume: The volume of scrap resources refers to the amount of recyclable scrap, which primarily comes from self-generated scrap, processed scrap, obsolete scrap and imported scrap. This volume is influenced by various factors such as national crude steel production, yield rate, in-use steel stock and scrap recycling rate. Due to the dispersed sources of scrap and the lack of accurate statistical methods, predictions for self-generated and processed scrap typically use conversion coefficient methods, while obsolete scrap is often predicted using the "in-use steel stock conversion method" and the "steel product life cycle method." This article employs the in-use steel stock conversion method to forecast the volume of scrap resources globally and in China.

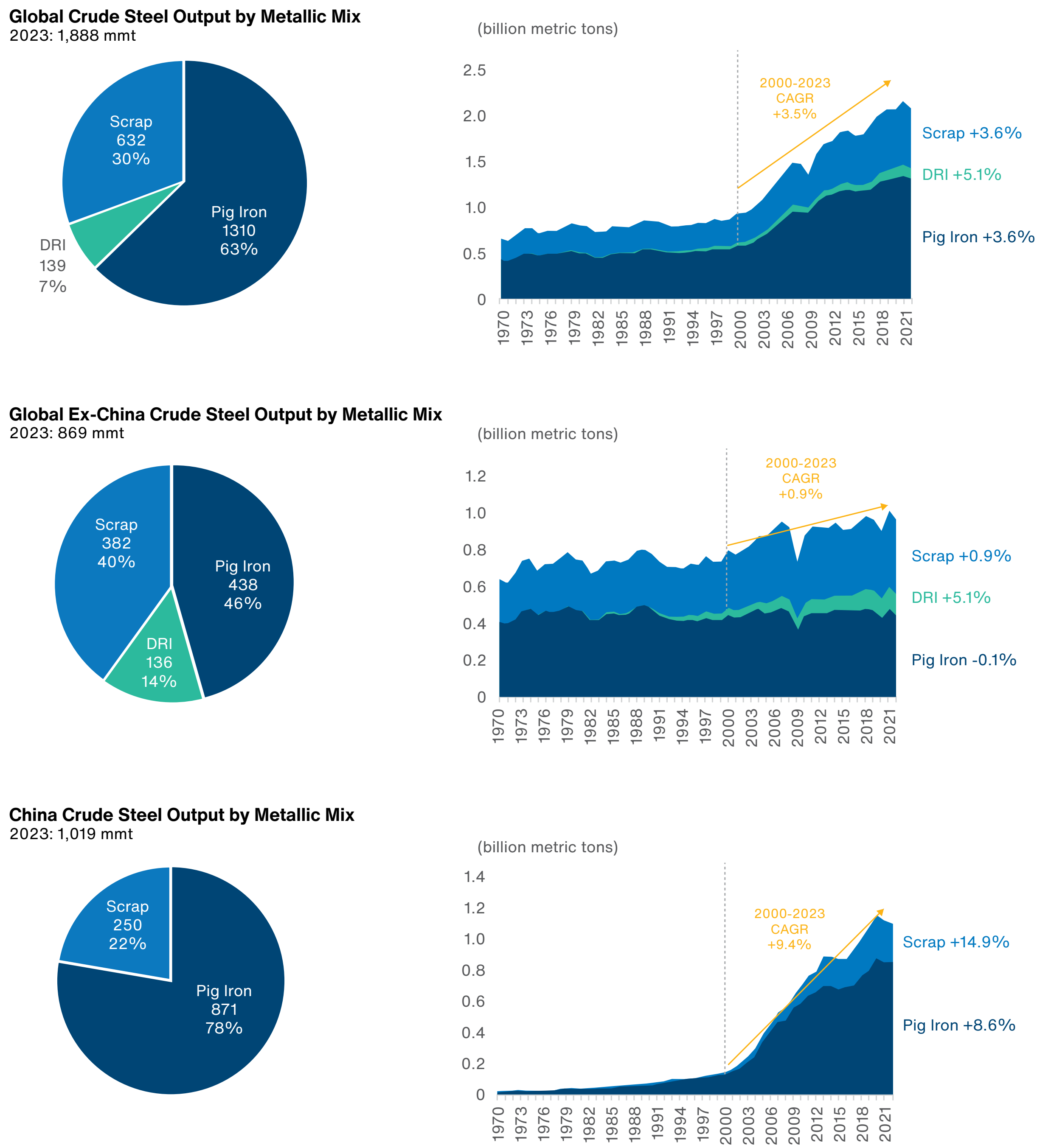
In-use steel stock refers to the total weight of all steel products in use within a country or region. The core of the in-use steel stock conversion method lies in determining an appropriate conversion coefficient, which depends on the "age" distribution of the steel products currently in service. In society's in-use steel stock, if most of the steel products in service are relatively "young," then the conversion coefficient will be lower; conversely, if most of them are "old," the coefficient will be higher. Based on data from countries like the United States and Japan, the global deprecation conversion coefficient is set at 1.2%, while for China, it is 1.4%, used to calculate future obsolete scrap resources.

The calculation of in-use steel stock can be accomplished using two primary methods: the first method involves field surveys of steel products and converting them into iron weight; the second method derives from calculating the new production volume over a certain period (such as a year) and accumulating this data. The first method requires substantial labor and costs, and it presents challenges in converting results into equivalent iron, with no comprehensive surveys conducted in Japan since the Science and Technology Agency conducted its last survey in 1983. The second method originates from the United States, specifically the Batelle Memorial Institute in 1957, and is currently utilized by the U.S., South Korea and Japan for estimating in-use steel stock.

The challenge of calculating national in-use steel stock lies in quantifying the indirect trade of steel in products. For global in-use steel stock, only steel production volume and total scrap consumption need to be considered. This article employs two fundamental formulas for calculating in-use steel stock. Eq. 1 addresses global in-use steel stock, while Eq. 2 focuses on country-level in-use steel stock. All variables in both equations are measured in million metric tons (Mt/year). This framework provides a comprehensive approach to track steel stock changes while accounting for various forms of steel flows in the material cycle.

Figure 7

Changes in the global composition of ferrous raw materials 1970–2023.



$$\text{Global in-use steel stock increment} = \text{Current year's total finished and semifinished steel production} - \text{Current year's obsolete scrap consumption} \quad \text{(Eq. 1)}$$

$$\text{A country's annual in-use steel stock increment} = \text{Current year's total crude steel production} - \text{Current year's net semifinished and finished steel product exports} - \text{Current year's indirect net steel exports in further manufactured goods} - \text{Current year's net obsolete scrap exports} - \text{Current year's steel scrap consumption} \quad \text{(Eq. 2)}$$

where scrap consumption encompasses all types of scrap: home scrap, prompt scrap and obsolete scrap. Indirect net steel exports account for the net export of steel embedded in manufactured goods (e.g., appliances, construction materials, automotive parts, and consumer goods).

The steel product life cycle method estimates the average useful life of various steel products, combining this with historical production or consumption data to project the volume of steel products that will be scrapped each year, which is then multiplied by the corresponding recovery rate. This method sums the recyclable scrap volumes of all categories to estimate the total volume of obsolete scrap resources for that year. The primary challenge lies in categorizing steel products and determining their average useful lives.

Prediction of Global In-Use Steel Stock and Scrap Resources: Based on the calculation formula for the increment of in-use steel stocks provided in the previous section, and using the predictions of crude steel production for the global, Chinese and global ex-China contexts outlined in the section titled China Crude Steel Demand Forecast, combined with historical data from the World Steel Association and research reports by Takamatsu Nobuhiko[4] and Hayashi Seiichi,[5] the following predictive conclusions regarding in-use steel stock levels, per capita in-use steel stocks, and the quantities of self-produced/processed/depreciated scrap resources have been derived (see Table 5):

- From 1870 to the end of 2023, the global in-use steel stock amounts to 38.9 billion tons, with a per capita in-use stock of 4.8 tons.
- In 2023, global crude steel production is projected to be 1.89 billion tons, with scrap consumption at 630 million tons, leading to an increase in steel stock of approximately 1.2 billion tons.
- Between 2000 and 2023, the global increase in in-use steel stock is expected to reach 22.5 billion tons, accounting for 58% of the total stock; this stock is anticipated to be converted into scrap within 20 to 40 years.
- By 2050, it is expected that the global in-use steel stock will reach 71.1 billion tons, resulting in a per capita stock of 7.3 tons, an increase of 2.5 tons from 2023, with an average annual increase of 0.09 tons.
- In 2050, the global crude steel production is forecasted to be 2.63 billion tons, with scrap consumption at 1.42 billion tons, representing 49% of the iron content.
- Of the 1.42 billion tons of scrap resources/consumption projected for 2050, depreciated scrap will account for 1.03 billion tons, which is 72%, an increase of 530 million tons compared to 498 million tons in 2023, with the percentage rising by 9%.

Global Iron Ore Demand Forecast

Based on the forecasts of global crude steel demand, in-use steel stock and scrap resources mentioned earlier, it is assumed that future global carbon reduction efforts will advance comprehensively, and carbon taxes will compel the steel industry to accelerate the development and utilization of scrap. This analysis does not consider any limitations that processing pathways might impose on scrap usage; rather, it aims to maximize the utilization of scrap resources. Consequently, the demand for iron ore, based on the difference between crude steel production and scrap resources, is estimated as follows (refer to Table 6):

- In 2023, global pig iron and DRI production is projected to be 1.452 billion tons (see Table 5 and Fig. 8), with iron ore consumption at 2.31 billion tons, where the contribution of iron elements constitutes 70%.
- By 2050, global production of pig iron and DRI is expected to reach 1.46 billion tons, corresponding to an iron ore demand of 2.34 billion tons, with the contribution of iron elements decreasing to 51% (see Fig. 9).

Global DRI Demand Forecast

DRI is produced by reducing iron ore or iron oxide pellets using a reducing agent at temperatures below their melting point, yielding a highly metallized iron product. DRI plays a crucial role in reducing energy consumption and carbon emissions in the steel industry, making

Table 5

Forecast of In-Use Steel Stock and Scrap Resources 2024–2050

	Crude steel production (mmt)			Scrap generation/ resources (mmt)			In-use steel stock (billion tons)			Per capita in-use steel stock (tons)		
Year	Global	China	Global ex-China	Global	China	Global ex-China	Global	China	Global ex-China	Global	China	Global ex-China
2000	850	129	722	317	10	306	16.4	1.7	14.6	2.7	1.4	3.0
2010	1,435	639	796	472	107	365	23.9	4.7	19.2	3.4	3.5	3.4
2020	1,882	1,065	817	644	282	361	35.1	10.5	24.5	4.5	7.4	3.8
2023	1,888	1,019	869	632	250	382	38.9	12.5	26.4	4.8	8.8	4.0
2025F	1,984	1,029	955	828	322	506	41.2	13.7	27.5	5.0	9.6	4.1
2030F	2,093	951	1,142	924	375	549	47.0	16.3	30.8	5.5	11.5	4.3
2035F	2,231	896	1,335	1,052	458	594	52.8	18.2	34.6	6.0	13.0	4.6
2040F	2,424	879	1,545	1,170	457	713	58.9	19.8	39.1	6.4	14.4	5.0
2050F	2,625	869	1,757	1,424	451	973	71.1	22.9	48.2	7.3	17.4	5.7
2023–2035F CAGR	1.4%	–1.1%	3.6%	4.3%	5.2%	3.7%	2.6%	3.2%	2.3%	1.7%	3.3%	1.3%
2035F–2050F CAGR	1.1%	–0.2%	1.8%	2.0%	–0.1%	3.3%	2.0%	1.5%	2.2%	1.4%	2.0%	1.4%
2023–2050F CAGR	1.2%	–0.6%	2.6%	3.1%	2.2%	3.5%	2.3%	2.3%	2.3%	1.5%	2.6%	1.4%

Figure 8

Forecast of global (a) and China's (b) in-use steel stock and scrap resources.

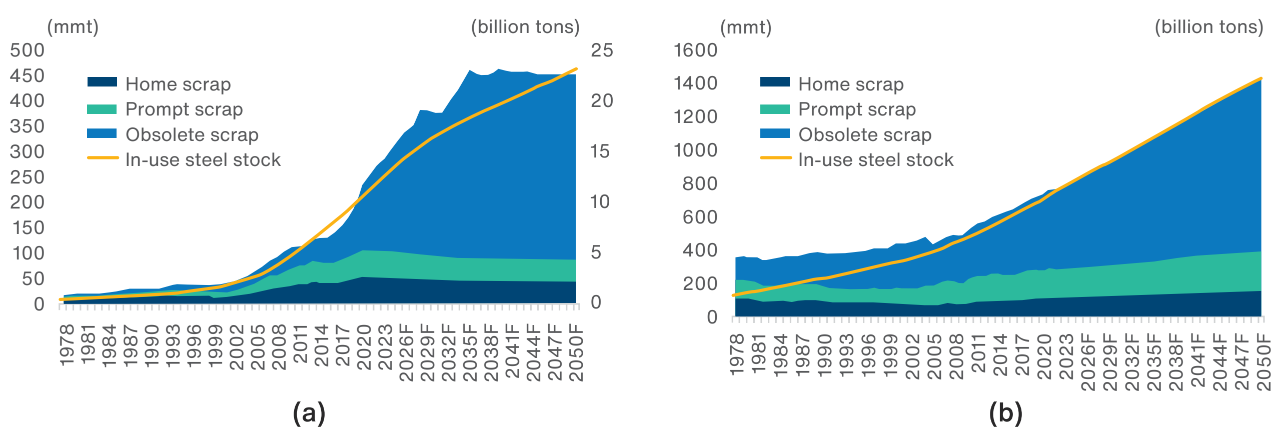


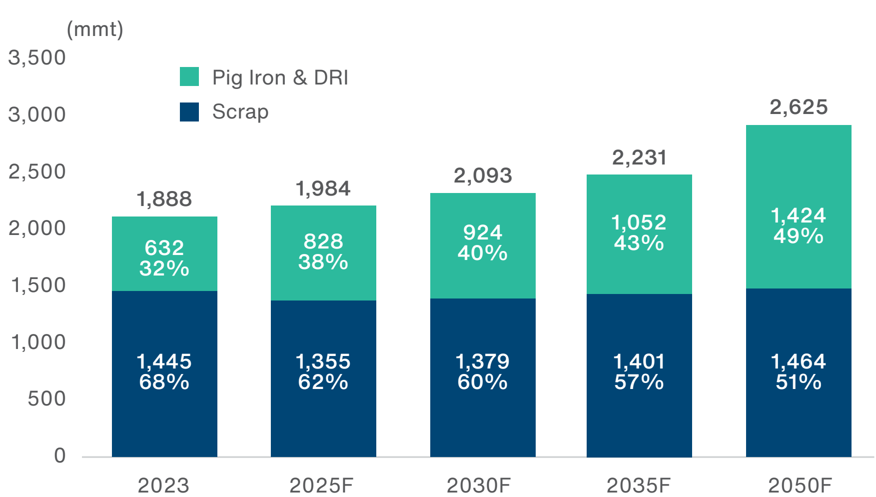
Table 6

Global Ferrous Element Demand Forecast 2024–2050

Year	Crude steel production (mmt)	Output of pig iron and DRI (mmt)	Scrap consumption (mmt)	Iron ore contribution	Scrap contribution	Iron ore demand (mmt)
2000	850	619	317	66%	34%	990
2010	1,435	718	351	45%	22%	1,148
2020	1,882	1,427	644	69%	31%	2,283
2023	1,888	1,445	632	70%	30%	2,312
2025F	1,984	1,355	828	62%	38%	2,167
2030F	2,093	1,379	924	60%	40%	2,206
2035F	2,231	1,401	1,052	57%	43%	2,242
2040F	2,424	1,496	1,170	56%	44%	2,393
2050F	2,625	1,464	1,424	51%	49%	2,342
2023–2035F CAGR	1,4%	–0.3%	4.3%	—	—	–0.3%
2035F–2050F CAGR	1.1%	0.3%	2.0%	—	—	0.3%
2023–2050F CAGR	1.2%	0%	3.1%	—	—	0%
2050F/2023	39.0%	1.3%	125.3%	—	—	—

Figure 9

Predictions of global ferrous element composition.

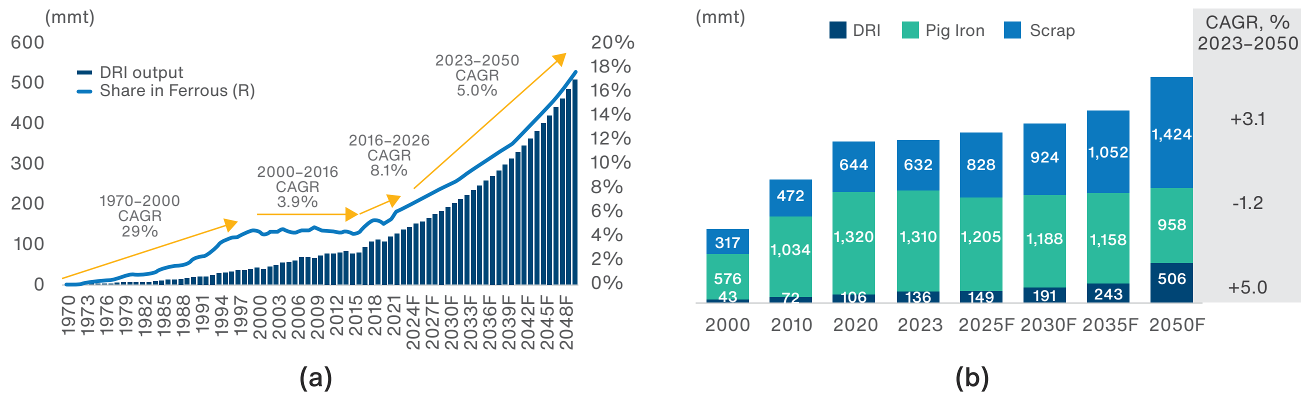


it a key raw material for promoting EAF steelmaking. In the future, the production of DRI using green hydrogen is expected to become an important decarbonization strategy.

The contribution of DRI to global ferrous supply began to increase in the 1970s, rapidly rising to approximately 4% around the year 2000. Although it continued to grow, its share fluctuated around 4.5% due to the development of the steel industry in China and resource endowments, until it experienced explosive growth starting in 2016. In 2023, the global production of DRI reached 136 million tons, contributing 6.5% to the global ferrous supply, achieving both record production and share levels. From 2016 to 2023, the

Figure 10

Global direct reduced iron demand forecast (a) and global ferrous raw materials demand forecast (b).



average annual growth rate of DRI was as high as 8.1%, with production increasing by 72% over seven years.

DRI plays a vital role in the current and future development of the steel industry, particularly in achieving energy savings, emissions reduction and green development, with significant growth potential. With breakthroughs in the technology to produce DRI from low-grade iron ore, it is expected that DRI production will continue to grow rapidly. Conservative estimates suggest that DRI demand will increase at a compound annual growth rate of 5.0%, reaching 510 million tons by 2050, with its contribution to ferrous supply reaching 18% (see Fig. 10). DRI is becoming a key area for the transformation and development of global steel enterprises, and its importance will increasingly become prominent.

Appendices: Steel Demand Forecasting: Methods, Improvements and Findings

Appendix 1 — Literature Review on Steel Demand Forecasting

The quest to accurately forecast steel demand has led to the development of several methods over the years, each with its own strengths and weaknesses. The literature on steel demand forecasting primarily includes traditional econometric methods, the Consumption Intensity (IU) method, the Steel Weighted Industrial Production (SWIP) calculation method, the in-use steel stock method, the inverted U-shaped curve, and the S-shaped demand curve principles.

Early attempts utilized Econometric Methods, pioneered by researchers like Labson et al. (1995)[6] and Pei and Tilton (1999),[7] which relied on historical data and economic indicators to model future demand. While these methods provided valuable insights, they often struggled to account for dynamic factors like technological advancements and material substitutions.

The Vector Autoregression (VAR) Model, introduced by Chen et al. (1991)[8] and later refined by Crompton (2000),[9] sought to address these limitations by incorporating multiple economic variables. However, the VAR model's reliance on past relationships can lead to unstable predictions when faced with unforeseen external shocks.

In the 1970s, the IU Method of Consumption Intensity, proposed by the International Iron and Steel Institute and championed by Malenbaum (1973, 1975), emerged as a powerful tool to analyze the relationship between economic development and steel consumption. This method's inverted U-shaped curve effectively illustrates the transition from steel-intensive growth to a more service-oriented economy.

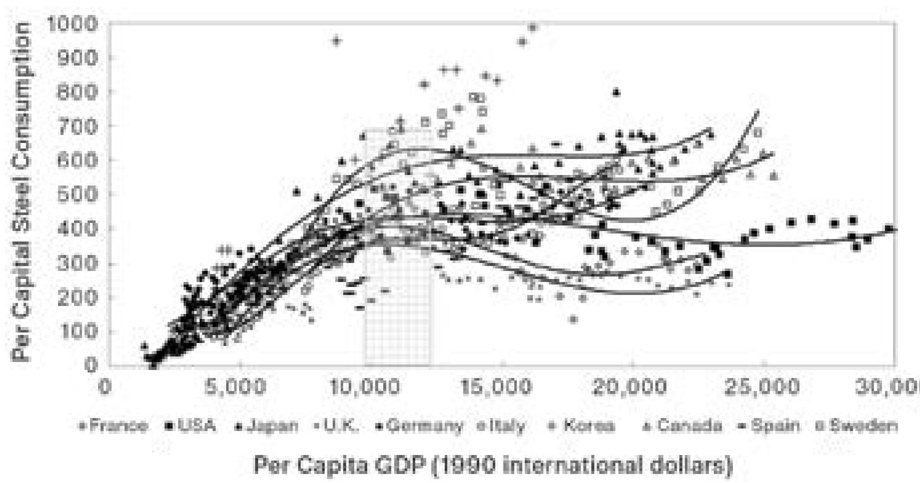
The turn of the millennium saw the rise of the SWIP method, promoted by the World Steel Association since 2007. This approach focuses on the weighted average of production indices for downstream industries, making it particularly effective in capturing short-term fluctuations in demand and inventory levels. However, accurately determining the weights assigned to different industries remains a significant challenge.

Meanwhile, researchers delved into long-term trends using the In-Use Steel Stock Method. Based on early estimates by Harrison S. Brown and further developed by scholars like Müller (2006, 2011[10]) and Pauliuk et al. (2012[11]–2013[12]), this method analyzes the relationship between economic growth and the accumulation of steel in use. While providing valuable insights into long-term dynamics, this approach requires extensive historical data and relies on assumptions about saturation points.

More recently, Chinese scholars, including Wang Anjian in 2010, proposed the S-Shaped Demand Curve Method. This method argues that resource consumption follows a predictable pattern across different stages of economic development, characterized by rapid growth followed by eventual decline. However, recent trends in China's steel consumption have challenged some of the method's predictions, highlighting the need for continuous refinement and adaptation of forecasting models in response to evolving global dynamics.

Figure A1

The S-Shaped Demand Curve.



Appendix 2 — Improvements to the S-Shaped Demand Curve Method and Key Findings

The Connotation of the Traditional S-shaped Demand Curve

The S-shaped demand curve principle, pioneered by Wang Anjian[13] and others,[14] indicates that the per capita consumption of crude steel exhibits three significant turning points across different countries (see Fig. A1):

- Launch Point: This marks the beginning of rapid growth in per capita steel consumption, typically occurring when per capita GDP reaches $3,000 (in 1990 international dollars). At this stage, the processes of industrialization and urbanization accelerate.
- Turning Point: This is the point at which the growth rate of per capita crude steel consumption reaches its maximum and begins to slow down, usually appearing when per capita GDP hits between $7,000 and $8,000. This phase corresponds to the peak of infrastructure development and the highest proportion of the secondary industry in GDP.
- Zero-Growth Point: As economic development progresses, urbanization improves, and infrastructure becomes more complete, steel demand peaks and enters a downward trend. The zero-growth point for per capita steel consumption generally occurs when per capita GDP reaches between $10,000 and $12,000. Following this, the market enters a post-plateau phase where per capita steel consumption remains high but experiences little to no increase.

Updates and Improvements to the Traditional S-Shaped Demand Curve

Using Steel Product Consumption to Replace Crude Steel Consumption, Reflecting Advances in Steel Production Efficiency: Due to the technological and equipment limitations in the early steel industry, there was a low yield of steel (see Fig. A2). Before 1990, steel product consumption was significantly lower than crude steel consumption (see Fig. A3). By adopting steel consumption in place of crude steel consumption

Figure A2

Steel yield in Japan from 1950 to 2022.

as a measure of steel demand, we can mitigate the effects of historical variations in steel yield, thus reflecting advances in steel production efficiency. This approach provides a more precise standard for long-term steel demand.

Taking Japan as an example, the per capita crude steel consumption peak of 814 kg occurred in 1973, surpassing the 801 kg recorded in 1990. However, the peak per capita steel product consumption of 751 kg was reached in 1991.

Using steel product consumption data as a substitute for crude steel consumption to assess the level of steel demand can mitigate the historical impact of variations in steel yield, thereby more accurately reflecting advancements in steel production efficiency. This approach provides a more precise benchmark for long-term steel demand forecasting.

Figure A3

Japan's per capita crude steel and steel product consumption from 1950 to 2022.

Replacing GDP Measured in 1990 International Dollars (GK$) With GDP Measured in 2017 International Dollars (GK$) for a More Accurate Assessment of Economic Development Levels: The GDP data used in the traditional S-curve analysis comes from the Groningen Growth and Development Centre (GGDC), which is based on 1990 benchmark international dollars (GK$). This article utilizes the GDP data series in 2017 benchmark international dollars (GK$) released by the GGDC in 2023 to update the S-curve model, replacing the 1990 GK$ GDP with the 2017 GK$ GDP. This adjustment allows for a more accurate evaluation of the economic development levels of countries worldwide.

Ensuring Consistency and Reliability of Analytical Data Using Consistent Source Data: This article strives to employ recognized, complete, and reliable official historical data series (Table A1) to replace and optimize previously used fragmented data from various sources, thereby ensuring the consistency and reliability of the analytical data.

Incorporating an Analysis of Indirect Imports and Exports to Reflect the Comprehensive Impact of International Trade on Steel Demand: The historical data on indirect imports and exports of steel from the World Steel Association is relatively short. Since 2009,

Table A1

Data Sources for the Report

Data type	Data source	Remarks
Population	United Nations	World Population Prospects 2022
Population of China	Yuwa Population Research, Liang Jianzhang, etc.	China Population Forecast Report 2023 Edition
GDP	Groningen Growth and Development Centre	PWT 10.01
Crude steel production/ consumption, steel product consumption	World Steel Association	
Steel yield rate	Japan Iron and Steel Federation, American Iron and Steel Institute	

the indirect net export ratio of steel in Japan and South Korea exceeded 30%, followed by a continuous decline thereafter. In contrast, Germany's ratio has maintained an upward trend, which explains why steel consumption in Germany has continued to grow even after its labor population ratio reached a peak.

Appendix 3 — Key Findings From the Improved S-Shaped Curve Analysis

Not All Countries Follow the Traditional S-curve in Their Steel Demand Development

This paper analyzes data on crude steel and steel product production and consumption from the World Steel Association and various national steel associations. The research process involved examining the economic and steel development histories of countries such as the United States, Japan, Germany and South Korea. Due to space limitations, these detailed historical analyses are presented in a separate report. The research reveals significant differences among these countries in their industrialization phases, policy orientations and economic development models. Notably, after considering the enhancement of steel yield, it is observed that only a few countries or regions exhibit steel product consumption patterns that align with the S-curve trajectory (see Fig. A4). Per capita steel product consumption varies across countries and shows different evolutionary paths, which can be broadly categorized into four main paths.

Traditional S-Curve With Lower Peaks: The United Kingdom and France underwent a prolonged industrialization process, reaching a per capita GDP of $20,000 (in 2017 GK dollars) when the per capita steel product consumption peaked at 300–400 kg. The United States experienced industrialization somewhat later, where a per capita GDP of $30,000 corresponded to a peak per capita steel product consumption of approximately 500 kg. During the post-industrialization period, these three countries saw a significant rise in the tertiary sector, with industries such as finance and services becoming key pillars of their economies, while the manufacturing sector's share declined. As the economic structure evolved, per capita steel product consumption in the United States fell to around 300 kg, while in the United Kingdom and France, it decreased to about 200 kg (see Fig. A5).

High-Peak S-Curve: The timing and pace of industrialization significantly influence peak per capita steel consumption across countries. Rapidly industrializing nations like Japan and South Korea have achieved notably higher peaks compared to early-industrialized Western countries.

In Japan, South Korea and Taiwan, per capita steel consumption reached extraordinary levels. Japan peaked at nearly 800 kg when its per capita GDP hit $30,000, while Taiwan, China reached 800-1,000 kg at $35,000. South Korea achieved the world's highest level, exceeding 1,100 kg at $40,000, largely driven by its robust shipbuilding industry (see Fig. A6). These exceptional levels can be attributed to two key factors: compressed industrialization periods and export-oriented economic policies, where limited domestic markets led to substantial indirect steel exports.

High Peak Platforms: The per capita steel product consumption in Germany, Italy, and Austria shows a fluctuating upward trend correlating with per capita GDP growth. When per capita GDP approaches $20,000, steel consumption peaks at 300–400 kg before experiencing a brief decline. Subsequently, as GDP continues to grow, consumption in Germany and Austria further increases to 400-500 kg, while Italy fluctuates between 300–600 kg (see Fig. A7).

These countries exemplify "High Peak Platforms" — a pattern characterized by sustained high levels of steel

Figure A4

Per capita GDP and per capita steel product consumption from 1950 to 2019.

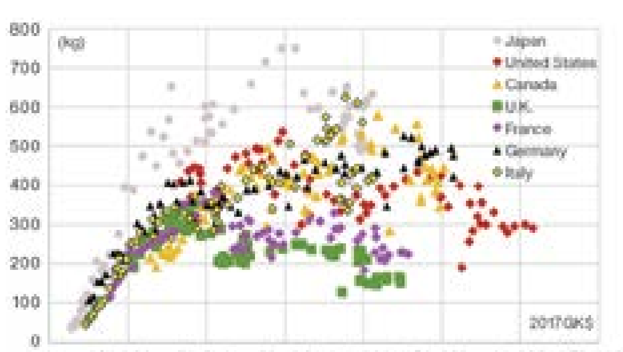


Figure A5

Average GDP and per capita steel product consumption in U.K. and U.S. from 1950 to 2019.

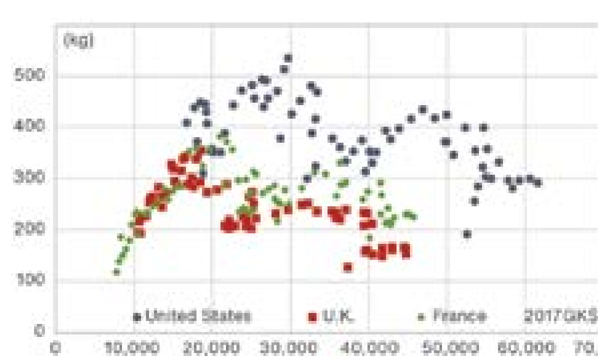


Figure A6

Per capita GDP and per capita steel product consumption in Japan, South Korea, and Taiwan, China from 1950 to 2019.

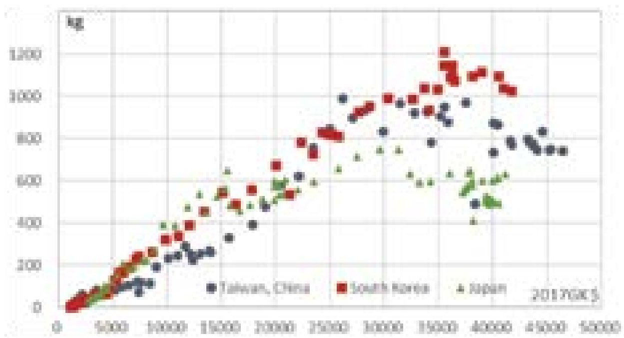
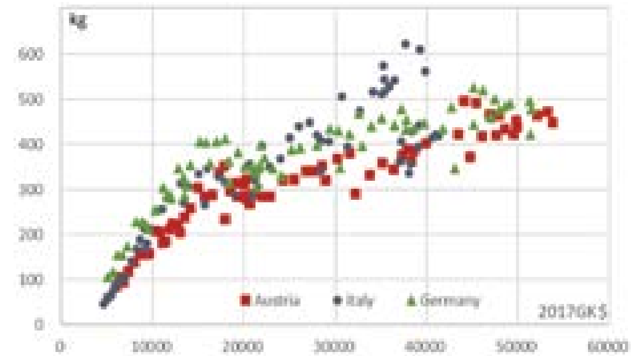


Figure A7

Per capita GDP and per capita steel products consumption in Austria from 1950 to 2019.

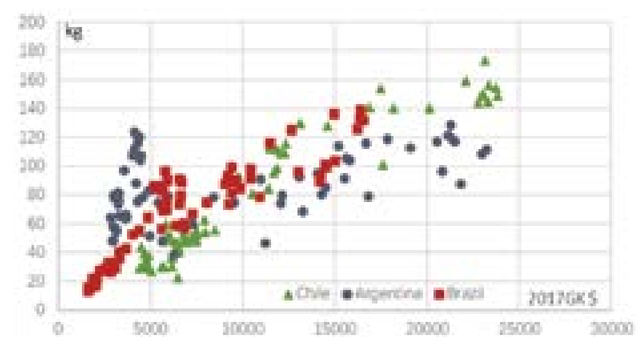


consumption post-industrialization. This phenomenon is primarily attributed to their continued emphasis on manufacturing development and industrial exports, enabling them to maintain elevated steel consumption levels even after initial peaks.

Persistently Low Levels: Countries in South America, such as Chile, Argentina, and Brazil, have encountered the middle-income trap during their development. Coupled with an inadequate industrial system, this has resulted in a low per capita steel product consumption rate, which has consistently remained around 100 kg (see Fig. A8).

Figure A8

Per capita GDP and per capita steel product consumption in South America from 1950 to 2019.



The Magnitude of Post-Peak Decline in Steel Demand Is Determined by Both Economic Structural Changes and Demographic Transitions

Changes in economic structure significantly affect the extent of decline following a peak. The per capita steel consumption in the United States has decreased much more than in other countries, largely due to the substantial transfer of American manufacturing to other nations and a higher share of the service sector in the economy. As a result, per capita steel consumption has fallen rapidly. However, the U.S. immigration policy has allowed the population to grow steadily over time, partially offsetting the decline in per capita consumption, leading to a relatively modest decrease in total steel consumption. In contrast, Japan faces a significant drop in domestic demand as its market size is notably small and its economy is highly dependent on external factors, exacerbated by the transfer of industrial chains. Germany benefits from its position within the large EU market, allowing its manufacturing sector to maintain stable output; thus, the decline in steel consumption is less severe than in Japan and the United States (see Table A2).

Table A2

Decline in Steel Consumption in 2022 Compared to Peak

Country	Overall decline (%)	Per capita decline ($)
U.S.	21	48
Japan	41	41
Germany	26	28
South Korea	13	18

Figure A9

Per capita crude steel and steel product consumption in Japan (a) and Germany (b) from 1950 to 2019.

(a)

(b)

Table A2

Steel Product Consumption and Per Capita Steel Consumption in Selected Countries

Country	Year range	Time period (years)	Steel product demand change (%)	Per capital steel product demand change (%)	Population change (%)	Steel product demand CAGR (%)	Per capita steel product demand CAGR (%)	Population CAGR (%)
USA	1973–1982	9	–38	–44	10	–2.5	–6.3	1.1
	1982–2000	18	75	42	24	3.2	1.9	1.2
	2000–2009	9	–51	–55	9	–7.6	–8.5	1.0
	2009–2014	5	81	73	4	12.6	11.6	0.9
	2014–222	8	–12	–16	5	–1.5	–2.1	0.6
Germany	1973–1982	9	–27	–26	–1	–3.4	–3.3	–0.2
	1982–2007	25	79	72	5	2.4	2.2	0.2
	2007–2022	15	–26	–28	3	–2.0	–2.2	0.2
Japan	1973–1982	9	–20	–26	8	–2.4	–3.3	0.8
	1982–1990	8	52	47	4	1.7	1.6	0.1
	1990–1998	8	–25	–26	2	–3.5	–3.7	0.2
	1998–2007	8	15	14	1	1.6	1.5	0.1
	2007–2022	15	32	–30	–3	–2.4	–2.4	–0.2
South Korea	2008–2022	14	–13	–18	7	–1.4	–1.4	0.5

Steel Demand Does Not Decline Linearly After Reaching Its Peak

Analysis of steel consumption patterns across developed economies reveals that post-peak demand does not follow a linear downward trajectory. Rather, the decline is characterized by periodic rebounds and fluctuations. This nonlinear pattern is particularly evident in the cases of Japan and Germany (see Fig. A9). The empirical evidence from these mature economies suggests that steel demand dynamics in the post-peak phase are more complex than simple linear decline models would indicate.

Steel Demand Rebounds by More Than Least 40% After 8–9 Years of Decline in Many Countries

After reaching their peak, steel consumption and per capita steel consumption in various countries generally undergo a continuous decline lasting 8 to 9 years. However, influenced by factors such as economic cycles, demographic shifts and changes in economic structure, some countries experience a rebound to a new plateau. Although this secondary peak is typically lower than the initial one, the rebound magnitude consistently exceeds 40% (see Table A3).

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