Lawrence Berkeley National Laboratory

LBL Publications

Title

Industrial Energy Intensity Benchmarking and Energy Transition in Inner Mongolia

Permalink

https://escholarship.org/uc/item/3st611zh

Authors

Lu, Hongyou
Zhou, Tianqi
Zhou, Nan

Publication Date

2023-06-01

Copyright Information

This work is made available under the terms of a Creative Commons Attribution-NonCommercial License, available at https://creativecommons.org/licenses/by-nc/4.0/

Peer reviewed

China Energy Program
Energy Technologies Area
Lawrence Berkeley National Laboratory

LBNL-2001513

Industrial Energy Intensity Benchmarking and Energy Transition in Inner Mongolia

Hongyou Lu, Tianqi Zhou, and Nan Zhou

June 2023

Disclaimer

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof, or the Regents of the University of California.

Lawrence Berkeley National Laboratory is an equal opportunity employer.

Copyright Notice

This manuscript has been authored by authors at Lawrence Berkeley National Laboratory under Contract No. DE-AC02-05CH11231 with the U.S. Department of Energy. The U.S. Government retains, and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for U.S. Government purposes.

Suggested citation:
Lu, H., T. Zhou, and N. Zhou. 2023. *Industrial Energy Intensity Benchmarking and Energy Transition in Inner Mongolia.* Lawrence Berkeley National Laboratory. Berkeley, CA. LBNL-2001513.

Industrial Energy Intensity Benchmarking and Energy Transition in Inner Mongolia

Hongyou Lu, Tianqi Zhou, and Nan Zhou

China Energy Program
Energy Technologies Area
Lawrence Berkeley National Laboratory
1 Cyclotron Road, MS 90R4000
Berkeley CA 94720-8136

June 2023

This work was supported by Energy Foundation under Lawrence Berkeley National Laboratory Contract No. DE-AC02-05CH11231 with the U.S. Department of Energy.

Contents

List of Figures

List of Tables

Acknowledgments

The authors would like to thank Tian Zhiyu and Xiong Huawen from the Energy and Research Institute of China, Jeff Wang from Greenworld (Beijing) Low-Carbon Economic-Technology Center, Prakash Rao, Lynn Price, and Vestal Tutterow of Lawrence Berkeley National Laboratory for their valuable contributions and review comments. This work was supported by Energy Foundation under Lawrence Berkeley National Laboratory Contract No. DE-AC02-05CH11231 with the U.S. Department of Energy.

List of Acronyms

BF	blast furnace
BOF	basic oxygen furnace
CCUS	carbon capture, utilization, and storage
CISA	China’s Iron and Steel Industry Association
CO_2	carbon dioxide
EAF	electric arc furnace
EI	energy intensity
FYP	five-year plan
GDP	gross domestic product
GHG	greenhouse gas
H_2	hydrogen
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
kgce	kilogram of coal equivalent
km	kilometer
kWh	kilowatt hour
MJ	megajoule
Mt	million tonnes
Mtce	million tonnes of coal equivalent
NBS	National Bureau of Statistics of China
NDRC	National Development and Reform Committee of China
PV	photovoltaic
PVC	polyvinyl chloride
RDP	regional domestic product
tce	tonnes of coal equivalent
TWh	terawatt hours
US DOE	United States Department of Energy
US EIA	United States Energy Information Administration
VA	value-added

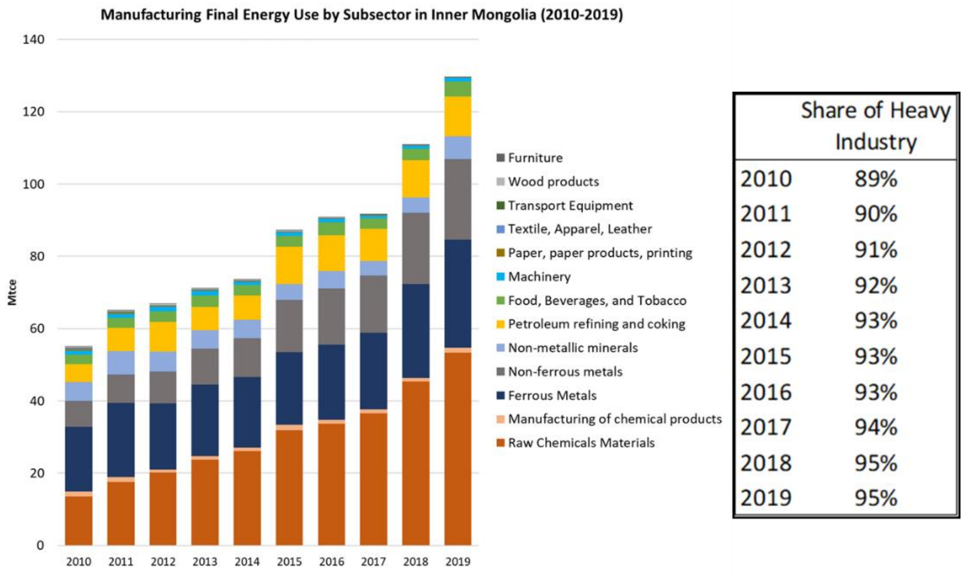
Executive Summary

The Inner Mongolia Autonomous Region (hereafter, Inner Mongolia) has significant energy resources in terms of coal, iron ore, wind, solar, and minerals. It is one of the major energy-producing provinces in China and will continue to play an important role in China’s energy transition. During the 13th Five-Year Plan (FYP) (2016–2020), Inner Mongolia failed to achieve its “Dual Control” targets, which included a required energy intensity reduction and a cap on increased energy consumption set by the central government. It is critical for Inner Mongolia to identify gaps and potential areas to improve its energy intensity.

The goals of this project are to provide technical analysis of the industrial sector in Inner Mongolia, including conducting energy intensity benchmark analysis in Inner Mongolia’s iron and steel industry and aluminum smelting industry, and providing information on major industrial corporations’ decarbonization commitments to inform Inner Mongolia’s long-term direction on carbon neutrality.

The industrial sector is the dominant driver of increasing energy use in Inner Mongolia, growing 12% per year on average from 2000 to 2020 and representing more than 80% of the total final energy use by 2020. Within the industrial sector, the share of contribution from the manufacturing sector has been increasing, reaching 60% of the total industrial final energy use by 2020. Production and supply of power, heat, and water, as well as the mining sector, accounted for 34% and 6%, respectively, in 2020.

Inner Mongolia’s manufacturing energy use is heavily concentrated in five subsectors: chemicals, ferrous metals, non-ferrous metals, non-metallic minerals, and petroleum refining and coking (Figure ES1). Collectively these five subsectors represented 95% of total manufacturing energy use in 2019 in Inner Mongolia, significantly higher than the Chinese national average, where the top five heavy industries contributed to 86% of total manufacturing energy use



	Share of Heavy Industry
2010	89%
2011	90%
2012	91%
2013	92%
2014	93%
2015	93%
2016	93%
2017	94%
2018	95%
2019	95%

Figure ES1. Manufacturing final energy use by subsector in Inner Mongolia (2010–2019)

Source: Inner Mongolia Autonomous Regional Bureau of Statistics 2022.
Notes: Mtce = million tonnes of coal equivalent; 1 Mtce = 29.31 PJ (10^{15} J) = 27.78 TBtu (10^{12} Btu)

Energy intensity benchmarking is a technical analysis that compares the industry's performance to industry averages, best practices, or prescribed indicators set in standards and guidelines (IEA 2021a). Energy intensity benchmarking can be a powerful tool to show the energy efficiency improvement potential. Conducting benchmarking regularly can also show how the industry or the facility has progressed over time.

Clearly defining the boundaries of each industry when conducting benchmarking comparisons is important. For iron and steel industry benchmarking, the following iron and steelmaking processes are included in the energy intensity benchmarking comparisons made in this report: coke making, pelletizing, sintering, ironmaking, steelmaking, casting, hot and cold rolling, and processing. All of the steel production in Inner Mongolia in 2017 (the latest year with available data) was primary steel, based on blast-furnaces and basic oxygen furnaces. Thus, we focused on primary steel energy intensity benchmarking in Inner Mongolia, and also compared its intensity to the Chinese industry average steel energy intensity that includes both primary and secondary steel production. For aluminum industry benchmarking, only primary aluminum smelting electricity use, excluding electricity consumption during starting up and shutting down of the smelters and other casting and finishing processes, is included in the electricity intensity benchmarking comparisons made in this report.

Defining the fuel and electricity conversion factors for benchmarking also plays an important role. This report uses China-specific fuel conversion factors, as fuel products vary in energy quality in different countries, because it is a higher priority to compare the performance of Inner Mongolia to China's national average and/or targets. For electricity conversion factors, this report uses the Direct Equivalent method that is used by the Intergovernmental Panel on Climate Change (IPCC).

A challenge of the benchmarking analysis is the lack of detailed energy use data for Inner Mongolia. The publicly accessible information only provides energy use data at the subsectoral level, but not at the level of a specific industry (e.g., iron and steel or aluminum smelting) or process (e.g., coking or ironmaking). Detailed energy use data after 2017 has been discontinued in the Inner Mongolia Yearbooks. Thus, this study used published 2017 data and made assumptions to calculate energy use at the specific industry level. The energy intensity benchmarking could be improved by having more detailed information for Inner Mongolia, such as energy consumption by energy source at the specific industry level rather than the subsectoral level, and energy use data by energy source at the process level (e.g., ironmaking, steelmaking, and primary aluminum smelting).

For primary steel production in Inner Mongolia, we found that the energy intensity was in the range of 632–737 kilograms of coal equivalent per tonne (kgce/t[1]) (18.5-21.6 GJ/t), varying depending upon the assumptions of ferroalloy energy intensity (Figure ES2).

---

[1] 1 kgce = 0.02937 gigajoule (GJ), https://www.iea.org/data-and-statistics/data-tools/unit-converter

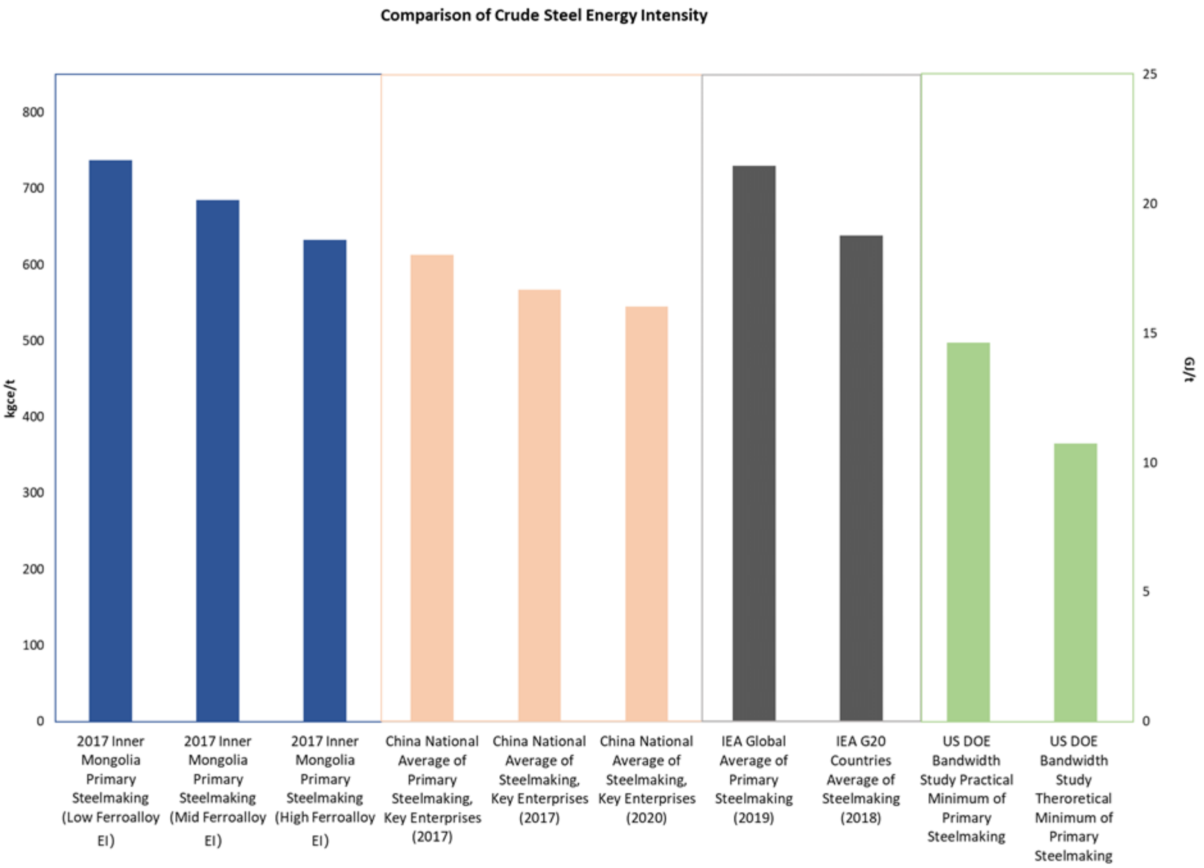


Figure ES2. Crude steel energy intensity in Inner Mongolia compared to the Chinese average, global average, and practical and theoretical minimum intensities.

Compared to the 2017 China national average of primary steel production in key enterprises, Inner Mongolia’s average crude steel energy intensity was 3–20% higher (Editorial Board of China Steel Yearbook 2017). Compared to the global average of primary steel intensity, Inner Mongolia’s performance ranges from 13% lower (in the High Ferroalloy EI assumption) to 1% higher (in the Low Ferroalloy EI assumption) (IEA 2020). Compared to the practical minimum energy intensity, which assumes the adoption of all R&D technologies under development worldwide, published in the U.S. DOE’s bandwidth study (US DOE 2015), Inner Mongolia’s primary steel industry is 27-48% higher.

Inner Mongolia’s average steel energy intensity is even higher when compared to an overall energy intensity that includes both primary and secondary steel production, or about 12-30% higher than China’s national average of the key enterprises.

The results show that Inner Mongolia has significant potential to reduce its steel energy intensity. The local and central government can use a range of policy measures, such as regulatory requirements to conduct energy assessments and energy-efficiency retrofits, fiscal and financial incentives, and information on technologies and practices, to promote the adoption of energy-efficiency technologies in the steel industry. As the country and Inner Mongolia look to decarbonize the economy and achieve its climate goals before 2060, it is also critical to support low-carbon steelmaking technologies, such as scrap-based secondary steel production and green hydrogen-based direct reduction of iron processes.

For primary aluminum smelting in Inner Mongolia, we estimate that the electricity intensity for 2017 was in the range of 13,396–13,950 kilowatt-hours per tonne (kWh/t), as shown in Figure ES3.

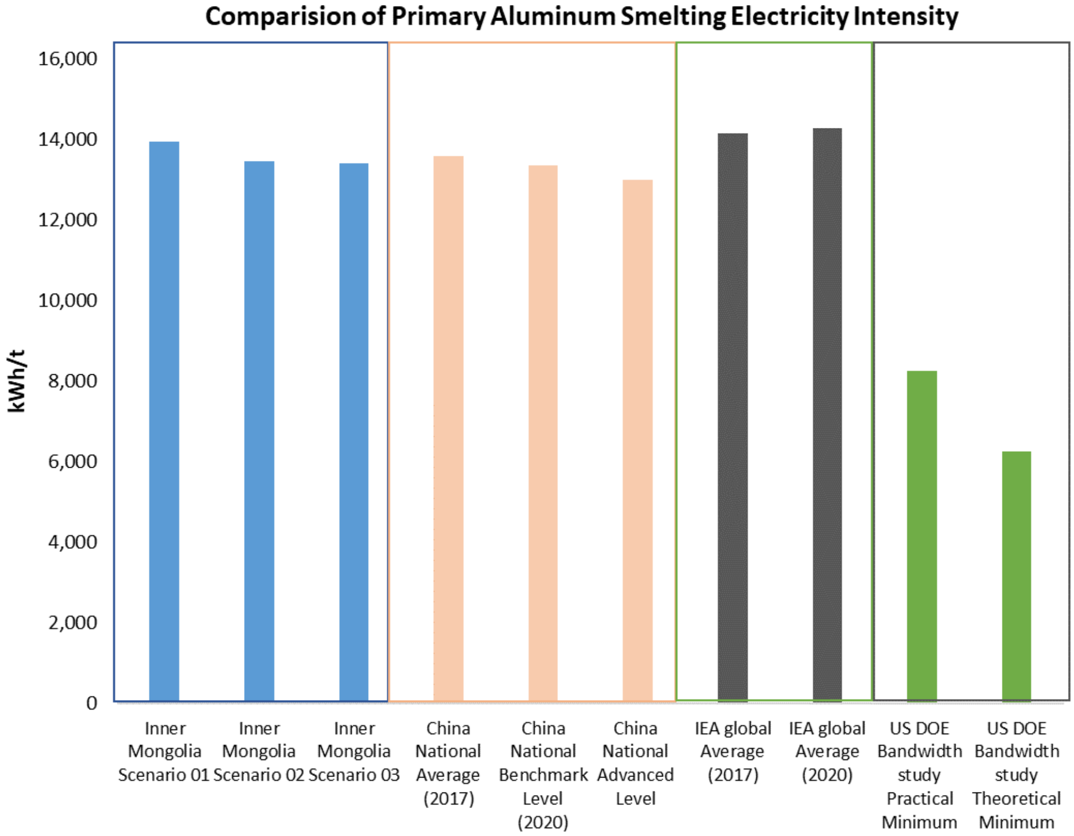


Figure ES3. Primary aluminum smelting electricity intensity in Inner Mongolia compared to the Chinese average, global average, and practical and theoretical minimum intensities.

Compared to the 2017 China national average of primary aluminum smelting (Wang 2021), Inner Mongolia's aluminum smelting electricity intensity is comparable, in the range of 1.3% lower (Scenario 03) and 2.7% higher (Scenario 01)[2]. Compared to the recently announced domestic benchmark and advanced electricity intensity levels on primary aluminum smelting (National Development and Reform Commission 2021a), Inner Mongolia's primary aluminum smelting electricity intensity is 0.3-4.5% higher than the national benchmark level, and 3-7.3% higher than the advanced level.

Compared to the global average electricity intensity of primary aluminum smelting (IEA 2022a), Inner Mongolia's electricity intensity is about 1.5-4.5% lower. But compared to the practical

---

[2] Please see Section 4.4 (Table 19) for details on the scenarios.

minimum electricity intensity (US DOE 2017), Inner Mongolia's intensity is significantly higher (more than 60% higher).

The results show the Inner Mongolia's primary aluminum smelting electricity intensity is comparable to the national average. Its electricity intensity can be further improved by increasing the share of recycled aluminum production. Policies on improving recycling collection and sorting, connecting participants along the supply chain, and implementing extended producer responsibility schemes could be considered (IEA 2022b). In addition, innovations (e.g., inert anodes in smelting and electric calcination in the alumina refining process) are being developed and piloted in the aluminum industry, specifically addressing process emissions from the smelting process. Inner Mongolia and the Chinese aluminum industry could invest in R&D and demonstrations of these technologies to achieve China's net-zero climate goal.

Energy intensity benchmarking is the first step to identifying potential energy-saving and emission-reduction potentials. It can be followed up with more detailed energy assessments, retrofits, and/or adopting energy-efficient and low-carbon technologies. In addition to industry-wide energy-intensity benchmarking, plant-level and process-level energy-intensity benchmarking can be conducted.

Many commercialized and cost-effective technologies and measures can be taken to improve the energy performance in the steel and aluminum industries in Inner Mongolia. China's national program on industrial energy efficiency, benchmarking, retrofit incentives, and financing models (e.g., energy service companies) since the 11th Five-Year Plan can be utilized as a model for local jurisdictions in Inner Mongolia. Technology guides, catalogues, and software tools have been published by various institutions, such as China's technology guides on industrial energy-conservation and emission reduction[3], catalogues on energy-efficiency[4], low-carbon[5], and clean production[6], industry tools developed by the Lawrence Berkeley National Laboratory[7], Energy Guides provided by the U.S. Energy Star program[8], and the Bandwidth Studies developed by the U.S. Department of Energy[9].

In addition, technical support on data analysis, capacity building to train energy managers at the plant-level, dissemination of best practices on how to implement and scale-up energy efficiency technologies, and policy guidance and incentives to support heavy industry's decarbonization are needed at the local level.

---

[3] National Development and Reform Committee of China, 2022. *Energy-Conservation and Emission Reduction Upgrade Implementation Guides for Energy-Intensive Industries.* https://www.ndrc.gov.cn/xxgk/zcfb/tz/202202/t20220211_1315446.html

[4] National Development and Reform Committee of China, 2014. *National Key Energy-Saving Technology Promotion Catalogues. https://www.ndrc.gov.cn/hdjl/yjzq/201412/t20141217_1165920.html*

[5] Ministry of Ecology and Environment of China, 2022. *National Low-Carbon Technology Catalogue (2022).* https://www.mee.gov.cn/xxgk2018/xxgk/xxgk06/202212/t20221221_1008424.html

[6] Ministry of Ecology and Environment of China, 2022. *National Advanced Technology Catalogue for Clean Production (2022).* https://www.mee.gov.cn/xxgk2018/xxgk/xxgk06/202301/t20230113_1012738.html

[7] Lawrence Berkeley National Laboratory, no date. *Industry Tools*: https://energyanalysis.lbl.gov/tools

[8] U.S. Energy Star, no date. *Energy Guides*: https://www.energystar.gov/industrial_plants/improve/energy-guides

[9] U.S. Department of Energy, no date. *Manufacturing Energy Bandwidth Studies*: https://www.energy.gov/eere/iedo/manufacturing-energy-bandwidth-studies

1. Introduction

1.1 Background

The Inner Mongolia Autonomous Region (hereafter, Inner Mongolia) is one of the major energy-producing provinces in China. With significant resources in coal, iron ore, wind, solar, and mineral resources, it plays and will continue to play an important role in China's energy transition.

During the 13th Five-Year Plan (FYP) (2016–2020), Inner Mongolia failed to achieve its "Dual Control" targets. "Dual Control" targets are set by the central government for each of the provinces and regions. The targets include a required percentage reduction in economic energy intensity (energy consumed per unit of value-added), as well as a limit on how much additional energy can be consumed during the five-year period. It is a key policy instrument that the Chinese government uses to achieve its energy and climate goals.

For Inner Mongolia, China's central government required the region to reduce its overall energy intensity by 14% compared to 2015, cap its energy increase at 35.7 million tonnes of coal equivalent (Mtce) by 2020, and limit its total energy use at 225 Mtce by 2020 (State Council 2017). However, by 2019, Inner Mongolia's economic energy intensity did not decrease; it increased by 9.5%. Inner Mongolia's total energy use increased by 66 Mtce, reaching a total of 253 Mtce, failing significantly in both of its "Dual Control" targets, as shown in (National Development and Reform Commission 2020).

Table 1. Inner Mongolia's 13th FYP Dual Control Targets Performance Compared to Actual

Dual Control	Target	Actual (as of 2019)
Energy Intensity Reduction	14% reduction from the 2015 level	9.5% increase from the 2015 level
Maximum Energy Increase	35.7 Mtce	66 Mtce

Sources: State Council 2017 and National Development and Reform Commission 2020.

In September 2020, President Xi Jinping announced that China would peak its carbon dioxide (CO_2) emissions before 2030 and achieve carbon neutrality before 2060 (Xinhua Net 2020). This pledge sent a strong message to transition the current way of energy supply and consumption to be more energy-efficient and low-carbon in all sectors of the economy and all provinces.

Achieving carbon neutrality, especially in hard-to-abate sectors such as industry, requires a multifaceted approach, including improvement of energy efficiency and material efficiency to reduce demand, increasing electrification (supported by a decarbonizing power sector), switching to low-carbon/green fuels, and implementing carbon capture, utilization, and storage (CCUS).

As shown in Table 2, many energy-efficiency measures are already commercialized and provide cost-effective energy-saving and emission-reduction impacts. These measures include component and system energy efficiency improvement, e.g., energy-efficient combustion systems, steam systems, pumps, fans, compressed air, and motor systems; smart energy management systems enabled by digital technologies and energy management systems; and waste heat recovery measures to maximize energy utilization.

For Inner Mongolia’s industry sector, these energy-efficiency measures and practices can be implemented in the near term and support the goals of the 14th Five-Year Plan (2021–2025) and China’s carbon peaking goals. Such implementation can also develop local capacity and the workforce in industrial energy efficiency to support Inner Mongolia’s long-term energy transition.

Table 2. Decarbonization pillars for the industrial sector

Technology Maturity	Demand Reduction	Energy Efficiency	Electrification	Fuel Switching and CCUS
Commercial, cost-effective	Produce higher quality, high performance, and longer-life products	Component (e.g., boilers, furnaces) and system energy efficiency (process heating systems, steam systems, compressed air systems)	High-efficiency electric heating (e.g., arc furnaces, induction furnaces)	Biomass for feedstocks and low-/high-temperature heat
	Increase post-consumer scrap recycling and collection rates	Smart energy management		Solar thermal
		Waste heat recovery and use		Geothermal
Commercial but not yet widely adopted	Material substitution	Integrative design	Expand electricity end-use applications (e.g., electrify industrial heat processes)	Carbon capture, utilization, and storage
	Alternative cement chemistries			
	Prefab construction		On-site or grid power generation using solar photovoltaic (PV) and wind turbines	
	Additive manufacturing / 3D printing			
Piloted but not commercialized	Alternative cement chemistries		Electrified manufacturing processes* (e.g., electrified cement kilns, electrolysis of iron ores)	Hydrogen as a feedstock or fuel

Note: * in R&D stage

1.2 Project Goal

The goal of the project is to provide technical analysis to the industry sector in Inner Mongolia, including conducting energy-efficiency benchmark analyses in some of the most energy-intensive industries in Inner Mongolia (iron and steel production and aluminum smelting), and provide information on major industrial corporations’ decarbonization commitments to inform Inner Mongolia’s long-term direction on carbon neutrality.

To support this goal, the project conducted quantitative energy intensity benchmarking in the steel and aluminum industries in Inner Mongolia, based on industry reports, peer-reviewed journals, research reports, and publicly accessible energy statistics released by the China and Inner Mongolia’s statistic bureaus. The project also summarized the decarbonization commitments of international companies in the steel, aluminum, and chemical industries to provide a qualitative benchmark to Inner Mongolia in terms of long-term directions on carbon neutrality.

This project report is organized as follows: Section 2 provides important background information on Inner Mongolia, including its natural resources, energy production, and industrial sector. Section 3 discusses China’s 14th Five-Year Plan and carbon neutrality policies, both at the national and provincial levels. Section 4 provides the methodology, calculations, assumptions, and results of energy intensity benchmarking of the steel and aluminum industries and compares the performance of Inner Mongolian industries to the national average, as well as to international values. Section 5 summarizes decarbonization commitments from Chinese and international companies in key industries.

Appendix A provides a summary of China’s industrial sector for readers interested in comparing Inner Mongolia’s situation to China’s national situation. Appendix B provides the references used in Section 5.

2. Understanding Inner Mongolia’s Energy Landscape

2.1 Inner Mongolia: Significant Natural Resources

Inner Mongolia is the third-largest province by landmass in China, accounting for 12.3% of China’s total land area (NBS 2021), after only Xinjiang and the Tibet Autonomous Regions. Inner Mongolia is rich in natural resources, especially coal, natural gas, iron ore, and rare-earth elements such as niobium, zirconium, and beryllium.

As shown in Table 3, Inner Mongolia has the second-largest coal reserves (32.7 billion tonnes), the fourth-largest iron ore reserves (16.12 billion tonnes), and the fifth-largest natural gas reserves (988.8 billion cubic meters) in China (Ministry of Natural Resources of China 2022). In addition, more than 80% of the world’s total and 90% of China’s total rare-earth metal reserves are located in Inner Mongolia (Guo 2013). It also has large reserves of ferrous metals, non-ferrous metals, precious metals, and non-metallic minerals.

Table 3. Basic statistics and natural resources in Inner Mongolia

	Value (2020)	**Unit**	**% of China**	**Ranking (out of 31 Provinces)***
Landmass	1.2	million km^2	12.3	3
Population	24.03	million	1.7	24
Regional Domestic Product (RDP)	1,736	billion yuan (2020 prices)	1.7	22
Income per capita	72,062	yuan (2020 prices)	102**	11
Coal reserves***	32.7	billion tonnes	15.7	2
Oil reserves ***	100.5	million tonnes	2.7	8
Natural gas reserves ***	988.8	billion cubic meters	15.6	4
Iron ore reserves ***	16.12	billion tonnes	7.9	5

Sources: NBS 2021; Inner Mongolia Autonomous Regional Bureau of Statistics 2022; Guo 2013; Ministry of Natural Resources of China 2022.
*include provinces, autonomous regions, and provincial-level municipalities. ** Percentage of the national average.
*** 2021 data

Compared to many coastal provinces, Inner Mongolia is not densely populated. As of 2020, Inner Mongolia has a total population of 24.03 million people, or 1.7% of the country’s total (Table 3). Similar to the national trend, rapid urbanization took place in Inner Mongolia over the last two decades. The share of the urban population increased from 42% in 2000 to 67% by 2020, 5% higher than the national average as of 2020. However, the Inner Mongolia population has been slightly declining since 2011, at about -0.3% per year on average from 2010 to 2020 (as shown in Figure 1).

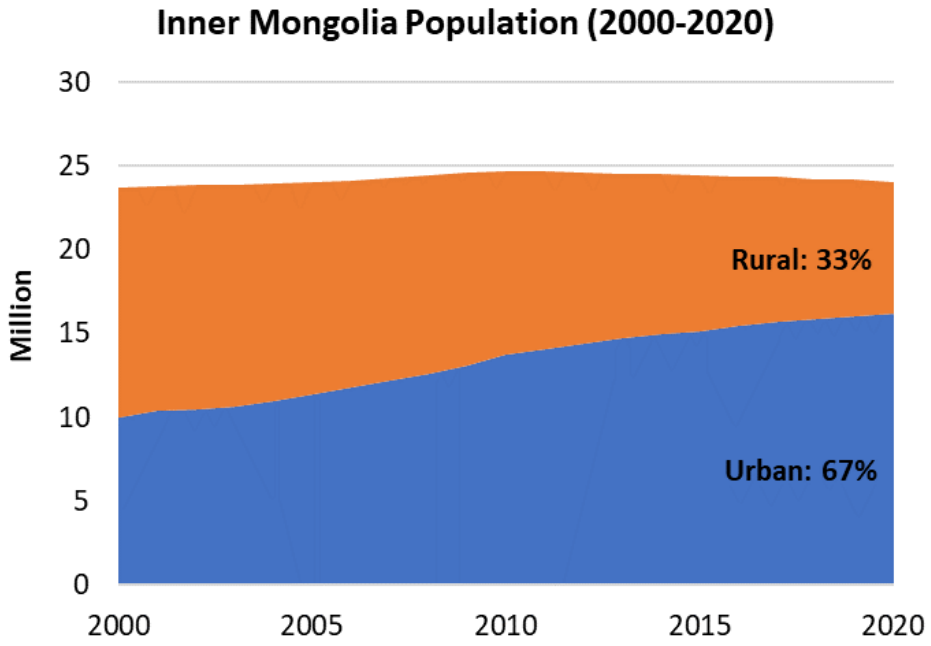


Figure 1. Inner Mongolia population (2000–2020)

Sources: NBS 2021; Inner Mongolia Autonomous Regional Bureau of Statistics 2022.

For Inner Mongolia itself, the energy demand driven by urbanization (e.g., constructing buildings, roads, sanitation systems, heating systems, and other energy and infrastructure systems) may have a relatively short-term impact—as the buildings and infrastructure may last for decades after they are developed. The declining overall population may have an offsetting effect on future energy demand over the long term.

From 2000 to 2005, Inner Mongolia experienced skyrocketing economic growth, with the regional domestic product (RDP) growing at 20% per year on average (Inner Mongolia Autonomous Regional Bureau of Statistics 2022), much faster than the national average of 9% per year during the same period, due to a combination of national factors (e.g., China joining the World Trade Organization in 2001) and the rapid growth of local industries (e.g., mining, coking, and manufacturing industries in Inner Mongolia).

From 2006 to 2015, Inner Mongolia had a relatively slower economic expansion; however, it still grew 14% per year on average, exceeding the national average of 10% annually (see Figure 2). After 2015, Inner Mongolia's economy slowed, increasing only 4% per year on average, driven by an overall slower national economy ("mini-recession") and COVID-19 impacts since 2020.

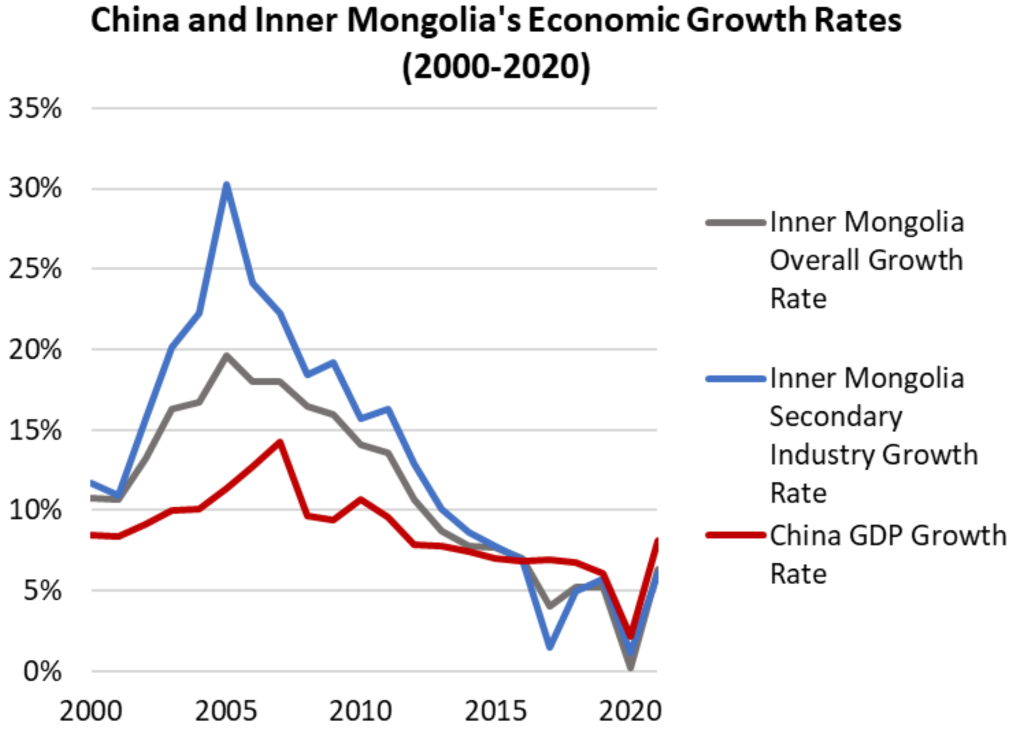


Figure 2. China and Inner Mongolia's economic growth rates (2000–2020)

Sources: NBS 2021; Inner Mongolia Autonomous Regional Bureau of Statistics 2022.

Industry plays a significant role in Inner Mongolia's local economy. As shown in Figure 3, the contribution to RDP from the secondary industry—which includes mining, manufacturing, construction, and production and distribution of power, heat, gas, and hot water—increased from 37% in 2000 to 46% in 2021 (Inner Mongolia Autonomous Regional Bureau of Statistics 2022). Interestingly, before COVID-19, the share of the secondary industry slightly declined from a higher share of 44% in 2012 to 39% in 2019. However, after 2020 it seems that the secondary industry "came back" with faster growth, compared to the primary and tertiary sectors.

During the 12th and 13th Five-Year Plans (2011–2015 and 2016–2020, respectively), the Chinese central government encouraged economic structural change. This included transitioning away from energy-intensive industry sectors to higher value-added manufacturing sectors, moving away from manufacturing to services sectors, and setting a target of increasing the share of tertiary sector contribution to national GDP to 56% by 2020. Based on the Chinese statistical boundaries, the primary sector includes agriculture, forestry, farming, and fishing; the secondary sector includes manufacturing, construction, and production and distribution of power, heat, gas, and hot water; and the tertiary sector includes services. Compared to the national trend in China where the share of tertiary sector has increased from more than 40% to 52% by 2020, it seems that Inner Mongolia is lagging behind. The share of the tertiary sector has been relatively flat (at around 40% of total regional domestic product), and decreased in both 2020 and 2021 (Figure 3).

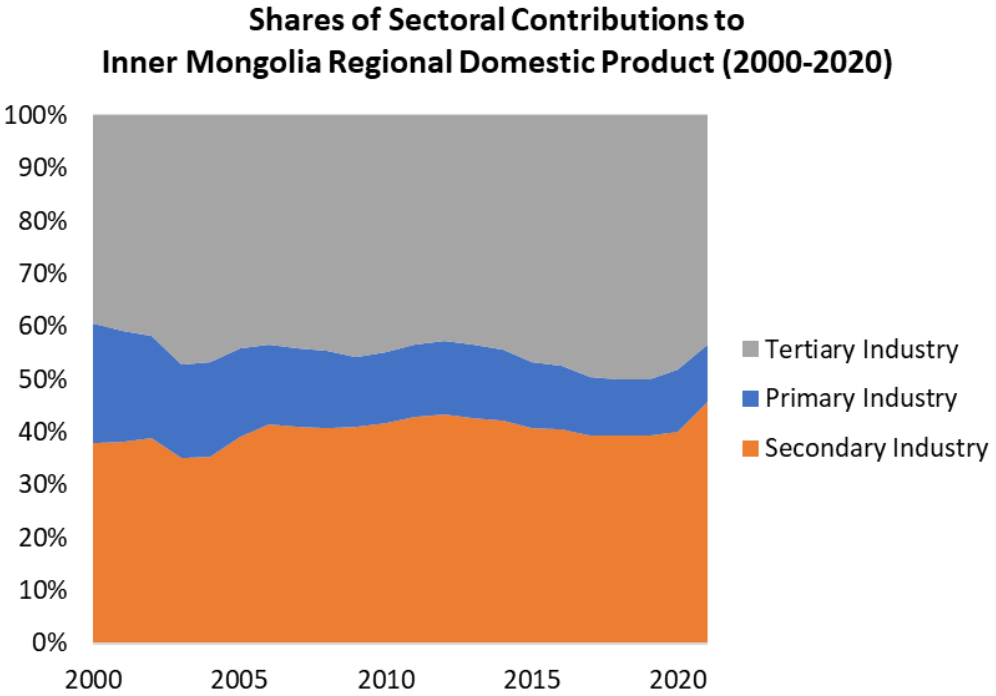


Figure 3. Shares of sectoral contributions to Inner Mongolia Regional Domestic Product

Sources: NBS 2021; Inner Mongolia Autonomous Regional Bureau of Statistics 2022.

Note: The primary sector includes agriculture, forestry, farming, and fishing; the secondary sector includes manufacturing, construction, and production and distribution of power, heat, gas, and hot water; and the tertiary sector includes services.

2.2 Inner Mongolia: A Key Energy Producer

Inner Mongolia plays an important role in China's energy supply system, as shown in Table 4. As of 2020, Inner Mongolia produced about 1,026 million tonnes (Mt) of coal and 472 Mt of coke. It was the second-largest coal producer (only after Shanxi Province) and the fourth-largest coke producer (after Shanxi, Shaanxi, and Hebei Provinces) in China (NBS 2022).

Table 4. Energy production in Inner Mongolia

	Value (2020)	% of China	Ranking (out of 31 Provinces)*
Coal production	1,025.51 Mt	26	2
Coke production	471.89 Mt	9	4
Thermal power generation	484.12 TWh	9	1
Wind power generation	72.63 TWh	15.6	1
Solar power generation	18.61 TWh	7.1	2

Source: NBS 2022.

*include provinces, autonomous regions, and provincial-level municipalities.

Inner Mongolia produced more than 1 billion tonnes of coal in both 2019 and 2020, accounting for more than a quarter of China's production. During 2010–2015, Inner Mongolia's annual coal production grew 3% per year, but accelerated and grew to about 5% per year during 2016–2020 (Figure 4). Coke production in Inner Mongolia followed a similar trend, growing 8.4% per year on average from 2010–2015, and production continued to grow at about 11% per year during 2016–2020 (Figure 5).

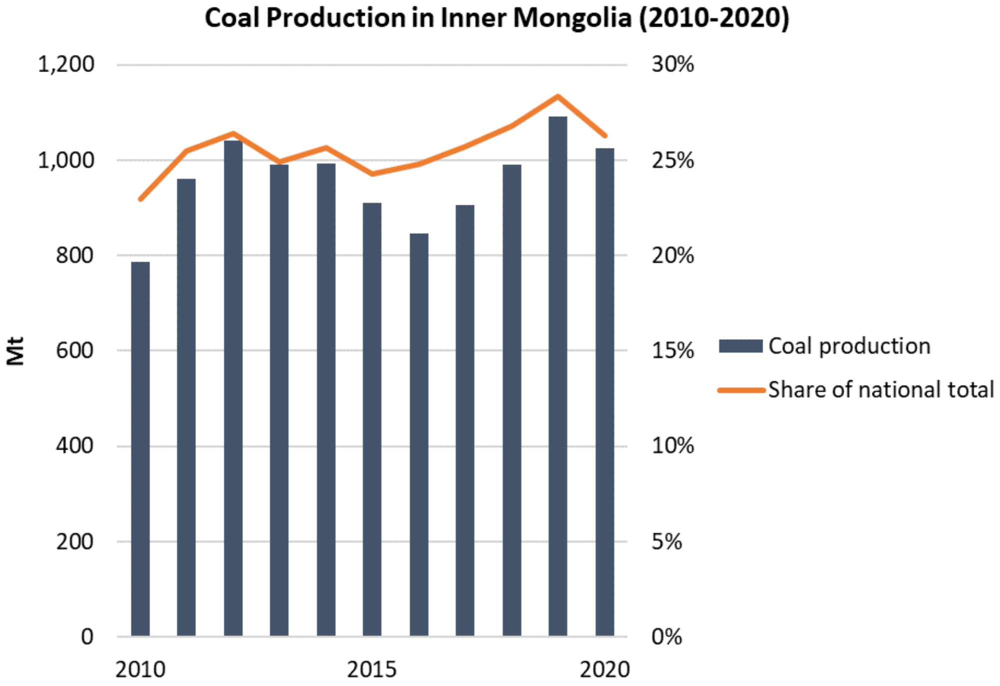


Figure 4. Coal production in Inner Mongolia (2010–2020)
Source: NBS 2022.

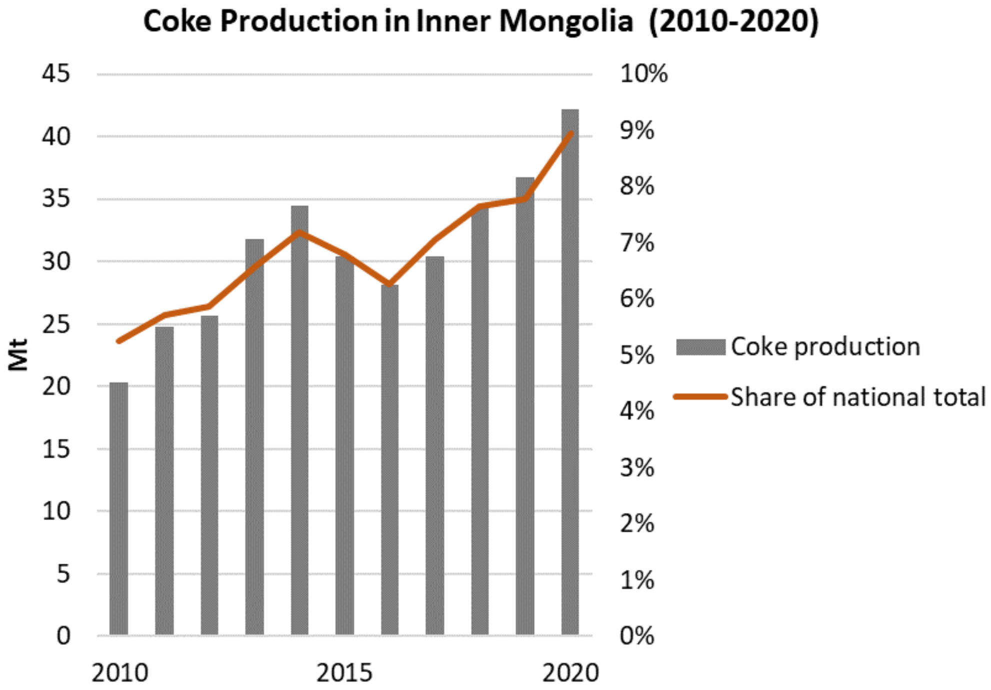


Figure 5. Coke production in Inner Mongolia (2010–2020)
Source: NBS 2022.

Given its plentiful and relatively low-cost coal resources, Inner Mongolia is the largest thermal power[10] generator in the country, accounting for 9% of China's total thermal power production in 2020 (NBS 2022). Inner Mongolia has significantly rich wind and solar resources and is the largest wind power- and the second largest solar power-producing province in China (see Table 4), representing about 16% and 7% of China's total wind and solar power generation, respectively, in 2020 (NBS 2022).

As shown in Figure 6, Inner Mongolia's power sector is dominated by coal power, accounting for 83% of the region's total electricity generation by 2020. Non-fossil power generation is led by wind power, followed by solar, with a small amount of hydropower generation. From 2015 to 2020, the share of non-fossil power generation in Inner Mongolia increased from 13% to 17%, an indication of "greening" the power sector. However, compared to the national average, which increased from 26% in 2015 to 32% in 2020, Inner Mongolia's power generation is still much more carbon-intensive than the national power sector (Figure 6).

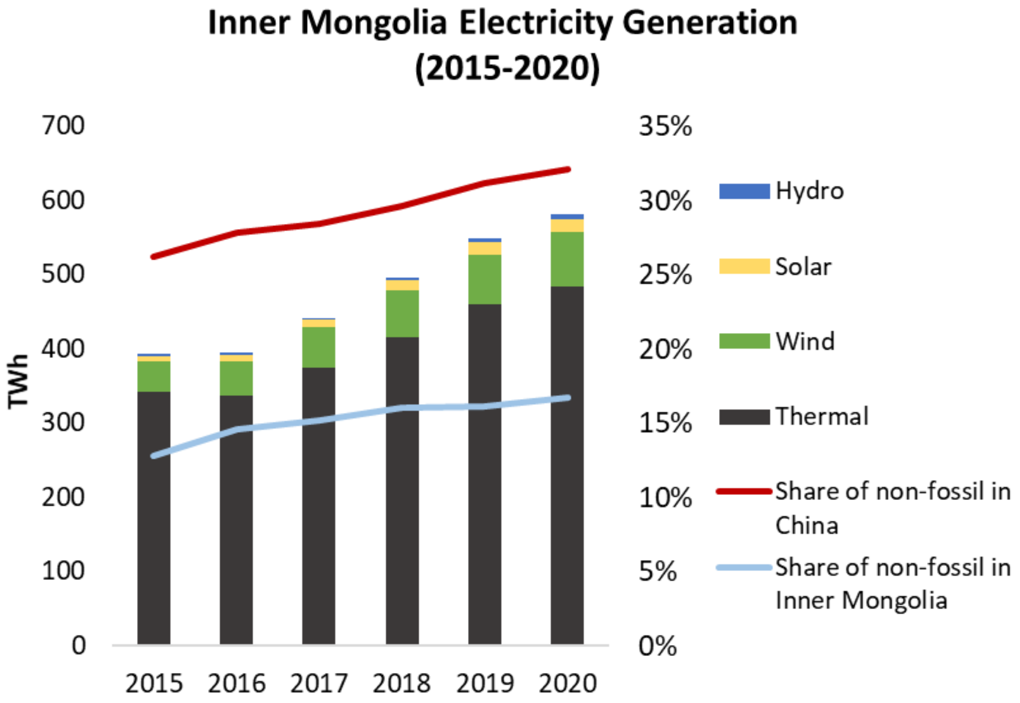


Figure 6. Electricity generation and share of non-fossil generation in Inner Mongolia
Source: NBS 2022.

Inner Mongolia's absolute amount of wind and solar power generation continues to increase and remains the largest wind power generation and the second largest (after Hebei Province) solar power-producing province in China, as of 2020. However, Inner Mongolia's contribution to China's national wind and solar power generation has declined since 2015, decreasing from 22% in 2015 to 15.6% in 2020 for wind, and declined from 15% in 2015 to 7% in 2020 for solar power generation (Figure 7). This indicates that renewable power generation development in

---

[10] The vast majority of thermal power generation comes from coal-fired power plants, with small amounts from oil and natural gas.

Inner Mongolia is growing, but the pace of renewable development is slower than the national total and other regions.

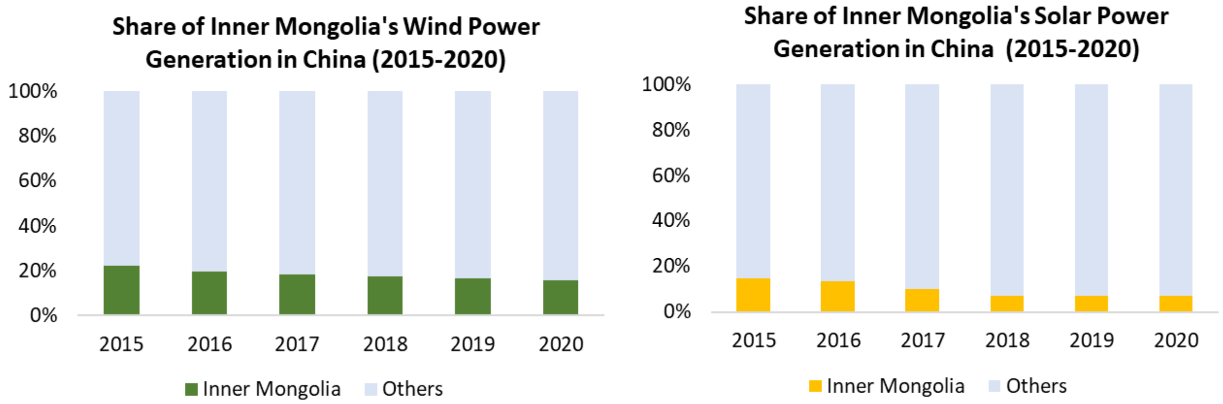


Figure 7. Share of wind and solar power generation in Inner Mongolia in China's total wind and solar power generation

Source: NBS 2022.

2.3 Inner Mongolia: The Industrial Sector

The industrial sector is the dominant driver of increasing energy consumption in Inner Mongolia. Industrial energy use grew 10 times in the last 20 years, increasing 12% per year on average. By 2020, the industrial sector was responsible for 82% of the total energy use in Inner Mongolia, followed by buildings[11] (13%), transport (4%), and the agriculture sector (2%), as shown in Figure 8. Over the past 20 years, the contribution of the industrial sector stayed at the level of 70%–80% of total energy use, reaching the highest point so far by 2020 (Inner Mongolia Autonomous Regional Bureau of Statistics 2022).

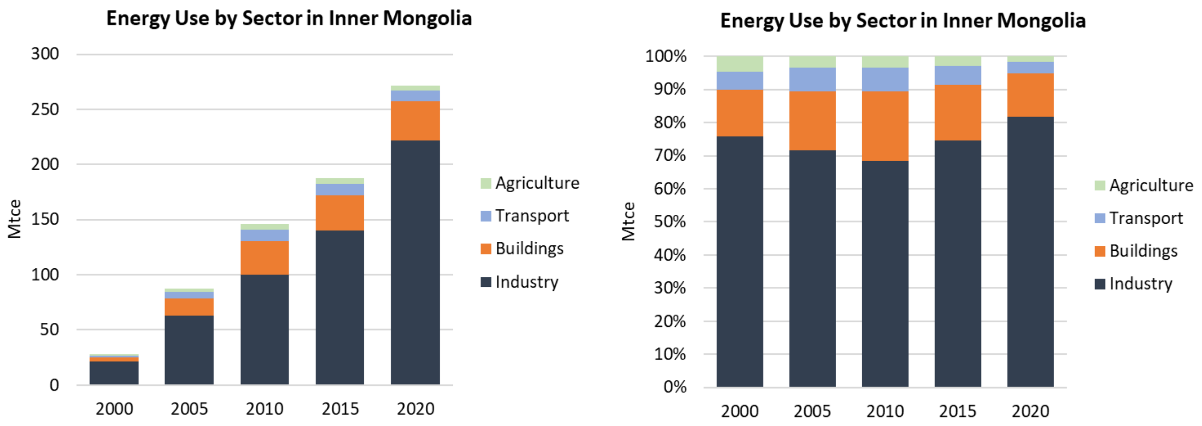


Figure 8. Energy use by sector and sectoral contributions in Inner Mongolia

Source: Inner Mongolia Autonomous Regional Bureau of Statistics 2022.

Note: *Industry* also includes construction. Here, the end-use sectoral breakdown is based on Inner Mongolia as well as China's energy balance tables, which is different from the sectoral categorization for the regional and national domestic product (e.g., primary, secondary, and tertiary).

---

[11] Including both residential, commercial, and public buildings.

In China's national and Inner Mongolia's energy statistics, the industrial sector is comprised of mining, manufacturing, and power, heat, and water production and supply. As shown in Figure 9, Inner Mongolia's manufacturing sector energy use increased from 55 Mtce in 2010 to more than 129 Mtce by 2020, growing 10% per year on average. Manufacturing's share in industrial energy use also increased from 50% in 2010 to 60% in 2020. Energy used by the mining sector, which includes coal mining, petroleum and natural gas exploration, and mining of basic metals and other minerals, remained between 8 Mtce and 14 Mtce during the period 2010–2020, on average declining 1% per year. The mining sector's share of total industrial energy use also declined from 13% in 2010 to 6% in 2020. In addition, the energy consumption of producing and supplying electricity, heat, and water increased 6% per year on average during the same period, and its contribution to total industrial energy use in Inner Mongolia also declined from 39% in 2010 to 34% in 2020 (Inner Mongolia 2022). Thus, the key driver of industrial sector energy use in Inner Mongolia is the manufacturing sector.

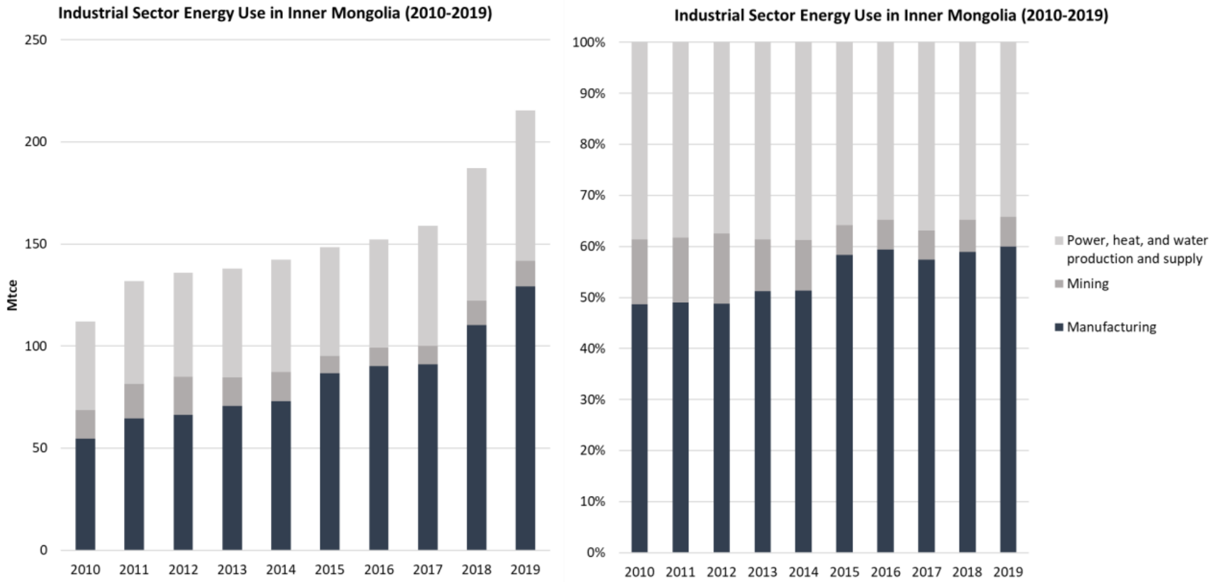
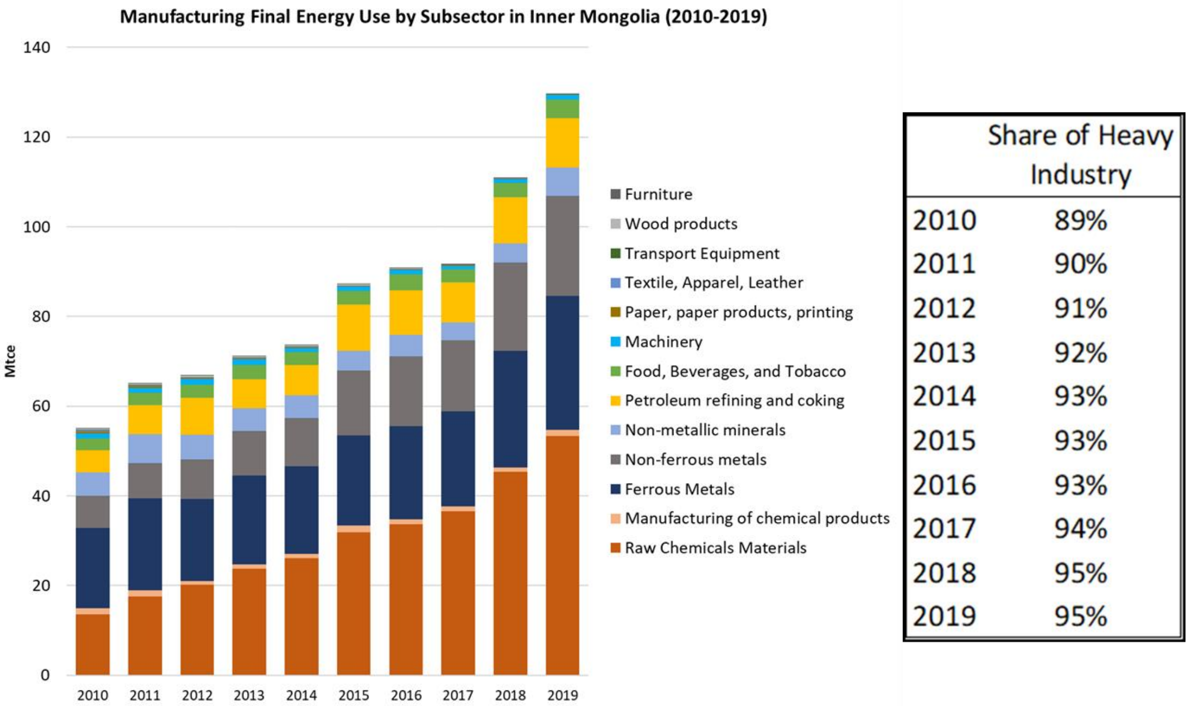


Figure 9. Industrial sector energy use in Inner Mongolia (2010–2019)

Source: Inner Mongolia Autonomous Regional Bureau of Statistics 2022.

In Inner Mongolia, manufacturing sector energy use is significantly concentrated in five energy-intensive industrial subsectors: chemicals (e.g., methanol), ferrous metals (e.g., iron and steel production), non-ferrous metals, (e.g., aluminum), non-metallic minerals (e.g., cement), and petroleum refining and coking. These five industrial subsectors are also collectively called "heavy industry," which represented 95% of all manufacturing energy use in Inner Mongolia in 2019 (Figure 10).



	Share of Heavy Industry
2010	89%
2011	90%
2012	91%
2013	92%
2014	93%
2015	93%
2016	93%
2017	94%
2018	95%
2019	95%

Figure 10. Manufacturing final energy use by subsector in Inner Mongolia (2010–2019)

Source: Inner Mongolia Autonomous Regional Bureau of Statistics 2022.

This share is higher than the average in China, where the national share of heavy industry in manufacturing energy use was 86% in 2019 (as shown in Figure A-1 in Appendix A). The “light industry” in Inner Mongolia, such as food, beverages, and tobacco, machinery, paper, textile, and manufacturing of transport equipment, only contributed less than 5% of manufacturing energy use.

The key industrial products produced by Inner Mongolia include cement, crude steel, methanol, calcium carbide, aluminum, ammonia, and flat glass. From 2010 to 2021, cement production declined sharply, dropping from 55 Mt to 37 Mt per year. Production from coal-based energy-intensive industries, such as calcium carbide, crude steel, aluminum, ammonia, and methanol production has been increasing, growing at 8%, 9%, 13%, 15%, and 22% per year on average, respectively (Figure 11).

More importantly, Inner Mongolia is a major producer of energy-intensive industrial products in China, especially aluminum, methanol, and calcium carbide, representing 15%, 22%, and 34% of the national production in 2021, respectively (Figure 12).

Calcium carbide is a key ingredient in producing polyvinyl chloride (PVC), which is widely used as a construction material (e.g., for pipes and window frames) in buildings, energy systems, and infrastructure projects. However, the production of calcium carbide is energy and carbon-intensive, as it heats limestone and coke in electric arc furnaces at a temperature of 2,000 °C. It requires significant electricity input, which is often supplied by onsite or nearby coal-fired power plants. Due to its vast resources of domestic coal and lack of ethylene supplies, China has relied on calcium carbide to supply more than 79% of its PVC production (Ding 2021), while the ethylene-based PVC production route supplies less than 20% of China's PVC production.

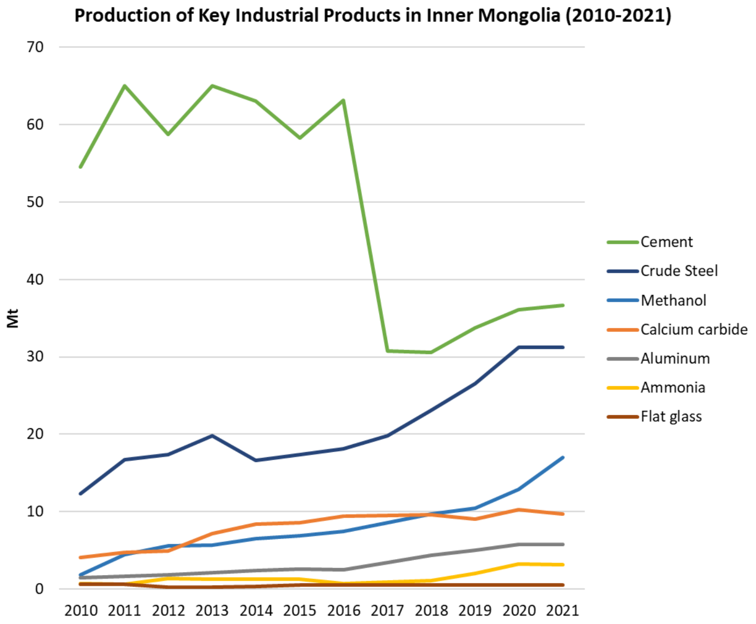


Figure 11. Production of key industrial products in Inner Mongolia (2010–2021)

Source: Inner Mongolia Autonomous Regional Bureau of Statistics 2022.

Note: cement production in Inner Mongolia has been declining since 2011 and had a significant drop in 2017 due to a combination of factors, such as overall weak cement demand (China's total cement production also declined by 3.1% in 2017) and phasing out of small, inefficient production capacities in Inner Mongolia. In 2017, Inner Mongolia reduced its production capacity by 17 Mt.

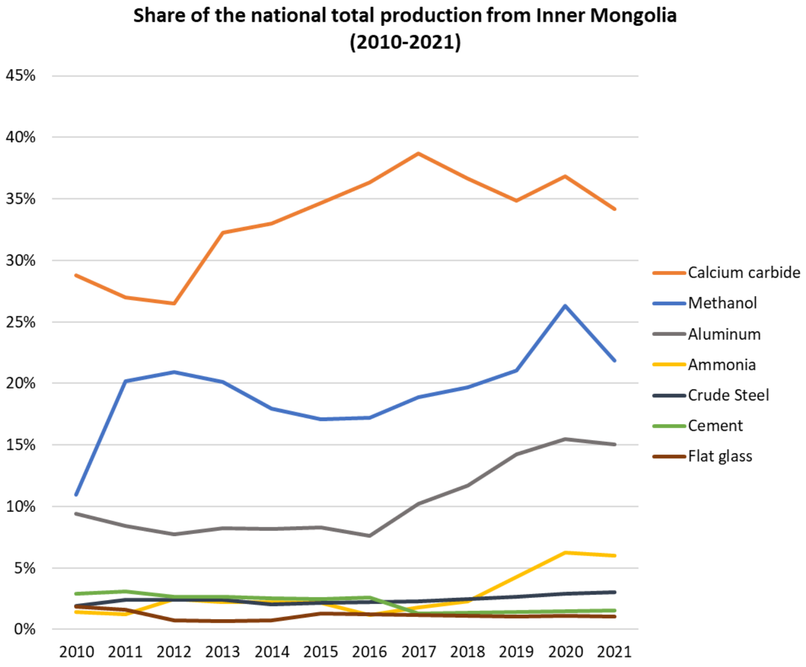


Figure 12. Share of national production from Inner Mongolia (2010–2021)

Source: Inner Mongolia Autonomous Regional Bureau of Statistics 2022.

In addition, Inner Mongolia relies on its coal resources and turns coal into methanol, which is an intermediate chemical product for plastics manufacturing (Yang 2022) and can be blended with other fuels, such as gasoline and liquefied petroleum gases (US EIA 2017). At the national level, more than 76% of China's methanol is produced from coal, and another 24% is from coke-oven gas and natural gas. About 45% of China's methanol production is used to produce olefins for plastic making (Great Wall Securities 2020).

3. The Urgency of the Industrial Sector's Energy Transition

3.1 National Policies

China has established a "1+N" policy framework to support it to peak emissions before 2030 and achieve carbon neutrality in 2060. On October 24, 2021, the Central Committee of the Chinese Communist Party and the State Council released the "Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy" (Xinhua Net 2021a). This *Guidance* is the overarching document and the 1 in the "1+N" policy framework. It reiterated the principles of "exercising nationwide planning," "prioritizing conservation," "leveraging the strength of the government and the market," "coordinating efforts on the domestic and international fronts," and "guarding against risks."

For the industrial sector, the *Guidance* calls for accelerating green production modes, such as:

- improving circular economy and resource utilization;
- optimizing and upgrading industrial structures, especially in steel, non-ferrous metals, petrochemicals, and building materials industries;
- curbing the irrational expansion of energy-intensive and high-emission projects, such as steel, cement, flat glass, electrolytic aluminum, petrochemical, and coal-based chemical industries; and
- developing green and low-carbon industries.

The *Guidance* emphasizes that the key measures for the industrial sector are:

- strengthening "the Dual Control" on energy intensity and energy consumption,
- significantly improving energy efficiency,
- strictly control fossil fuel consumption, and
- actively developing non-fossil energy.

On October 26, 2021, the State Council of China released the "Action Plan for Carbon Dioxide Peaking Before 2030" restating the near-term goals (2020–2030) as laid out in the *Guidance* (Xinhua Net 2021b). *The Action Plan* reiterated a similar set of working principles as the *Guidance* document, emphasizing national coordination, key areas, and key industries—including steel, non-ferrous metals, building materials, and petrochemical industries to peak early, as well as the principle of "reducing carbon emissions steadily and orderly" to "ensure national energy security and economic development as the bottom line" and "ensure national energy security, supply chain security, food security, and people's normal life."

A summary of key policies and targets for the industrial sector during the 14th Five-Year Plan (2021–2025) is provided in Table 5.

Table 5. National policies and targets to support energy transition during the 14th FYP

Areas	Targets
Energy intensity reduction	• Reduce energy use per unit of industrial value-added (VA) by 13.5% during the 14th FYP.
Carbon intensity reduction	• Reduce CO_2 emissions per unit of industrial VA by 18% during the 14th FYP.
Carbon peaking	• Achieve results in controlling CO_2 emissions in key industries, including iron and steel, non-ferrous metals, and building materials.
Energy efficiency improvement	• More than 30% of production capacity in key industries (including iron and steel, aluminum, cement, flat glass, oil refining, ethylene, ammonia, and calcium carbide) achieve internationally advanced levels.
Ultra-low emissions	• Retrofit 530 Mt of steel production capacity for ultra-low emissions by 2025. • Retrofit 850 Mt of clinker production by 2025. • Fully retrofit coal-fired boilers in air pollution prevention key regions by 2025.
Industry roadmaps	• Develop industry sector and specific industry carbon peaking implementation plans, roadmaps, and timetables. Key industries include iron and steel, petrochemicals and chemicals, non-ferrous metals, and building materials.
Resource utilization	• By 2025, recycled steel, paper, and non-ferrous metals reach 320 Mt, 60 Mt, and 20 Mt, respectively. By 2025, the production of copper, aluminum, and lead from recycled materials reach 4 Mt, 11.5 Mt, and 2.9 Mt, respectively.
Steel industry	• Reduce specific energy intensity by 2% by 2025. • Achieve carbon peaking before 2030. • Utilize more than 300 Mt of steel scrap by 2025. • Increase the electric arc furnace (EAF) share in total crude steel production to more than 15% by 2025.
Standards	• Develop and revise 100 green design evaluation standards. • Promote 10,000 green products.
Hydrogen industry	• Reach green hydrogen (H_2) production of 100,000–200,000 tonnes per year by 2025. • Develop H_2 industry innovation system, clean H_2 production, and supply system by 2030. • Develop H_2 industry system, covering transport, storage, and industry applications by 2035.

Source: Author summaries based on China’s 14th FYP documents.

3.2 Inner Mongolia Policies

Inner Mongolia released its *14th Five-Year Plan on Energy Conservation and Emission Reduction* on May 25, 2022. In addition, it also announced targets in terms of renewable energy development and hydrogen industry development. Table 6 summarizes key policies and targets from Inner Mongolia's 14th FYP.

Promoting industrial energy efficiency plays a key role in current policymaking. The Inner Mongolia government provides energy assessments to industrial facilities that have a total energy consumption of over 10,000 tonnes of coal equivalent (tce) per year, covering key industries such as steel, non-ferrous, chemicals, and building materials. The government also plans to compare local industrial energy-efficiency levels with national and international levels and then conduct energy retrofits. The government's goal is to have 30% of the production capacity (in the chemicals, steel, non-ferrous, and building materials industries) reach the domestic energy-efficiency advanced level. In addition, the government provides financial incentives of 200 yuan per tce saved for energy retrofit projects that can save more than 2,000 tce per year (The State Council Information Office 2022).

Table 6. Inner Mongolia policies and targets to support energy transition during the 14th FYP

Area	Target
Energy intensity reduction	- Reduce energy use per unit of industrial value-added (VA) by 16% during the 14th FYP.
Carbon intensity reduction	- Reduce CO_2 emissions per unit of industrial VA by 14% during the 14th FYP.
Coal production capacity	- Stay at the level of 1.3 billion tonnes
Green hydrogen	- Reach a hydrogen supply capacity of 1.6 million tonnes per year by 2025, with 30% from green hydrogen.
Wind power generation	- Increase from 73 terawatt-hours (TWh) in 2020 to 89 TWh by 2025.
Solar power generation	- Increase from 18.8 TWh in 2020 to 76 TWh by 2025.
Hydropower generation	- Increase from 5.7 TWh in 2020 to 6 TWh by 2025.
Biomass power generation	- Increase from 1.1 TWh in 2020 to 2.5 TWh by 2025.
Geothermal	- Increase from 7.5 million square meters (m^2) in 2020 to 10 million m^2 by 2025.
Biomass thermal energy	- Increase from 0.18 million tonnes in 2020 to 0.4 million tonnes by 2025.
Biogas	- Increase from 10 million cubic meters in 2020 to 200 million cubic meters by 2025.
Renewable consumption	- Increase the share of renewable power generation to 35% by 2025. - Increase the share of renewables in total energy use from 11% in 2020 to more than 18% by 2025.
Energy efficiency	- Implement energy efficiency retrofits, energy efficiency, and carbon emission benchmarking.
Coal-to-Chemical industry	- Moderately develop coal-to-liquids, coal-to-gas, coal-to-methanol, coal-to-olefins, and coal-to-ethylene glycol. - Centered around Ordos City, develop a modern coal-to-chemicals industrial demonstration park.
Chemical industry	- Strictly control newly added capacity in calcium carbide and PVC. - Encourage the development of special resin products, such as vinyl resin and chlorinated PVC.
Coking industry	- Centered around Wuhai and Baotou cities, develop the coking industry.
Steel industry	- Promote industry retrofits and upgrades in the steel industry.
Aluminum industry	- Increase the local processing rate of aluminum to 70%, and increase the categories of post-processing aluminum products to 50 by 2025.
Cement industry	- Strictly control newly added capacity in the cement industry. - Develop and promote cement-based products for prefabrication.

Note: Inner Mongolia's *14th Five-Year Plan on Energy Conservation and Emission Reduction* included a total of 10 energy conservation and emission reduction programs. Here, only industry-related programs are listed.

3.3 Literature Review of Energy Use and Emissions in Inner Mongolia

Limited research has been conducted on Inner Mongolia's energy transition with very few studies focusing on industrial energy intensity benchmarking. Previous research on Inner Mongolia has been primarily centered on analyzing the factors driving energy use and emissions in the region. Both Qian et al. (2010) and Wu et al. (2016) utilized the decomposition method. Qian et al. (2010) showed that economic activity contributed the most (89.22%) to Inner Mongolia's energy-related CO_2 emission increases from 1999 to 2008, while the industrial structure and population increase also contributed positively to the emissions increase, at 17.01% and 2.78%, respectively. Energy intensity reduction and energy structure improvement were the offsetting factors to the CO_2 emission increase (Qian et al., 2010). Wu et al. (2016) further showed that energy-intensive industries accounted for close to 90% of total increased industrial CO_2 emissions during 2003-2012 using the Logarithmic Mean Divisia Index decomposition method (Wu et al. 2016).

A few studies analyzed whether Inner Mongolia's social economic development was on a sustainable trajectory. Shang et al. (2019) quantified the temporal patterns of socioeconomic growth, energy consumption, and food and water footprints of Inner Mongolia from 1987 to 2015 and showed that socioeconomic progress was accompanied by rapidly rising environmental pressures, as manifested in the significant increase in water resource use and energy consumption. The study suggested that for Inner Mongolia to become more sustainable, "the problems of environmental degradation and social inequality must be addressed through institutional changes to balance socioeconomic development and environmental protection, as well as to reduce the urban-rural income gap and socioeconomic inequity in general." (Shang et al. 2019). Zhang (2022) used the data from 2015 to 2019 and examined Inner Mongolia's potential transition trajectories and showed that although the trajectories are different, the outcome of an energy mix with a higher share of renewable energy is similar (Zhang, J. 2022).

Other studies on Inner Mongolia looked into the impacts of industrial development on Inner Mongolia's environment. For example, Hu et al. (2018) investigated the characteristics of heavy-metal pollution in the soil of a typical non-ferrous metal mine in Chifeng, Inner Mongolia (Hu et al. 2018). Zhang et al. (2019) developed pathways for clean heating in Inner Mongolia and showed that "by replacing coal boilers with clean heating resources, the clean heating sources pathway could reduce coal consumption by about 41%, with 33% annual cost savings in 2018 compared with the reference pathway." (Zhang et al., 2019).

Our literature review did not find studies on Inner Mongolia's industrial energy efficiency—especially regarding how Inner Mongolia's steel and aluminum industry compares to the national average and international benchmarks, which is the focus of this report.

4. Energy Intensity Benchmarking of Key Industries in Inner Mongolia

4.1 Methodology

Previous studies show it can be challenging to achieve meaningful and useful energy intensity benchmarking. When comparing energy consumption, energy intensity, and carbon intensity across companies, provinces, regions, and countries, researchers may face several challenges. Different methods vary in multiple aspects, including indicators, boundary definitions, and conversion factors.

Researchers found that physical-based indicators, instead of economic indicators, provide a more robust analysis for international comparison (Worrell et al. 1997). But previous literature also used different physical indicators, from energy used per crude steel production (Worrell et al. 1997) to per tonne of shipped steel (Stubbles 2000) making comparisons difficult. Internationally, various policy programs have used different indicators, ranging from total energy consumption (e.g., Japan's Keidanren Voluntary Action Plan), energy intensity (e.g., European Union [EU] emissions trading systems), to thermal energy efficiency (e.g., US Energy Policy Act) (Tanaka 2008).

In this study, we use the physical energy intensity of crude steel production as the indicator because this is what Chinese government programs have been using in their product minimum energy performance standards, national benchmarking programs, and often in key policy documents such as the Five-Year Plans.

Boundary definition

Boundary definitions[12] play a critical role in calculating energy intensity and using different boundary definitions makes comparisons at best difficult, if not impossible (Tanaka 2008), as shown in Figure 13. For the steel industry, the Intergovernmental Panel on Climate Change (IPCC) guidelines includes greenhouse gas (GHG) emissions from ironmaking, steel-making continuous casting, and on-site power plants, as well as emissions from rolling mills and other processes. Under the EU's Emissions Trading Systems, rolling mills and other processes are excluded, but by-product gases are included (Tanaka 2008). World Resources Institute (WRI) / World Business Council for Sustainable Development (WBCSD) guidelines include both purchased electricity as well as onsite production processes, but not including by-product gas (Tanaka 2008).

In addition, the GHG calculation methodology guidelines published by American Iron and Steel Institute uses a "cradle-to-gate" boundary, which includes processes to mine, transport, and produce raw materials, as well as iron and steelmaking processes, and other down-stream processes (AISI 2022). The steel sector emissions reporting guidance developed by RMI and WBCSD set a benchmarking boundary (for all products) that includes upstream activities (e.g., iron ore mining, limestone quarry, and coal mining), raw material preparation (e.g., pelletizing,

---

[12] Common terms such as Scope 1, Scope 2, and Scope 3 are used when defining boundaries of energy use and emissions. As defined by the Greenhouse Gas Protocol, Scope 1 emissions include "direct" emissions, i.e., emissions from sources that are owned or controlled by the site; while Scope 2 emissions include emissions of purchased electricity. Scope 3 emissions are from all other indirect sources, such as production and transporting other raw materials (GHG Protocol 2008).

sintering, coking), ironmaking, steel making, and hot rolling. Processes such ass annealing and finishing are only required for relevant products (RMI, 2022).

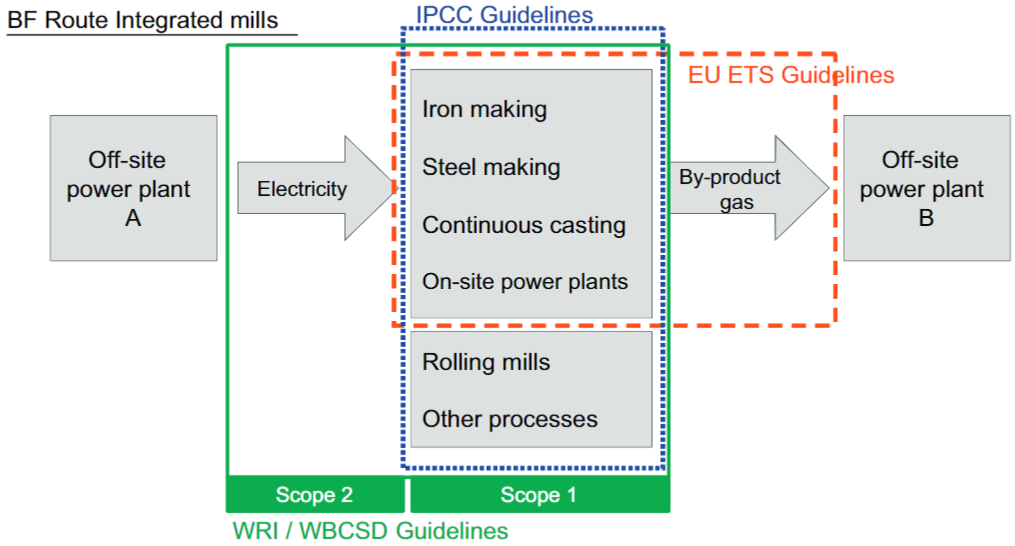


Figure 13. Different boundary definitions by international guidelines for GHG emissions accounting for integrated steel mills

Source: Tanaka 2008.

In this study, we include the following iron and steelmaking processes: coke making, pelletizing, sintering, ironmaking, steelmaking, casting, hot and cold rolling, and processing. Coal is an important material, as it provides thermal energy and acts as a feedstock for coke production. It is for this reason that coal inputs for both fuel consumption and feedstock for coke-making are included. Inner Mongolia is a net energy-exporting province in China, and one of the largest coke-producing provinces (the fourth largest in China) in 2020. While explicit data on coke interprovincial trade is lacking, and specific data on coke inflows to Inner Mongolia are not clear, we assume that the inflow of coke products to Inner Mongolia is minimal.

This study does not consider the energy use of the ferroalloy industry for two reasons. First, because of the energy-intensive and carbon-intensive nature of producing iron and steel, this study focuses on energy consumption during the iron and steelmaking process. Second, publicly accessible data from Inner Mongolia does not provide detailed energy consumption by energy source for the ferroalloy industry, which makes the benchmarking analysis very challenging, if not impossible.

This study also did not include the energy consumption needed to produce other energy-intensive products in the steel industry, such as electrodes and refractories as the focus of the study is on iron and steel production. This approach was taken in previous studies such as Hasanbeigi et al. (2014) and Stubbles (2000). In addition, upstream energy use (e.g., mining) and downstream energy use (e.g., finished product processing) are not included in this study.

Energy conversion factors: Fuel

In regards energy conversion factors, different institutions and countries use different conversion factors to convert fuel and electricity usage to standardized energy use. For example, China and the U.S. use different conversion factors for other bituminous coal and clean coal (Hasanbeigi et al. 2014), where China uses wet-based coal and the U.S. uses dry-based coal.

Table 7 compares fuel conversion factors used by the International Energy Agency (IEA), China, and the United States Energy Information Administration (US EIA). Based on the IEA's *Key World Energy Statistics (2021), China Energy Statistical Yearbook 2021*, and the US EIA's *Monthly Energy Review* of December 2022, it is clear that countries and regions vary in fuel conversion factors. In addition, while IEA and China often use the lower heating value (net calorific value), the U.S. often uses the higher heating value (gross calorific value). The difference between the net and gross calorific value is due to the latent heat of water vaporization during combustion. Lower heating values are normally 5%–6% lower than higher heaving values for solid and liquid fuels and about 9%–10% less for natural gas (Tréanton 2008).

Table 7. Fuel conversion factors used by IEA, China, and the U.S.

Fuel	**IEA** Lower Heating Value	**China** Lower Heating Value	**US EIA** Higher Heating Value	**Unit**
Coking Coal		26.34	33.34	MJ/kg
Other Bituminous Coal	22.17	20.91	23.93	MJ/kg
Coke		28.44		MJ/kg
Refinery Gas	48.10	46.00		MJ/kg
Liquefied Petroleum Gas (LPG)	47.30	50.18	45.81	MJ/kg
Gasoline	44.80	43.07	46.78	MJ/kg
Kerosene	43.80	43.07	47.03	MJ/kg
Diesel Oil	43.30	42.65		
Fuel Oil	40.20	41.82	45.94	MJ/kg
Natural Gas	35.04	35.58*	38.71	MJ/m^3
Coke Oven Gas		17.36*		MJ/m^3
Other Coal Gas		10.45		MJ/m^3
Benzene		41.82		MJ/kg
Coal Tar		33.45		MJ/kg

Sources: IEA 2021b; NBS 2022; US EIA 2022.
Note: MJ stands for megajoule.
*China reported a range of lower heating values for natural gas and coke oven gas. Natural gas: 32.238–38.931 MJ/m^3; coke oven gas: 16.726–17.981 MJ/m^3. The data reported in the table show the averages of reported lower heating values (NBS 2022).

Recognizing that fuel products vary in energy quality in different countries, the IEA adopted an approach of a unified system of average energy conversions for all countries. However, considering that this study is focused on Inner Mongolia within China, coal heating values vary by country, and its challenging to have a clear understanding of data collection boundaries, it is more important to compare Inner Mongolia with the national average in China than with other countries. In addition, Hasanbeigi et al. (2014) have shown that the effects of country-specific lower heating values are quite small on the energy-intensity results. Thus, this study uses China-specific fuel conversion factors for the benchmarking analysis.

Energy conversion factors: electricity

Electricity consumption is an important part of the total energy use in the industry. To include electricity use, different statistical methods may use different conversion factors to convert electricity usage (often reported in kilowatt-hours) to standardized energy units, such as joules or tonnes of coal equivalent (tce), as used in China.

This study adopts the electricity conversion approach used by the IPCC, which is the Direct Equivalent method. In this approach, electricity consumption is converted to standardized energy consumption based on the electricity's calorific value, using the equation of 1 kWh = 3.6 MJ = 0.1229 kgce.

It is important to point out that China uses both methods to convert electricity consumption into standardized energy units. In addition to the Direct Equivalent method, it also uses its own method, the Power Plant Coal Consumption method, to convert primary electricity into standardized energy units based on the average amount of energy used in power plants in a specific year, treating all primary electricity as if it were generated in a thermal power plant (Lewis et al., 2015). For the most recent year available (2019), this method values primary electricity as 1 kWh = 8.76 MJ = 0.2989 kgce.

Comparisons of the different methods used to convert primary electricity into standard units are shown in Table 8.

.

Table 8. Electricity conversion factors

Primary Electricity Conversion Method	**Power Plant Coal Consumption**	**Direct Equivalent**	**Partial Substitution**	**Physical Energy Content**
Adopted by:	China	IPCC	US EIA, BP, World Energy Council, IIASA	IEA, Eurostat, UN Statistics
Electricity source:				
Nuclear energy	Conversion to standard units based on the average heat rate (kgce/kWh) of coal-fired plants in a given year. 1 kWh = 8.76 MJ = 0.2989 kgce in 2019	Defined as 1 kWh = 3.6 MJ = 0.1229 kgce	Assumes 32.6% (EIA) to 38% (BP) efficiency	Assumes 33% efficiency: 1 kWh = 10.9 MJ = 0.372 kgce
Hydropower			Assumes 37% (EIA) to 38% (BP) efficiency	Assumes 100% efficiency: 1 kWh = 3.6 MJ = 0.1229 kgce
Renewable electricity (solar PV, solar thermal, and wind)			Assumes 37% (EIA) to 38% (BP) efficiency	Assumes 100% efficiency for solar PV and wind: 1 kWh = 3.6 MJ = 0.1229 kgce Assumes 33% efficiency for solar thermal: 1 kWh = 10.9 MJ = 0.372 kgce
Geothermal energy			Assumes 37% (EIA) to 38% (BP) efficiency	Assumes 10% efficiency: 1 kWh = 36 MJ = 1.229 kgce

Sources: Kraan et al. 2019; Lewis et al. 2015; UN Department of Economic and Social Affairs, Statistics Division 2018; US EIA 2019.

Note: IIASA = International Institute for Applied Systems Analysis

Data Sources

We use publicly accessible information from Inner Mongolia, including both industrial production (crude steel and aluminum production) and energy consumption. The data source is from the *Inner Mongolia Statistical Yearbook*, published by the Inner Mongolia Autonomous Regional Bureau of Statistics and available at: http://tj.nmg.gov.cn:18080/datashow/pubmgr/publishmanage.htm?m=queryPubData&procode=0003.

Until 2018, the Bureau of Statistics published "Consumption of Total Energy and its Main Varieties by Sector" for industrial subsectors in the *Inner Mongolia Statistical Yearbook*. For example, in the *Inner Mongolia Statistical Yearbook 2018*, Table 7-8 provides industrial subsectoral total energy use and energy consumption by source in 2017, including coal, coke, crude oil, gasoline, kerosene, diesel oil, fuel oil, natural gas, and electricity. However, after 2018, *the Inner Mongolia Statistical Yearbook* no longer publishes energy consumption by energy source or by industrial subsectors. It only publishes the total energy use of all of the "industry," which includes various mining and manufacturing sectors. That is why this study uses 2017 data for the energy intensity benchmarking analysis.

4.2 Steel Industry in Inner Mongolia

The steel industry is one of the most energy-intensive industries in Inner Mongolia, representing 23% of the manufacturing energy use in Inner Mongolia in 2019 (Inner Mongolia Autonomous Regional Bureau of Statistics 2022). Inner Mongolia's crude steel production increased from 12 Mt in 2010 to 31 Mt in 2021, growing 9% per year on average (Figure 14).

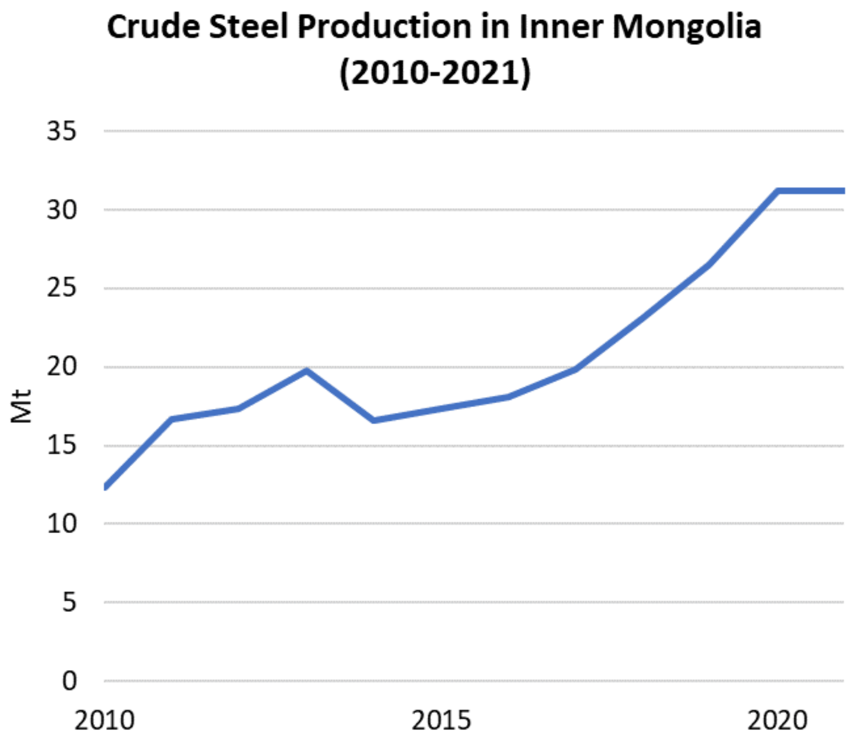


Figure 14. Crude Steel Production in Inner Mongolia (2010–2021)

Source: Inner Mongolia Autonomous Regional Bureau of Statistics 2022.

According to the Global Steel Plant Tracker, developed by the Global Energy Monitor and released in March 2022, Inner Mongolia has 10 steel companies, as shown in Table 9. Of the 10 steel companies, only two—Inner Mongolia Baotou Steel Union and Baotou Da'an Iron and Steel Company—are members of China's Iron and Steel Industry Association (CISA), according to the July 2019 CISA member list. To be a CISA member, companies must have an annual steel production of 1 Mt/year or higher and meet the national requirements in production equipment, environmental protection, permitting, and product quality (CISA 2021). This lack of membership among Inner Mongolia steel companies indicates that most are generally smaller in scale, compared to the national average.

Table 9. List of steel companies in Inner Mongolia

#	City	Company name (English)	Company name (Chinese)	Status	Nominal crude steel capacity (kt/year)	Nominal iron capacity (kt/year)	Steelmaking process
1	Baotou	Inner Mongolia Baotou Steel Union Co., Ltd.	内蒙古包钢钢联股份有限公司	Operating	17,500	15,900	Integrated (BF-BOF)
	Baotou	Inner Mongolia Baotou Steel Union Co., Ltd. (EAF expansion)	内蒙古包钢钢联股份有限公司	Proposed	750	0	EAF
	Baotou	Inner Mongolia Baotou Steel Union Co., Ltd. (BOF expansion)	内蒙古包钢钢联股份有限公司	Proposed	1,150	0	Integrated (BF-BOF)
2	Baotou	Inner Mongolia Baotou Jiyu Iron and Steel Co., Ltd.	包头市吉宇钢铁有限责任公司	Operating	1,100	803	Integrated (BF-BOF)
	Baotou	Inner Mongolia Baotou Jiyu Iron and Steel Co., Ltd. (BF-BOF expansion)	包头市吉宇钢铁有限责任公司	Proposed	1,250	1,130	Integrated (BF-BOF)
3	Baotou	Inner Mongolia Yaxin Longshun Special Steel Co., Ltd.	内蒙古亚新隆顺特钢有限公司	Operating	2,000	2,000	Integrated (BF-BOF)
	Baotou	Inner Mongolia Yaxin Longshun Special Steel Co., Ltd. (BF expansion)	内蒙古亚新隆顺特钢有限公司	Proposed	0	1,430	Integrated (BF-BOF)
4	Baotou	Baotou Da’an Iron and Steel Co., Ltd.	包头市大安钢铁有限责任公司	Operating	1,200	1,100	Integrated (BF-BOF)
5	Baotou	Baotou Baoxin Special Steel Co., Ltd.	包头市宝鑫特钢有限责任公司	Operating	600	800	Integrated (BF-BOF)
6	Baotou	Mingtuo Ferritic Stainless Steel Co., Ltd.	明拓铁素体不锈钢有限公司	Proposed	800	0	EAF
7	Baotou	Inner Mongolia Wanzhou Special Steel Co., Ltd.	内蒙古万洲特钢有限责任公司	Proposed	575	0	EAF

8	Wuhai	Wuhai Baogang Wanteng Iron and Steel Co., Ltd.	乌海市包钢万腾钢铁有限责任公司	Operating	2,000	2,000	Integrated (BF-BOF)
9	Ordos	Inner Mongolia Desheng Metal Products Co., Ltd.	内蒙古德晟金属制品有限公司	Operating	1,095	1,080	Integrated (BF-BOF)
10	Chifeng	Chifeng Yuanlian Steel Co., Ltd.	赤峰远联钢铁有限责任公司	Operating	2,450	1,130	Integrated (BF-BOF)

Source: Global Energy Monitor 2022.
Note: BF-BOF: blast furnace and basic oxygen furnace; EAF: electric arc furnace.

As of 2017, all of Inner Mongolia's steel production capacity (28 Mt/year) was based on primary (or integrated) steel production, i.e., blast furnace and basic oxygen furnace (BF-BOF), as shown in Figure 15. Since then, several plants proposed plans to add secondary steel production capacity based on the electric arc furnace (EAF) production route. As of March 2022, Inner Mongolia had a total steel production capacity of 32 Mt (including both existing and proposed capacity), with 93% in BF-BOF and 7% in EAF production routes (Global Energy Monitor 2022). Comparatively, EAF production plays a bigger role nationally, representing 11% of total production by 2020.

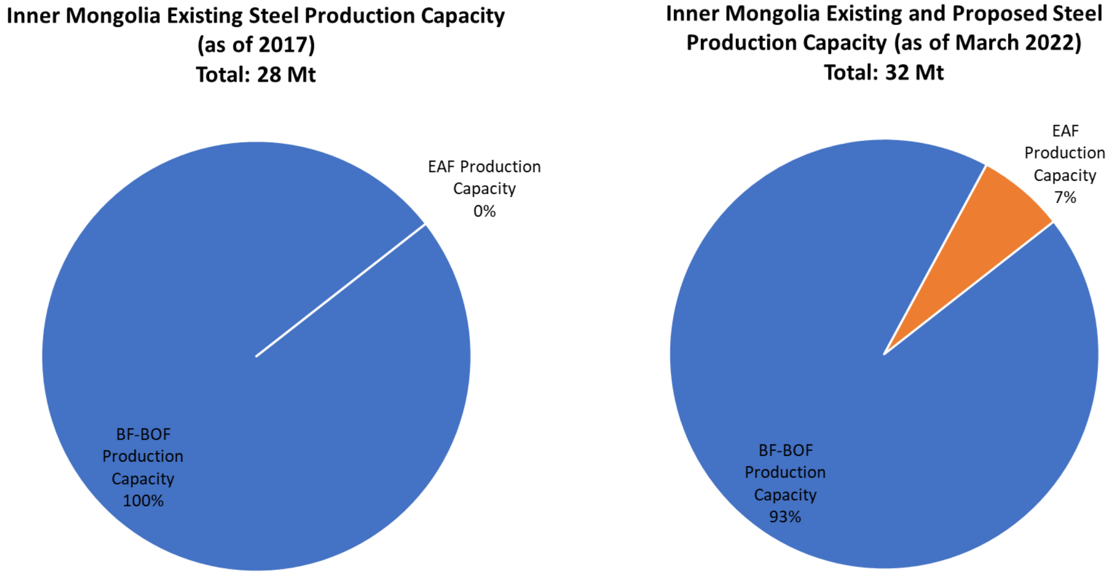


Figure 15. Steel production capacity by process in Inner Mongolia (2017 and 2022)
Source: Global Energy Monitor 2022.
Note: The percentages include existing and proposed steel production capacity.

4.3 Steel Industry Energy Intensity Benchmarking

The Inner Mongolia Statistical Yearbook 2018 reported the industrial subsector of "smelting and pressing of ferrous metals" energy use by source in 2017, as shown in Table 10. Based on the China-specific fuel conversion factors (see earlier Table 7) and using the Direct Equivalent method of converting electricity consumption to standardized energy units, we calculated the total energy use of the Inner Mongolian industrial subsector to be 29.12 Mtce in 2017.

Table 10. Energy use by source of smelting and pressing of ferrous metals in Inner Mongolia (2017)

	Mtce	Mt	Mt	Mt	Mt	Mt	bcm	TWh
Sector	**Total Energy Use***	**Coal**	**Coke**	**Gasoline**	**Kerosene**	**Diesel**	**Natural Gas**	**Electricity**
Smelting and pressing of ferrous metals	29.12	17.02	10.88	0.0025	0.0001	0.07	0.10	50.17

Source: Inner Mongolia Autonomous Regional Bureau of Statistics 2022.
Notes: * based on the Direct Equivalent method; bcm = billion cubic meters; TWh = terawatt-hours

The ferroalloy industry is an important part of the "smelting and pressing of ferrous metals" subsector (subsector B31). According to China's industrial classification standard (GB/T 4754-2017) (NBS 2017), energy use of B31 includes iron making (B3110), steel making (B3120), steel pressing and processing (B3130), and steel alloy smelting (B3140). As noted earlier, in the publicly accessible data published in the *Inner Mongolia Statistical Yearbook 2018*, only the energy use of B31 is reported. Thus, it is important to remove the energy use of steel alloy smelting (B3140) to get a more accurate estimate of the energy consumption of iron and steel making, which also includes steel pressing and processing according to this study's boundary definition.

In 2017, Inner Mongolia produced about 6.9 Mt of ferroalloys, representing 21% of China's total ferroalloys that year (China Building Materials Information 2018; Li 2018). Inner Mongolia is one of the largest producers of ferroalloys in China, especially for high-carbon ferrochrome, manganese silicon alloy, and ferrosilicon (Table 11).

Table 11. Ferroalloy production in Inner Mongolia (2017)

Ferroalloys	2017 Inner Mongolia Production (Mt)	Share of National Production (2017) (%)
High-carbon ferrochrome	2.85	64
Manganese silicon alloy	2.02	34
Ferrosilicon	1.27	37
High carbon ferromanganese (electric furnace)	0.38	25
Ferromanganese (blast furnace)	0.38	25

Sources: Qianzhan Research Institute 2021; Sina Finance 2022; mysteel 2022; China Industry Information Net 2018; CNFEOL 2018.

Ferroalloy production is energy-intensive, particularly electricity-intensive. Based on studies by Lu et al. (2016) and Hasanbeigi et al. (2014), as well as China's *Minimal Energy Performance Standard for Ferroalloy (GB 21341-2017)*, we estimated the average ferroalloy energy intensity in Inner Mongolia at three ranges: low (2.1 tce/t), medium (2.25 tce/t), and high (2.4 tce/t) (Lu, Price, and Zhang 2016; Hasanbeigi et al. 2014; General Administration of Quality Supervision, Inspection and Quarantine of China and Standardization Administration of China 2017). Based on the low, medium, and high ferroalloy energy intensity assumptions, we estimated that crude steel energy intensity for primary steelmaking in Inner Mongolia in 2017 was in the range of 632~737 kgce/t (18.5~21.6 GJ/t) (Table 12).

Table 12. Crude steel energy intensity in Inner Mongolia (2017)

Inner Mongolia Energy Use (2017)	Low Ferroalloy Energy Intensity Assumption	Medium Ferroalloy Energy Intensity Assumption	High Ferroalloy Energy Intensity Assumption	Unit
Smelting and pressing of ferrous metals	29.12	29.12	29.12	Mtce/year
Ferroalloy industry energy use	14.5	15.54	16.58	Mtce/year
Iron and steel industry energy use	14.62	13.58	12.54	Mtce/year
Crude steel energy intensity (BF-BOF)	736.89	684.66	632.43	kgce/t
Crude steel energy intensity (BF-BOF)	21.6	20.1	18.5	GJ/t

As shown in Table 12, the final estimated crude steel energy intensity is very sensitive to the assumption used for ferroalloy energy intensity. When the energy intensity of the ferroalloys decreases by 0.1 tce/t, the crude steel energy intensity correspondingly increases by 5%–5.5%, and vice versa. We used a low bound and a high bound of ferroalloy energy intensity assumptions, with the intent to capture the most likely energy intensity range for crude steel production. This is a compromise we had to make in conducting the benchmarking analysis. This approach could be improved if we could obtain the following data and information for Inner Mongolia:

- Specific energy intensity by ferroalloy types
- Total energy consumption of the iron and steel industry
- Energy consumption of the iron and steel industry by energy source

Because all steel production in Inner Mongolia in 2017 was primary steel production (BF-BOF process), we compared the estimated steel intensity to the national and global averages of primary steel production, as well as practical and theoretical minimum intensities (Figure 16). In addition, we also compared Inner Mongolia's primary steel energy intensity to the overall steel industry average, including both primary and secondary steelmaking, in China and globally.

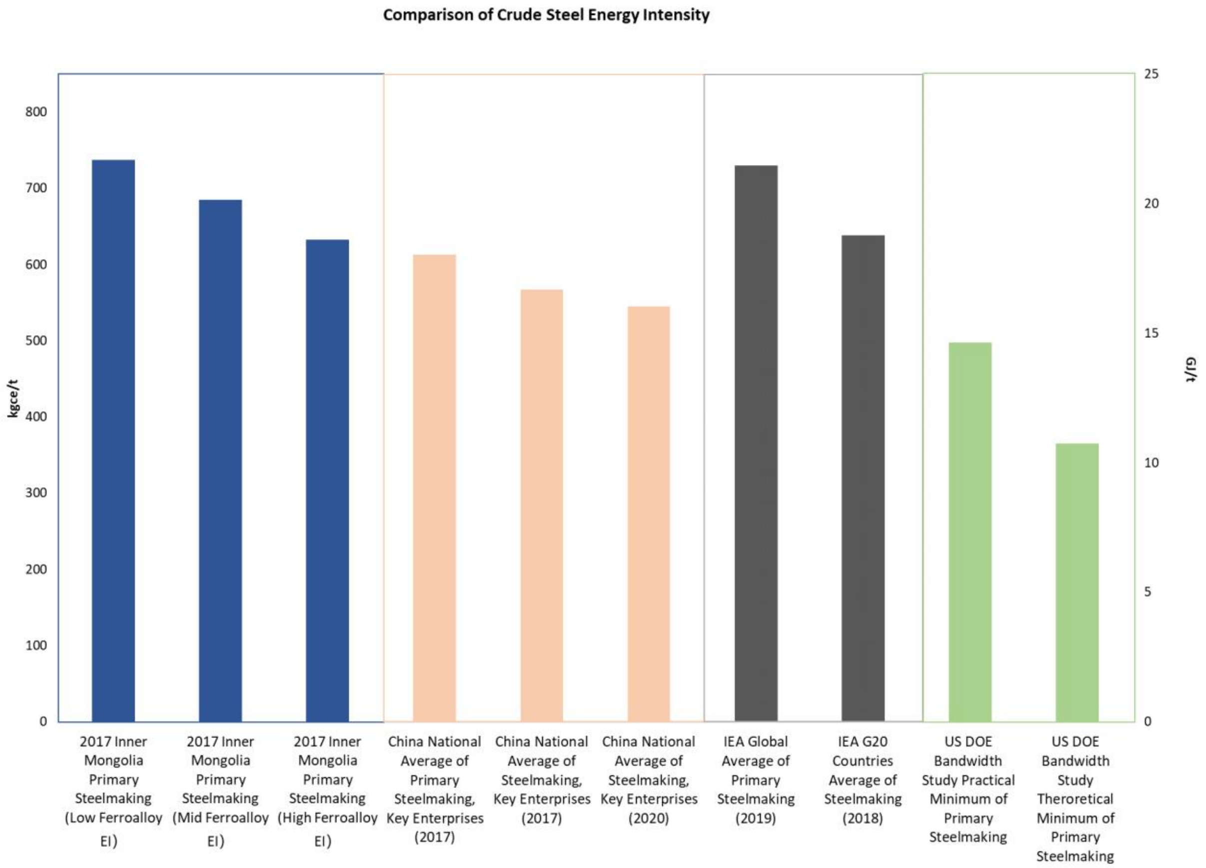


Figure 16. Crude steel energy intensity in Inner Mongolia compared to the Chinese average, global average, and practical and theoretical minimum intensities

Note: G20 countries include Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russia, Saudi Arabia, South Africa, South Korea, Turkey, the U.K. and the U.S., as well as the European Union.

In terms of primary steelmaking (BF-BOF process), China's national average energy intensity in 2017 was 613 kgce/t (18 GJ/t) (Editorial Board of China Steel Yearbook 2017). Inner Mongolia's primary steelmaking energy intensity is 3-20% higher (Figure 16).

The IEA reported that the global average primary steelmaking energy intensity was 730 kgce/t (21.4 GJ/t) in 2019, and used the Direct Equivalent method for electricity conversion (IEA 2020). Compared to the reported global average of BF-BOF steel intensity, Inner Mongolia's crude steel energy intensity ranges from 13% lower (in the High Ferroalloy EI assumption) to 1% higher (in the Low Ferroalloy EI assumption).

The DOE's bandwidth study of the iron and steel industry reported the practical minimum and theoretical minimum of crude steel energy intensities for primary steelmaking (U.S. DOE 2015). The bandwidth study defines the practical minimum to be "the energy consumption that may be possible if applied R&D technologies under development worldwide are deployed," and the theoretical minimum to be "the least amount of energy required under ideal conditions, which typically cannot be attained in commercial applications" (U.S. DOE 2015). This study calibrated the reported energy intensity based on the boundary definition of this report and estimated the practical and theoretical minimum of primary steel energy intensity to be 498 kgce/t (14.6 GJ/t) and 365 kgce/t (10.7 GJ/t), respectively. Compared to the practical minimum, Inner Mongolia's average intensity in 2017 was 27% to 48% higher.

In terms of overall steelmaking energy intensity, which considers both primary (BF-BOF) and secondary (scrap-based EAF) steelmaking processes, we compared Inner Mongolia's performance to the national and global averages. According to the *Iron and Steel Industry Upgrade Plan (2016–2020)* released by China's Ministry of Industry and Information Technology, the government reported the crude steel energy intensity, including both primary and secondary steelmaking of the key enterprises[13] was 572 kgce/t (16.8 GJ/t) in 2015, with the aim to achieve a goal of less than 560 kgce/t (16.4 GJ/t) by 2020. Extrapolating to 2017, the crude steel energy intensity target would have been 567 kgce/t (16.6 GJ/t). Compared to the national target of 2017, Inner Mongolia's average crude steel energy intensity in 2017 was 12% to 30% higher than the national target.

Other studies reporting China's crude steel energy intensity include the *China Energy Statistical Yearbook 2021* (NBS 2022), the *2020 Energy Data* published by Wang Qingyi (Wang 2021), and studies conducted by Zhang et al. (2018) and He and Wang (2017). However, the *China Energy Statistical Yearbook 2021* did not use the Direct Equivalent method; it used the China Coal Power Plant method to convert electricity use into standardized energy units. For other studies, it is not entirely clear which fuel and electricity conversion factors were used to calculate China's crude steel intensity. One recent study by Hasanbeigi and Springer (2019) used the Direct Equivalent method and estimated the overall energy intensity for China's steel industry was at 648 kgce/t (19 GJ/t) in 2016.

Compared to the global energy intensity of the steel industry at 638 kgce/t (18.7 GJ/t) (IEA 2021a), Inner Mongolia's crude steel energy intensity ranges from 1% lower (in the High Ferroalloy EI assumption) to 15% higher (in the Low Ferroalloy EI assumption).

To summarize, the comparisons show that in 2017, Inner Mongolia's primary steel energy intensity is comparable (1% higher) or potentially even better (13% lower) than the global average. However, compared to the domestic average energy intensity of primary steel production, Inner Mongolia is 3-20% higher. Its energy intensity can be further improved significantly when compared to the practical minimum energy intensity. Even though all steel production in Inner Mongolia in 2017 was from the primary steel (BF-BOF) process, we compared its performance to steel energy intensity that includes both primary and secondary, given the substantial energy-saving impact of scrap-based steel production. This comparison shows that Inner Mongolia's performance was 12-30% higher than the national average.

The results show that Inner Mongolia has significant potential to reduce its steel energy intensity. The local and central government can use a range of policy measures, such as regulatory requirements to conduct energy assessments and energy-efficiency retrofits, fiscal and financial incentives, and information on technologies and practices, to promote the adoption of energy-efficiency technologies in the steel industry.

---

[13] National averages of crude steel energy intensity are often reported for key steel enterprises only in China.

As the country and Inner Mongolia look to decarbonize the economy and achieve its climate goals before 2060, it is also critical to support low-carbon steelmaking technologies, such as scrap-based secondary steel production and green hydrogen-based direct reduction of iron processes.

Many commercialized and cost-effective technologies and measures can be taken to improve the energy performance in the steel and aluminum industries in Inner Mongolia. China's national program on industrial energy efficiency, benchmarking, retrofit incentives, and financing models (e.g., energy service companies) since the 11th Five-Year Plan can be utilized as a model for local jurisdictions in Inner Mongolia. Technology guides, catalogues, and software tools have been published by various institutions, such as China's technology guides on industrial energy-conservation and emission reduction[14], catalogues on energy-efficiency[15], low-carbon[16], and clean production[17], Lawrence Berkeley National Laboratory[18], the U.S. Energy Star program[19], and the U.S. Department of Energy's Bandwidth Study on the Iron and Steel Industry[20].

Policies such as improving steel recycling rates, improving recycled steel quality, adopting recycling technologies, providing incentives, and encouraging inter-provincial scrap circulation can increase scrap availability in Inner Mongolia.

4.4 Aluminum Industry in Inner Mongolia

The aluminum industry is the third largest energy-consuming industry in Inner Mongolia, after chemicals and ferrous metals manufacturing. It accounted for 17% of the manufacturing energy use in Inner Mongolia in 2019 (Inner Mongolia Autonomous Regional Bureau of Statistics 2022). Aluminum production from Inner Mongolia has increased significantly from about 1.5 Mt in 2010 to 5.8 Mt in 2021, growing 13% per year on average, as shown in Figure 17. As of 2021, Inner Mongolia's aluminum production reached 15% of the national total production, ranking third after Shandong Province and Xinjiang Province.

---

[14] National Development and Reform Committee of China, 2022. *Energy-Conservation and Emission Reduction Upgrade Implementation Guides for Energy-Intensive Industries.* https://www.ndrc.gov.cn/xxgk/zcfb/tz/202202/t20220211_1315446.html

[15] National Development and Reform Committee of China, 2014. *National Key Energy-Saving Technology Promotion Catalogues. https://www.ndrc.gov.cn/hdjl/yjzq/201412/t20141217_1165920.html*

[16] Ministry of Ecology and Environment of China, 2022. *National Low-Carbon Technology Catalogue (2022).* https://www.mee.gov.cn/xxgk2018/xxgk/xxgk06/202212/t20221221_1008424.html

[17] Ministry of Ecology and Environment of China, 2022. *National Advanced Technology Catalogue for Clean Production (2022).* https://www.mee.gov.cn/xxgk2018/xxgk/xxgk06/202301/t20230113_1012738.html

[18] Lawrence Berkeley National Laboratory, no date. *Industry Tools*: https://energyanalysis.lbl.gov/tools

[19] U.S. Energy Star, no date. *Energy Guides*: https://www.energystar.gov/industrial_plants/improve/energy-guides

[20] U.S. Department of Energy, 2015. *Bandwidth Study U.S. Iron and Steel Manufacturing*. https://www.energy.gov/eere/iedo/articles/bandwidth-study-us-iron-and-steel-manufacturing

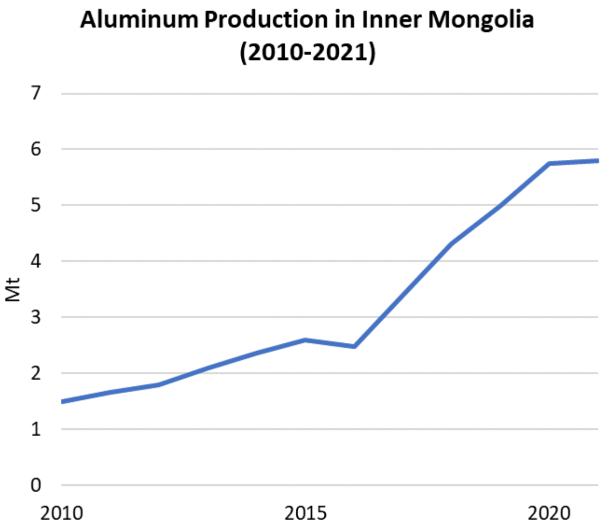


Figure 17. Aluminum production in Inner Mongolia (2010–2021)
Source: Inner Mongolia Autonomous Regional Bureau of Statistics 2022.

We found at least 10 aluminum-producing companies in Inner Mongolia, as shown in Table 13. These 10 companies have a total production capacity of 6.3 Mt per year. Most of the companies are located in Tongliao City and Baotou City. The majority of the aluminum companies in Inner Mongolia rely on on-site captive power (eight out of ten companies), while two companies use grid electricity.

Table 13. List of aluminum production companies in Inner Mongolia

#	City	Company Name (English)	Company Name (Chinese)	Nominal Aluminum Production Capacity (kt/year)
1	Tongliao	Inner Mongolia Jinlian Aluminum Co., Ltd.	内蒙古锦联铝材有限公司	1,050
2	Tongliao	Inner Mongolia Huomei Hongjun Aluminum Power Co., Ltd.	内蒙古霍煤鸿骏铝电有限责任公司	860
3	Tongliao	Inner Mongolia Chuangyuan Metal Co., Ltd.	内蒙古创源金属有限公司	787
4	Baotou	Baotou Xinhengfeng Energy Co., Ltd.	包头市新恒丰能源有限公司	500
5	Baotou	East Hope Baotou Rare Earth Aluminum Co., Ltd.	东方希望包头稀土铝业有限责任公司	860
6	Baotou	Baotou Aluminum Co., Ltd.	包头铝业有限公司	560
7	Baotou	Inner Mongolia Huayun New Materials Co., Ltd.	内蒙古华云新材料有限公司	750
8	Ordos	Ordos Mengtai Aluminum Co., Ltd.	鄂尔多斯市蒙泰铝业有限责任公司	500

9	Hohhot	Inner Mongolia Datang International New Energy Co., Ltd.	内蒙古大唐国际新能源有限公司	280
10	Tongliao	Inner Mongolia Tongshun Aluminum Co., Ltd.	内蒙古通顺铝业	115

Source: China Merchants Futures 2021

4.5 Aluminum Industry Energy Intensity Benchmarking

Aluminum can be produced either through virgin materials (primary production) or recycled materials (secondary production), as shown in Figure 18. Virgin aluminum is produced from the smelting of alumina, which is produced from bauxite ores. It is one of the most electricity-intensive industries.

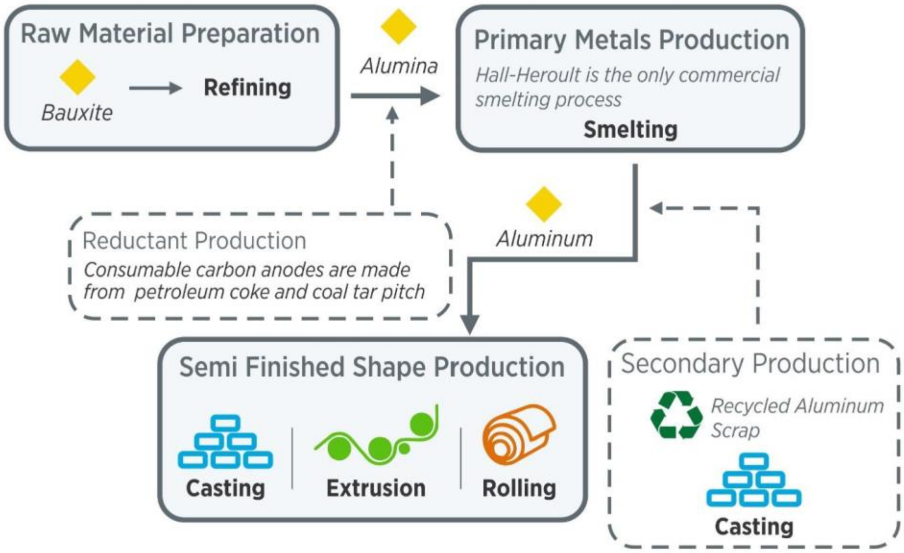


Figure 18. Aluminum production process

Source: U.S. Department of Energy 2017.

One study shows that on average aluminum smelting accounts for about 69% of the total energy used to produce aluminum products, which also includes mining, alumina production, and fabrication. Smelting aluminum requires a significant amount of electricity inputs; on average, 85% of the energy use is from electricity (Cushman-Roisin and Cremonini 2021). Thus, the carbon intensity of the electricity used to produce aluminum has a significant impact on the aluminum industry's CO_2 emissions.

Recycling aluminum has significant energy benefits, as secondary aluminum production that relies on scrap only requires 5% of the energy needed to produce primary aluminum (Tabereaux and Peterson 2014). China's secondary aluminum production has been growing steadily, increasing from 1.42 Mt in 2000 to 7.4 Mt by 2020 (China Business Intelligence Net 2022). However, compared to China's increasing total aluminum production, the share of secondary aluminum has been declining from 15% in 2018 to 12.8% in 2020 (Insight and Info 2022). The government's goal is to increase secondary aluminum production to 11.5 Mt by 2025. China's secondary aluminum production is located in coastal areas where aluminum scrap materials are more available. It is reported that the Holingol City of Inner Mongolia will add 1 Mt of secondary aluminum production capacity by 2025 (Jingyang Zhang 2022). For this study, it is assumed that all aluminum production in Inner Mongolia in 2017 was primary aluminum production.

The latest year of data on the industry's detailed energy use is 2017. *The Inner Mongolia Statistical Yearbook 2018* reported the industrial subsector of "smelting and pressing of non-ferrous metals" energy use by source in 2017, as shown in Table 14. Based on the China-specific fuel conversion factors (see earlier Table 7) and using the Direct Equivalent method of converting electricity consumption to standardized energy units, we calculated the total energy use of this industrial subsector to be 27.92 Mtce.

Table 14. Energy use by source of smelting and pressing of non-ferrous metals in Inner Mongolia (2017)

	Mtce	Mt	Mt	Mt	Mt	Mt	Mt	Mt	bcm	TWh
Sector	**Total Energy Use***	**Coal**	**Coke**	**Crude Oil**	**Gasoline**	**Kerosene**	**Diesel**	**Fuel Oil**	**Natural Gas**	**Electricity**
Smelting and pressing of non-ferrous metals	27.92	26.35	0.19	NA	0.00	0.00	0.02	0.00	0.24	70.05

Source: Inner Mongolia Autonomous Regional Bureau of Statistics 2022.
Notes: *based on the Direct Equivalent method; bcm = billion cubic meters; TWh = terawatt hours.

According to China's industrial classification standard (GB/T 4754-2017) (NBS 2017), the subsector of the smelting and pressing of non-ferrous metals (subsector B32) includes smelting of common non-ferrous metals (B321), smelting of precious metals (B22), smelting of rare earth metals (B323), production of non-ferrous metal alloys (B324), and pressing of non-ferrous metals (B325). Similar to the case of the iron and steel industry, the publicly accessible data (i.e., the Inner Mongolia Statistical Yearbooks) only provide information at the subsector B32 level (Table 14). Thus, it is necessary to estimate the aluminum industry's energy use, which is a subset of the smelting of common non-ferrous metals (B321) and pressing of non-ferrous metals (B325).

In 2017, Inner Mongolia produced a total of 4.57 Mt of non-ferrous metals. Aluminum production represented the largest share: about 74%. Four other major types of non-ferrous metals—copper, zinc, lead, and magnesium—collectively accounted for 24% of Inner Mongolia's total non-ferrous metal production. Other non-ferrous metals, such as tin and other rare earth metals, accounted for about 2% of its total production in 2017 (Table 15).

Table 15. Aluminum and other non-ferrous metals production in Inner Mongolia (2017)

Material	**Inner Mongolia Production (Mt)**	**Share of Total Production (%)**
Aluminum	3.4	74
Refined copper	0.24	5
Refined zinc	0.6	13
Refined lead	0.23	5
Refined magnesium	0.02	0.4

Other non-ferrous metals	0.93	2
Non-ferrous metals total	4.57	100

Source: Inner Mongolia Autonomous Regional Bureau of Statistics 2022.

We used the reported national energy intensity for copper, zinc, lead, and magnesium smelting (Table 16), as it is very challenging to gain access to specific energy intensity for Inner Mongolia. Based on Table 15 and Table 16, we calculated that the smelting of four non-ferrous metals (copper, zinc, lead, and magnesium) accounted for about 3.3% of total reported energy use in the subsector (subsector B321).

Table 16. Reported national energy intensity for copper, zinc, lead, and magnesium (2017)

Material	**Reported National Energy Intensity in 2017 (kgce/t)**	**Sources**
Copper smelting	359	Wang 2021
Zinc smelting	876	China Nonferrous Metals Industry Association 2021
Lead smelting	367.2	China Nonferrous Metals Industry Association 2021
Magnesium smelting*	4,000	Ministry of Industry and Information Technology 2013

Note: For magnesium, we used the national target for 2015.

Given the uncertainty in specific energy intensities for Inner Mongolia, we conducted a sensitivity analysis assuming Inner Mongolia's energy intensity of copper, zinc, lead, and magnesium smelting is 10% higher or 10% lower than the national average in 2017, as shown in Table 17. The results show that smelting copper, zinc, lead, and magnesium only accounted for about 3%–3.6% of total energy use in the subsector.

Table 17. Estimating energy use in smelting other non-ferrous metals (2017)

Material	**Sensitivity Analysis (SA) 01: 10% increase from the national average**		**Sensitivity Analysis (SA) 02: 10% decrease from the national average**	
	Estimated Inner Mongolia Energy Intensity (kgce/t)	Energy Use (Mtce)	Estimated Inner Mongolia Energy Intensity (kgce/t)	Energy Use (Mtce)
Copper smelting	394.9	0.09	323.1	0.08
Zinc smelting	963.6	0.58	788.4	0.47
Lead smelting	403.9	0.09	330.5	0.08
Magnesium smelting*	4,400	0.09	3600	0.07
Sum		*0.85*		*0.7*
Share of reported subsector energy use		*3.6%*		*3%*

Note: SA = sensitivity analysis

Assuming that the smelting and pressing of other major non-ferrous metals accounted for about 3.3% of reported subsectoral energy use in 2017, the energy consumption of smelting and pressing of aluminum in Inner Mongolia in 2017 was calculated to be about 27 Mtce (Table 18), with a comprehensive energy intensity of aluminum smelting of 232.8 kgce/kg in Inner Mongolia in 2017.

Table 18. Energy use by source of smelting and pressing of aluminum in Inner Mongolia (2017)

	Mtce	Mt	Mt	Mt	Mt	Mt	Mt	Mt	bcm	TWh	kgce/kg
	Total Energy Use*	**Coal**	**Coke**	**Crude Oil**	**Gasoline**	**Kerosene**	**Diesel**	**Fuel Oil**	**Natural Gas**	**Electricity**	**Overall Energy Intensity**
Aluminum	27.00	25.48	0.19	-	0.00	0.00	0.02	0.00	0.23	67.73	232.8

Notes: *based on the Direct Equivalent method; bcm = billion cubic meters; TWh = terawatt hours.

A key metric of the aluminum industry's energy efficiency is how much electricity is consumed for aluminum smelting. According to the Chinese accounting method, this does not include electricity consumed during the shutting down and restarting stages (National Development and Reform Commission 2021b), or other processes such as casting and finishing. Aluminum smelting is an electricity-intensive process in the aluminum manufacturing industry. A study citing a United Nations report shows that direct electricity consumption from aluminum smelting may be up to 85% of the total energy used in the aluminum industry, which includes mining, bauxite refining, smelting, and fabrication (Cushman-Roisin and Cremonini 2021).

We developed three scenarios to estimate the electricity intensity of aluminum smelting in Inner Mongolia. The key assumption is the share of electricity used for aluminum smelting in total electricity use for the industry. Considering electricity in the aluminum smelting process is also used for starting up, shutting down, maintenance, and other auxiliary processes, we used the range of 65% to 70%, as shown in Table 19. The results show that the electricity intensity of primary aluminum production in Inner Mongolia in 2017 was in the range of 13,396–13,950 kWh/t.

Table 19. Aluminum smelting electricity intensity in Inner Mongolia (2017)

Scenarios	Share of electricity used for aluminum smelting (%)	Electricity uses for smelting (TWh)	Electricity intensity (kWh/t)
Scenario 01	70	47.4	13,950
Scenario 02	67.5	45.7	13,452
Scenario 03	65	45.5	13,396

We compared our results to the reported national average in 2017, the announced national benchmark and advanced levels for primary aluminum production, as well as the global average, and practical and theoretical minimum intensities (Figure 19).

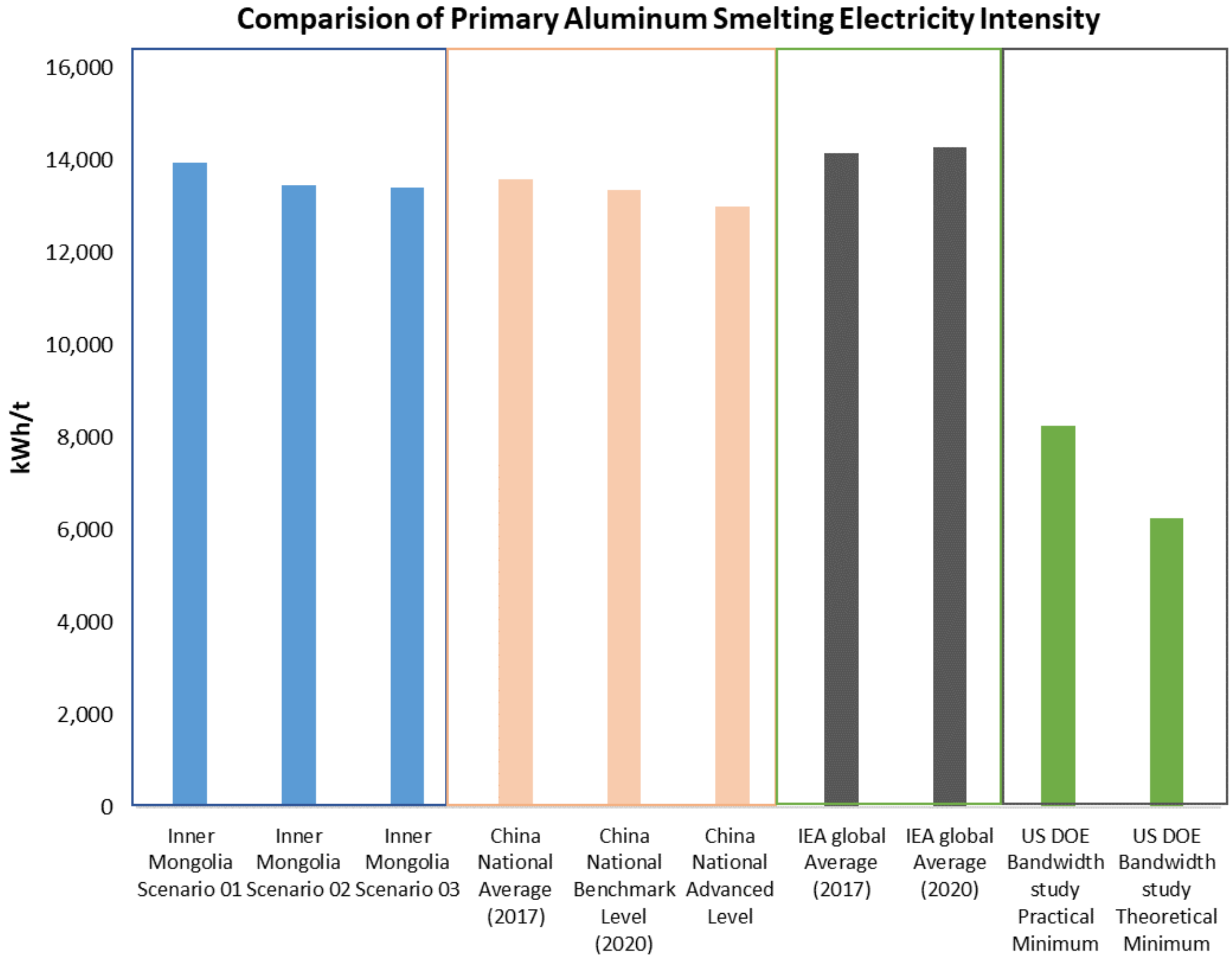


Figure 19. Primary aluminum smelting electricity intensity in Inner Mongolia compared to the Chinese average, global average, and practical and theoretical minimum intensities

China's average electricity intensity for primary aluminum production in 2017 is reported to be 13,577 kWh/t (Wang 2021). Compared to the 2017 national average, Inner Mongolia's aluminum electricity intensity is quite comparable, in the range of 1.3% lower (Scenario 03) and 2.7% higher (Scenario 01).

China's National Development and Reform Committee (NDRC) recently released the 2021 version of China's benchmark and advanced levels for key industries, including primary aluminum production (National Development and Reform Commission 2021a). The NDRC guidance shows the national benchmark is at 13,350 kWh/t, and the advanced level is even lower, at 13,000 kWh/t. Compared to China's national benchmark in 2021, Inner Mongolia's aluminum smelting electricity intensity is 0.3% – 4.5% higher. Compared to China's national advanced level, the aluminum smelting electricity intensity in Inner Mongolia is 3% to 7.3% higher.

The IEA reports the global average electricity intensity of primary aluminum smelting from 2000 to 2020 (IEA 2022a). The global average in 2020 was 14,273 kWh/t, which was an increase from

14,161 kWh/t in 2017. Compared to the global electricity intensity of primary aluminum smelting, Inner Mongolia's electricity intensity is about 1.5% to 5.4% lower.

The U.S. DOE's bandwidth study on aluminum smelting reported a practical and theoretical minimum electricity intensity of 8,239 kWh/t and 6239 kWh/t, respectively (US DOE 2017). Compared to the practical minimum intensity, which is defined as "the energy consumption that may be possible if applied R&D technologies under development worldwide are deployed", Inner Mongolia's level is significantly higher (>60%).

To summarize, Inner Mongolia's electricity intensity of primary aluminum production is lower (at 1.5% to 5.4% lower) than the global average in 2017 and 2020, and is comparable to China's national average in 2017. However, it is higher than the national benchmark (0.3-4.5% higher) and advanced levels (3-7.3% higher) recently set by NDRC in 2021. Inner Mongolia's aluminum smelting can still be substantially improved, as shown in the comparison to the U.S. DOE's practical minimum electricity intensity.

Energy use and emissions from primary aluminum production in Inner Mongolia can be significantly reduced by increasing the share of recycled aluminum production. Inner Mongolia is building a 1 Mt recycled aluminum production facility in Holingol City by 2025. Policies for improving recycling collection and sorting, connecting participants along the supply chain, and implementing extended producer responsibility schemes could be considered (IEA 2022b). In addition, innovations (e.g., inert anodes in smelting and electric calcination in the alumina refining process) are being developed and piloted in the aluminum industry, specifically addressing process emissions from the smelting process. Inner Mongolia and the Chinese aluminum industry could invest in the R&D of these technologies to achieve China's net-zero climate goal before 2060.

5. International Decarbonization Development in Heavy Industry

The steel, aluminum, and chemical industries are among the largest sources of GHG emissions globally. Decarbonization, or the process of reducing carbon dioxide emissions, is an important step in addressing climate change. In recent years, there have been increasing international efforts to decarbonize these industries, including measures such as transitioning to forms of energy with lower emissions, investing in research and development of low-carbon technologies, and implementing policies to incentivize the adoption of these technologies.

We summarize current international progress in terms of major global producers' decarbonization commitments in the steel, aluminum, and chemical industries. In addition to the steel and aluminum industries, we also added the chemical industry, as it is one of the largest energy-using industries in Inner Mongolia.

While different companies may have different products and production routes, or may vary in raw materials and type of electricity used, a collective review of corporate-level decarbonization goals may provide some indicative direction for future industry development. Such information may be useful for Inner Mongolia to develop strategies and policies for achieving China's carbon neutrality goals in the mid to long-term.

Many international and large state-owned Chinese companies have goals for emissions abatement and achieving carbon neutrality. However, some of the companies from China, especially non-state-owned companies, do not have a clear decarbonization goal.

5.1 Steel Industry

Table 20 provides the decarbonization goals of key steel companies from Inner Mongolia, as well as the Top-8 largest steel-producing companies in the world. Out of the ten steel companies in Inner Mongolia (see the full list in Table 9), two steel companies are members of China's Iron and Steel Industry Association (CISA), including Inner Mongolia Baotou Steel Union Co., Ltd., and Inner Mongolia Baotou Da'An Iron & Steel Co., Ltd. Particularly, Inner Mongolia Baotou Steel is the largest steel company in Inner Mongolia, representing more than 50% of total steel production in the region.

Globally, large steel corporations have established CO_2 emission reduction goals and/or goals to achieve carbon neutrality. Notable, Inner Mongolia Baotou Steel Union Company has developed its CO_2 peaking (by 2023) and carbon neutrality (by 2050) goals.

Table 20. Decarbonization goals of major steel companies in Inner Mongolia and the World

Country	Company	Production in 2021 (Mt)	Decarbonization Goals	Ownership
China: Inner Mongolia*	Inner Mongolia Baotou Steel Union Co., Ltd.	16.4	Peak CO_2 emissions by 2023 and achieve carbon neutrality by 2050	Publicly traded company
China: Inner Mongolia*	Inner Mongolia Baotou Da'An Iron & Steel Co., Ltd.	11**	Unclear decarbonization goals	Privately owned
China	Baowu Group	120	Aims for peak CO_2 emissions by 2023, reduce 30% of emissions by 2035, and achieve carbon neutrality by 2050	Central-wholly-owned
China	Ansteel Group	55.7	Peak CO_2 emissions by 2025, and reduce 30% of emissions from the peak by 2035	State-owned
China	Jiangsu Shagang Group	44.2	Unclear decarbonization goals	Privately owned
China	HBIS Group	41.6	Peak CO_2 emissions by 2022, reduce 10% of emissions from the peak by 2025, reduce 30% of emissions from the peak by 2030, and achieve carbon neutrality by 2050	State-owned
China	Jianlong Group	36.7	Peak CO_2 emissions by 2025, reduce 20% of emissions from the peak by 2033, decrease carbon intensity by 25% from the 2020 level by 2033, and achieve carbon neutrality by 2060	Privately owned
Luxemburg (HQ)	ArcelorMittal	79.3	Reduce CO_2 emissions by 30% by 2030, and be carbon neutral by 2050	Privately owned
Japan	Nippon Steel Corporation	49.5	Achieve a 30% or more reduction in total CO_2 emissions by 2030 compared to 2013, and become carbon neutral by 2050	Publicly traded company
South Korea	POSCO	43.0	Reduce CO_2 emissions by 20% by 2030 and 50% by 2040, and achieve net-zero emissions by 2050	Publicly traded company

Sources: See Appendix B.

Notes: *we only included two steel companies from Inner Mongolia on this table, as they are members of China's Iron and Steel Industry Association (CISA). The list of other steel companies in Inner Mongolia can be found in Table 9. **production capacity. HQ: headquarter.

5.2 Aluminum Industry

In the aluminum industry, Table 21 identifies the decarbonization commitments from two of the largest aluminum production companies in Inner Mongolia and the largest nine aluminum production companies in the world. Out of the ten aluminum companies in Inner Mongolia (see the full list in Table 13), two aluminum companies – Inner Mongolia Jinlian Aluminum Co., Ltd. and Inner Mongolia Huomei Hongjun Aluminum Power Co., Ltd. – are the largest, representing 17% and 15% of Inner Mongolia's aluminum production in 2021, respectively.

Many large Chinese and international companies have established CO_2 emission reduction goals and/or goals of achieving carbon neutrality. However, the two largest aluminum-producing companies in Inner Mongolia have not yet established any clear decarbonization goals.

Table 21. Decarbonization goals of major aluminum companies in Inner Mongolia and the World

HQ Country	Company	Production in 2021 (Mt)	Decarbonization Goals	Ownership
China: Inner Mongolia*	Inner Mongolia Jinlian Aluminum Co., Ltd.	0.99	Unclear decarbonization goals	Privately owned
China: Inner Mongolia	Inner Mongolia Huomei Hongjun Aluminum Power Co., Ltd.	0.88	Unclear decarbonization goals	Centrally-controlled joint venture
China	Chinalco	6.7	Aims for peak carbon emissions before 2025, 40% cut by 2035.	Centrally owned
China	Hongqiao Group	5.7	Strive to keep its peak carbon emissions before 2025 and to reach net-zero emissions before 2055.	Publicly traded company
China	Xinfa Group	3.6	Unclear decarbonization goals	Publicly traded company
China	State Power Investment Corporation (SPIC)	2.4	Will reach the peak carbon emission in China by 2023 and will contribute to global clean energy and low-carbon development.	Centrally owned
Russia	RUSAL	3.8	Aims to become net zero by 2050 and to reduce GHG emissions by at least 35% by 2030.	Publicly traded company
London	Rio Tinto	3.2	Accelerate actions to decarbonize its assets in the short term and aim for a 15% reduction in emissions by 2025.	Publicly traded company

United States	Alcoa	2.2	Achieve net-zero GHG emissions across all global operations by 2050.	Publicly traded company
United Arab Emirates	Emirates Global Aluminum (EGA)	2.5	Committed to net zero GHG emissions by 2050 to support low-carbon industries to contribute towards the achievement of the UAE's Net Zero by 2050 Strategic Initiative.	State-owned
Norway	Norsk Hydro	2.2	Aims to achieve net zero carbon emissions by 2050 or earlier and is pursuing three decarbonization paths to reduce the carbon footprint of aluminum to net zero.	Publicly traded company

Source: See Appendix B.

Note: *we only included the two largest aluminum production companies in Inner Mongolia based on the production capacity and production in 2021. The list of other aluminum companies in Inner Mongolia can be found in Table 13. HQ: headquarter.

5.3 Chemical Industry

For a hard-to-abate industry like the chemical industry, Table 22 shows the key chemical companies in Inner Mongolia as well as the largest chemical companies in the world.

Several international companies have established carbon emission reduction or carbon neutrality goals but domestically, only China Sinopec has announced a decarbonization target by 2050. Inner Mongolia's major chemical companies, such as Junzheng Energy & Chemical and Wuhai Chemical Industry, have not developed any goals yet.

Table 22. Decarbonization goals of major chemical companies in Inner Mongolia and the World

Country	Company	Decarbonization Goals	Ownership
China: Inner Mongolia	Junzheng Energy & Chemical Group	Unclear decarbonization goals	Publicly traded company
China: Inner Mongolia	Wuhai Chemical Industry Limited Company	Unclear decarbonization goals	Privately owned
China	China Sinopec	Peak carbon emissions by 2030 and achieve carbon neutrality by 2050.	Centrally owned, publicly traded
China	Sinochem	Unclear decarbonization goals	Centrally owned
Germany	BASF	Reduce CO_2 emissions by 25% by 2030 and achieve net-zero CO_2 emissions globally by 2050	Publicly traded company
US	Dow	Reduce net annual carbon emissions by 15% by 2030, compared with 2020; carbon neutral by 2050	Publicly traded company
UK	Ineos	Achieve a 35% intensity reduction in GHG emissions by 2028, compared to 2018	Publicly traded company
Saudi Arabia	Sabic	Reduce Scope 1 and 2 emissions by 20% from the 2018 baseline by 2030 and achieve carbon neutrality by 2050	Central-wholly-owned
Taipei	Formosa Plastics	Reduce CO_2 emissions by 35% by 2030 from the 2007 level and achieve carbon neutrality by 2050	Publicly traded company
South Korea	LG Chem	Achieve net zero by 2050	Publicly traded company
Japan	Mitsubishi Chemical	26% reduction in Japan by the fiscal year 2030 compared to FY 2013	Publicly traded company

UK	Linde	Achieve a 35% intensity reduction in GHG emissions by 2028, compared to 2018	Publicly traded company
US	LyondellBasell Industries	Achieve a 15% reduction in CO_{2e} emissions per ton of product produced by 2030 compared with 2015	Publicly traded company

Source: See Appendix B.
Note: International companies are ranked by chemical sales in 2020.

6. References

American Iron and Steel Institute (AISI). “Steel Production Greenhouse Gas Emissions Calculation Methodology Guidelines”, November 3, 2022. https://www.steel.org/wp-content/uploads/2022/11/AISI-GHG-Emissions-Calculation-Methodology-Guidelines-final-11-3-22.pdf

China Building Materials Information. 2018. “China Steel Industry Data of 2017 Released.” 2018. http://www.cbmf.org/mobile/_470515/_1577052/6755074/index.html.

China Business Intelligence Net. 2022. “2022 China Recycled Aluminum Industry Outlook and Investment Research.” https://m.askci.com/news/chanye/20220725/1748351934685.shtml.

China Industry Information Net. 2018. “2017 China Manganese Silicon Alloy Production and Supply.” 2018. https://www.chyxx.com/industry/201808/669303.html.

China Merchants Futures. 2021. “China Merchants Futures: Impact of Double Controls in Inner Mongolia: Aluminum Production Allocation and Cost.” February 10, 2021. https://finance.sina.cn/futuremarket/qszx/2021-02-10/detail-ikftssap5159193.d.html.

China Nonferrous Metals Industry Association. 2021. “2020 China Non-Ferrous Metals Industry Economic Operation Report.” http://lwzb.stats.gov.cn/pub/lwzb/tzgg/202107/W020210723348607267532.pdf.

China Iron and Steel Industry Association (CISA). 2021. “Membership Introduction of China’s Iron and Steel Industry Association.” 2021. http://www.chinaisa.org.cn/gxportal/xfgl/portal/content.html?articleId=f45b2924e2e9d92212933cb7409d94a7ee76f49fdf79158c1cd00eb0592c9b8e&columnId=0e9486b16fd79331de0e92e8c2c3968519b20df5fa5ed6dd3f450654ce9b9d82.

CNFEOL. 2018. “2018 Ferrochrome Market Review.” 2018. https://www.cnfeol.com/price/market_analysis/internal/20190102/103000232212.aspx.

Cushman-Roisin, Benoit, and Bruna Tanaka Cremonini. 2021. “Chapter 1 - Materials.” In *Data, Statistics, and Useful Numbers for Environmental Sustainability*, edited by Benoit Cushman-Roisin and Bruna Tanaka Cremonini, 1–16. Elsevier. https://doi.org/10.1016/B978-0-12-822958-3.00012-1.

Ding, Guibin. 2021. “History of the Digital Transition of China’s Chlor-Alkali Industry.” 2021. http://www.ccin.com.cn/detail/96d0b562ad19ee2434b662b18149dd83/news.

Editorial Board of China Steel Yearbook. 2017. China Steel Yearbook 2017. Beijing, China.

Editorial Board of China Steel Yearbook. 2021. China Steel Yearbook 2021. Beijing, China.

General Administration of Quality Supervision, Inspection and Quarantine of China, and Standardization Administration of China. 2017. “The Norm of Energy Consumption per Unit Product of Ferroalloy (GB 21341-2017).” 2017. https://std.samr.gov.cn/gb/search/gbDetailed?id=71F772D81D0AD3A7E05397BE0A0AB82A.

Global Energy Monitor. 2022. “Global Steel Plant Tracker, Global Energy Monitor, March 2022 Release.” https://globalenergymonitor.org/projects/global-steel-plant-tracker/.

Great Wall Securities. 2020. “Petrochemical Special Reports 01: Methanol.” 2020. https://stock.finance.sina.com.cn/stock/go.php/vReport_Show/kind/search/rptid/636045203993/index.phtml.

Greenhouse Gas Protocol (GHG Protocol). 2008. " Calculating Greenhouse Gas Emissions from Iron and Steel Production", https://ghgprotocol.org/calculation-tools#sector_specific_tools_id

Guo, Rongxing. 2013. *Regional China: A Business and Economic Handbook*. Palgrave Macmillan. https://link.springer.com/book/10.1057/9781137287670.

Hasanbeigi, Ali, Lynn Price, Zhang Chunxia, Nathaniel Aden, Li Xiuping, and Shangguan Fangqin. 2014. “Comparison of Iron and Steel Production Energy Use and Energy Intensity in China and the U.S.” *Journal of Cleaner Production* 65 (February): 108–19. https://doi.org/10.1016/j.jclepro.2013.09.047.

Hasanbeigi, Ali, and Cecilia Springer. 2019. “How Clean Is the U.S. Steel Industry?” https://www.globalefficiencyintel.com/us-steel-industry-benchmarking-energy-co2-intensities.

He, Kun, and Li Wang. 2017. “A Review of Energy Use and Energy-Efficient Technologies for the Iron and Steel Industry.” *Renewable and Sustainable Energy Reviews* 70 (April): 1022–39. https://doi.org/10.1016/j.rser.2016.12.007.

Hu, Zhigang, Chensheng Wang, Keqing Li, and Xinyou Zhu. 2018. “Distribution Characteristics and Pollution Assessment of Soil Heavy Metals over a Typical Nonferrous Metal Mine Area in Chifeng, Inner Mongolia, China.” *Environmental Earth Sciences* 77 (18): 638. https://doi.org/10.1007/s12665-018-7771-1.

IEA. 2020. “Iron and Steel Technology Roadmap.” October 2020. https://www.iea.org/reports/iron-and-steel-technology-roadmap.

IEA. 2021a. "Driving Energy Efficiency in Heavy Industries", March. https://www.iea.org/articles/driving-energy-efficiency-in-heavy-industries

IEA. 2021b. “Key World Energy Statistics 2021 – Analysis.” https://www.iea.org/reports/key-world-energy-statistics-2021.

IEA. 2022a. “Energy Intensity of Primary Aluminium Smelting by Region, 2000-2020 – Charts – Data & Statistics.” IEA. 2022. https://www.iea.org/data-and-statistics/charts/energy-intensity-of-primary-aluminium-smelting-by-region-2000-2020.

IEA. 2022b. "Aluminum". September. https://www.iea.org/reports/aluminium

Inner Mongolia Autonomous Regional Bureau of Statistics. 2022. *Inner Mongolia Statistical Yearbook 2022*. China Statistics Press. http://tj.nmg.gov.cn:18080/files_pub/content/PAGEPACK/bc68854b528043ee865bc3a622b13a17/zk/indexce.htm.

Insight and Info. 2022. “Analysis of China’s Secondary Aluminum Industry.” 2022. https://www.chinabaogao.com/market/202208/605099.html.

IPCC. n.d. “2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 2. Energy. Chapter 2.” Accessed January 23, 2023. https://www.ipcc-nggip.iges.or.jp/public/2006gl/.

Kraan, O., Chappin, E., Kramer, G.J., Nikolic, I., 2019. “The influence of the energy transition on the significance of key energy metrics” *Renewable and Sustainable Energy Reviews* 111: 215-233, https://doi.org/10.1016/j.rser.2019.04.032

Lewis, J., Fridley, D., Price, L., Lu, H., and Romankiewicz, J., 2015. “Understanding China’s non-fossil energy targets,” *Science*, November 27. 350 (6265): 1034-1036. DOI: 10.1126/science.aad1084.

Li, Yongtao. 2018. “Industiral Economic Development of Inner Mongolia Achieved Significant Results.” *Inner Mongolia Daily*, December 12, 2018. http://www.gov.cn/xinwen/2018-12/13/content_5348330.htm.

Lu, Hongyou, Lynn Price, and Qi Zhang. 2016. "Capturing the Invisible Resource: Analysis of Waste Heat Potential in Chinese Industry." *Applied Energy* 161 (January): 497–511. https://doi.org/10.1016/j.apenergy.2015.10.060.

Ministry of Industry and Information Technology. 2013. "Guidance opinions on non-ferrous metals industry", China Nonferrous Net. 2013. https://www.cnmn.com.cn/ShowNews1.aspx?id=262552.

Ministry of Natural Resources of China. 2022. "2021 Statistic Table of National Mineral Resource Reserves." https://www.mnr.gov.cn/sj/sjfw/kc_19263/kczycltjb/.

Mysteel. 2022. "China and the World's Ferrochrome Production." 2022. https://www.sohu.com/a/www.sohu.com/a/517300645_121123910.

National Bureau of Statistics. 2021. "Annual Data." https://data.stats.gov.cn/easyquery.htm?cn=C01.

National Development and Reform Commission. 2020. "NDRC Invited and Had Discussion with Energy Conservation Authorities in Inner Mongolia." 2020. https://www.ndrc.gov.cn/fzggw/jgsj/hzs/sjdt/202009/t20200918_1239134.html?code=&state=123.

National Development and Reform Commission. 2021a. "High Energy-Consuming Industry Key Area Energy Efficiency Advanced and Benchmark Levels." 2021. https://www.ndrc.gov.cn/xwdt/tzgg/202111/t20211115_1304013_ext.html.

National Development and Reform Commission. 2021b. "Main Technical Indicator and Calculation Method." https://www.ndrc.gov.cn/xxgk/zcfb/tz/202108/P020210827597610873948.pdf.

National Bureau of Statistics (NBS). 2017. "Industrial Classification for National Economic Activities（GB/T 4754—2017）." http://www.stats.gov.cn/tjsj/tjbz/hyflbz/201710/t20171012_1541679.html.

National Bureau of Statistics (NBS). 2021. *China Statistical Yearbook 2021*. China Statistics Press. http://www.stats.gov.cn/tjsj/ndsj/2021/indexch.htm.

National Bureau of Statistics (NBS). 2022. *China Energy Statistical Yearbook 2021*. China Statistics Press.

Qian, G, Y Zhang, and J Wu. 2010. "Decomposition Analysis of Changes in Energy Consumption and Carbon Emissions in Inner Mongolia." *Technology Economics (Chinese)* 29 (12). http://leml.la.asu.edu/jingle/Wu-Publications-PDFs/2010/2010%23Qian_etal-%E5%86%85%E8%92%99%E5%8F%A4%E8%83%BD%E6%BA%90%E6%B6%88%E8%B4%B9%E7%A2%B3%E6%8E%92%E6%94%BE%E5%8F%98%E5%8C%96%E7%9A%84%E5%88%86%E8%A7%A3%E5%88%86%E6%9E%90.pdf.

Qianzhan Research Institute. 2021. "Current Status of Ferrosilicon Market Supply and Demand." 2021. https://solar.ofweek.com/2022-01/ART-260001-8420-30545141.html.

RMI. 2022. *Steel Emissions Reporting Guidance*. August. https://rmi.org/wp-content/uploads/2022/09/steel_emissions_reporting_guidance.pdf

Shang, Chenwei, Tong Wu, Ganlin Huang, and Jianguo Wu. 2019. "Weak Sustainability Is Not Sustainable: Socioeconomic and Environmental Assessment of Inner Mongolia for the Past Three Decades." *Resources, Conservation and Recycling* 141 (February): 243–52. https://doi.org/10.1016/j.resconrec.2018.10.032.

Sina Finance. 2022. “Understanding Inner Mongolia Region Manganese Silicon Industry.” August 17, 2022. https://finance.sina.com.cn/money/future/roll/2022-08-17/doc-imizmscv6607429.shtml.

State Council. 2017. “State Council Notice on Energy Conservation and Emission Reduction Comprehensive Working PLan during the 13th Five-Year Plan.” 2017. http://www.gov.cn/zhengce/content/2017-01/05/content_5156789.htm.

Stubbles, John. 2000. “Energy Use in the U.S. Steel Industry: A Historical Perspective and Future Opportunities.” Energetics, Inc., Columbia, MD (US). https://doi.org/10.2172/769469.

Tabereaux, Alton T., and Ray D. Peterson. 2014. “Chapter 2.5 - Aluminum Production.” In *Treatise on Process Metallurgy*, edited by Seshadri Seetharaman, 839–917. Boston: Elsevier. https://doi.org/10.1016/B978-0-08-096988-6.00023-7.

Tanaka, Kanako. 2008. “Assessment of Energy Efficiency Performance Measures in Industry and Their Application for Policy.” *Energy Policy* 36 (8): 2887–2902. https://doi.org/10.1016/j.enpol.2008.03.032.

The State Council Information Office. 2022. “Inner Mongolia Held a Briefing on the Implementation Plan of Energy Conservation and Emission Reduction during the 14th Five-Year Plan.” 2022. http://www.scio.gov.cn/xwfbh/gssxwfbh/xwfbh/neimenggu/Document/1725419/1725419.htm.

Tréanton, Karen. 2008. “Units of Measurement and Conversion Factors: International Workshop on Energy Statistics.”

United States Department of Energy (US DOE). 2017. “Bandwidth Study U.S. Aluminum Manufacturing.” Energy.Gov. 2017. https://www.energy.gov/eere/amo/downloads/bandwidth-study-us-aluminum-manufacturing.

United States Department of Energy (US DOE). 2015. “Bandwidth Study U.S. Iron and Steel Manufacturing.” https://www.energy.gov/eere/amo/downloads/bandwidth-study-us-iron-and-steel-manufacturing.

United Nations (UN), Department of Economic and Social Affairs, Statistics Division (2018). *International Recommendations for Energy Statistics.* https://unstats.un.org/unsd/energystats/methodology/ires/

United States Energy Information Administration (US EIA). 2017. “U.S. Energy Information Administration - EIA - Independent Statistics and Analysis.” 2017. https://www.eia.gov/todayinenergy/detail.php?id=30072.

United States Energy Information Administration (US EIA). 2022. “Monthly Energy Review: December 2022.” https://www.eia.gov/totalenergy/data/monthly/index.php.

United States Energy Information Administration (U.S. EIA), 2019. *Monthly Energy Review.* https://www.eia.gov/totalenergy/data/monthly/pdf/sec1_3.pdf

Wang Qingyi. 2021. “2020 Energy Data.” https://www.efchina.org/Reports-zh/report-lceg-20210430-3-zh.

Worrell, Ernst, Lynn Price, Nathan Martin, Jacco Farla, and Roberto Schaeffer. 1997. “Energy Intensity in the Iron and Steel Industry: A Comparison of Physical and Economic Indicators.” *Energy Policy*, Cross-country comparisons of indicators of energy use, energy efficiency and CO2 emissions, 25 (7): 727–44. https://doi.org/10.1016/S0301-4215(97)00064-5.

Wu, Rina, Jiquan Zhang, Yuhai Bao, Quan Lai, Siqin Tong, and Youtao Song. 2016. “Decomposing the Influencing Factors of Industrial Sector Carbon Dioxide Emissions in Inner Mongolia Based on the LMDI Method.” *Sustainability* 8 (7): 661. https://doi.org/10.3390/su8070661.

Xinhua Net. 2020. “Xi Focus: Xi Announces China Aims to Achieve Carbon Neutrality before 2060.” 2020. http://www.xinhuanet.com/english/2020-09/23/c_139388764.htm.

Xinhua Net. 2021a. “Full Text: Working Guidance For Carbon Dioxide Peaking And Carbon Neutrality In Full And Faithful Implementation Of The New Development Philosophy.” 2021. http://www.news.cn/english/2021-10/24/c_1310265726.htm.

Xinhua Net. 2021b. “Full Text: Action Plan for Carbon Dioxide Peaking Before 2030.” 2021. http://www.news.cn/english/2021-10/27/c_1310270985.htm.

Yang, Zeyi. 2022. “China Is Betting Big on Another Gas Engine Alternative: Methanol Cars.” MIT Technology Review. 2022. https://www.technologyreview.com/2022/09/30/1060508/china-betting-methanol-cars/.

Zhang, Jinghong. 2022. “Configuration of Energy Transition Factors in Inner Mongolia: A Qualitative Fuzzy Logic Approach.” Hochschulbibliothek der Technischen Hochschule Köln. https://doi.org/10.57683/EPUB-1972.

Zhang, Jingyang. 2022. “Holingol of Inner Mongolia: High Quality Development of New ‘Aluminum’ Industry.” China Science Daily. 2022. http://stdaily.com/index/kejixinwen/202208/dd92983053394c5ca3cd570e567b8078.shtml

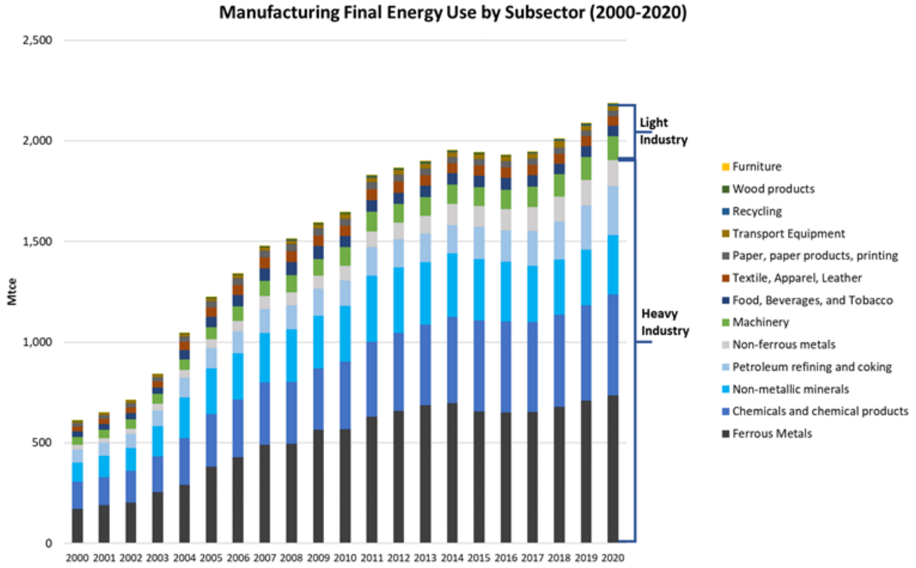
Zhang, Qi, Jin Xu, Yujie Wang, Ali Hasanbeigi, Wei Zhang, Hongyou Lu, and Marlene Arens. 2018. “Comprehensive Assessment of Energy Conservation and CO2 Emissions Mitigation in China’s Iron and Steel Industry Based on Dynamic Material Flows.” *Applied Energy* 209 (January): 251–65. https://doi.org/10.1016/j.apenergy.2017.10.084.

Zhang, Yichi, Jianjun Xia, Hao Fang, Hetao Zuo, and Yi Jiang. 2019. “Roadmap towards Clean Heating in 2035: Case Study of Inner Mongolia, China.” *Energy* 189 (December): 116152. https://doi.org/10.1016/j.energy.2019.116152.

Appendix A: An Overview: China's industry sector

The industry is the largest end-use sector, accounting for 65% of China's total primary energy use and 70% of total energy-related CO_2 emissions in 2020 (National Bureau of Statistics 2021; IPCC n.d.) China's industrial energy use and emissions are dominated by heavy industries such as steel, cement, and chemicals.

Since joining the World Trade Organization (WTO) in 2001, China has become the world's factory, with a diverse variety of manufacturing sectors. However, in terms of energy use, the majority of China's manufacturing final energy use is consumed by five manufacturing subsectors: ferrous metals, chemicals and chemical products, non-metallic minerals, petroleum refining and coking, and non-ferrous metals (Figure A-1). These five heavy industries accounted for 87% of the final energy use in China's manufacturing sector in 2020, up from 80% in 2000.

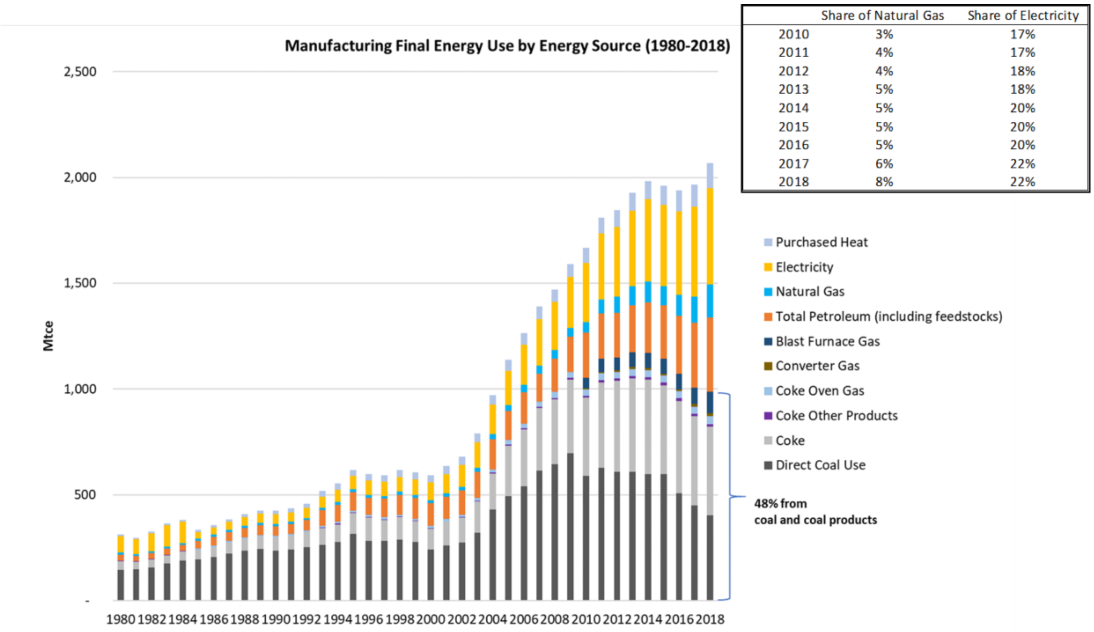


	Share of Heavy Industry
2000	80%
2001	80%
2002	80%
2003	82%
2004	82%
2005	83%
2006	82%
2007	83%
2008	82%
2009	83%
2010	84%
2011	85%
2012	85%
2013	86%
2014	86%
2015	86%
2016	86%
2017	86%
2018	86%
2019	86%
2020	87%

Figure A-1. Manufacturing final energy use by subsector in China (2000–2020)
Source: NBS, various years.

As shown in Figure A-1, the ferrous metals industry, dominated by the manufacture of iron and steel, is the leading energy-consuming industry, accounting for 34% of manufacturing final energy use in China in 2020. Steel and steel products used in buildings, machinery, vehicles, energy systems, shipping, appliances, railways, containers, and other urban infrastructure systems are the key material for China's urbanization. The second largest energy-using manufacturing industry is chemicals and chemical products, representing about 23% of manufacturing's final energy use. This industry produces materials such as plastics and fertilizers. The non-metallic minerals subsector produces key building and infrastructure materials, such as cement and glass, contributing 14% of the final energy demand in China's manufacturing sector in 2020, a decline from 17% in 2010. However, this subsector's share of CO_2 emissions is higher because cement-making produces CO_2 from the calcination of carbonate minerals, in addition to CO_2 from fossil fuel combustion. Petroleum refining and coking, as well as non-ferrous metals (producing metals such as aluminum and copper), accounted for 11% and 6% of the final manufacturing energy use in 2020, respectively.

China’s manufacturing sector traditionally relied heavily on coal as its energy input. In 1980, more than 60% of the final manufacturing energy demand was met by coal and coal products (47% direct coal use and 14% coke use). Petroleum (including feedstocks) and natural gas accounted for 9% and 3% of the final manufacturing energy demand, respectively. By 2018, while coal and coal products were still the largest energy input, contributing to 48% of the final manufacturing energy use, the share of direct use of coal sharply declined from 47% in 1980 to 19% in 2018. The decline of direct coal use was most significant in the last few years, due to China’s increasingly stringent air pollution control policies. However, it is also noteworthy that the share of coke and coke products increased from 14% in 1980 to 28% in 2018. From 2010 to 2018, the share of coke and coke products stayed essentially the same (Figure A-2). In addition, the share of natural gas increased from 3% in 2010 to 8% in 2018, while the share of electricity also increased from 17% in 2010 to 22% in 2018.



	Share of Natural Gas	Share of Electricity
2010	3%	17%
2011	4%	17%
2012	4%	18%
2013	5%	18%
2014	5%	20%
2015	5%	20%
2016	5%	20%
2017	6%	22%
2018	8%	22%

Figure A-2. Manufacturing final energy use by energy source in China (1980–2018)
Source: NBS, various years.

Electricity generation in China has become cleaner over the years, with the share of thermal power (electricity generation from coal, petroleum, and natural gas) decreasing from 83% in 2000 to 68% in 2021 (NBS 2022). Wind and solar power generation accounted for 7% and 4% of total electricity generation in China (CEC 2022). China’s industrial sector energy transition needs to consider the decarbonization progress in China’s grid, as well as the implications of the energy transition on China’s power sector.

Compared to other countries, China’s industrial sector relies more heavily on fossil fuels. While the share of coal use in China declined to 48% in 2018, the share of coal use in India, Japan, Germany, and the United States was 46%, 18%, 10%, and 6%, respectively (Figure A-3). China also has one of the highest shares of fossil-energy inputs in the industrial sector. About 72% of final industrial energy use is from coal, petroleum, and natural gas in China, while the share in other selected countries ranges from 51% (Germany) to 72% (Japan) (IEA 2021b; NBS 2020).

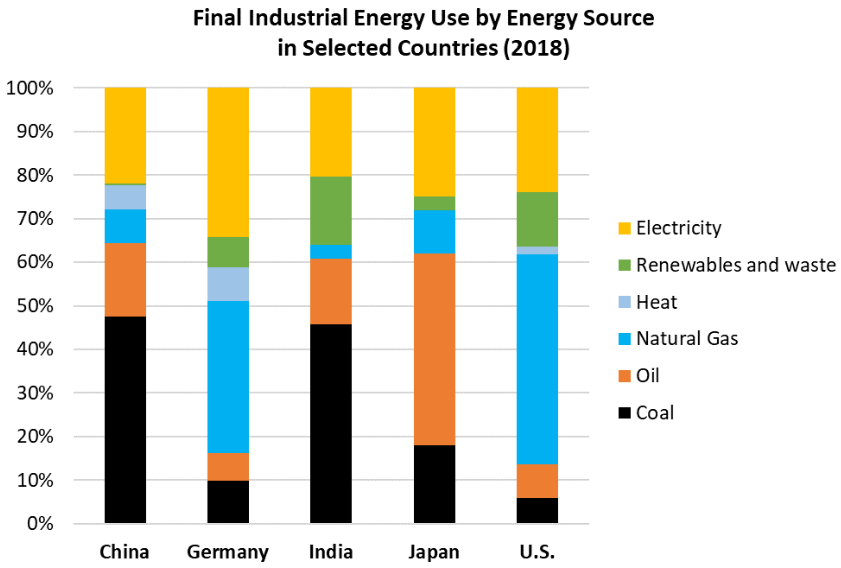


Figure A-3. Final industrial energy use by source in selected countries (2018)

Sources: IEA 2021b; NBS 2020.

Notes: (1) China energy data is from NBS (2020); energy data for other countries are from IEA (2021b); (2) both data sets include non-energy use; (3) IEA (2021b) defines "Renewables and waste" to include on-site "hydro, geothermal, solar, wind, and tide/wave/ocean energy and the use of these energy forms for electricity and heat generation, as well as solid biofuels, liquid biofuels, biogases; industrial waste and municipal waste"; (4) "Electricity" refers to electricity purchased from the grid, which was generated via a mixture of renewable and non-renewable sources.

In terms of China's energy-related CO_2 emissions, the industrial sector contributes the most, accounting for about 70% of China's total CO_2 emissions in 2020, as shown in Figure A-4.

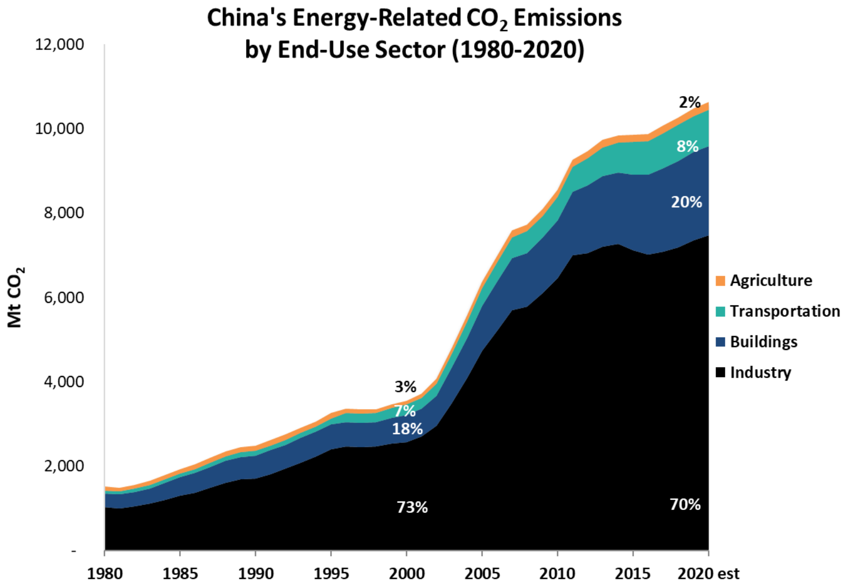


Figure A-4. China's energy-related CO_2 emissions by end-use sector (1980–2020)

Sources: NBS, various years; IPCC 2006.

Notes: (1) Energy data from NBS were converted to CO_2 emissions using IPCC emissions factors. (2) The industry sector also includes construction.

Appendix B: Citations for company decarbonization targets

Citations for Table 20. Decarbonization goals of major steel companies in Inner Mongolia:

1. "China to boost policies to promote development of intelligent transport." Xinhuanet. http://www.xinhuanet.com/2021-01/20/c_1127006254.htm.
2. "ArcelorMittal sets 2050 group carbon emissions target of net zero." ArcelorMittal. https://corporate.arcelormittal.com/media/press-releases/arcelormittal-sets-2050-group-carbon-emissions-target-of-net-zero.
3. "China's BYD to supply EVs to Japan's Nippon Rent-A-Car." Xinhuanet. http://www.xinhuanet.com/fortune/2021-03/13/c_1127207319.htm
4. "Nippon Steel aims for zero-carbon emissions by 2050." Nippon Steel. https://www.nipponsteel.com/en/csr/env/warming/zerocarbon.html.
5. "POSCO pledges to achieve carbon neutrality by 2050 and lead low-carbon society." POSCO. https://newsroom.posco.com/en/posco-pledges-to-achieve-carbon-neutrality-by-2050-and-lead-low-carbon-society/.
6. "Line chart of China's crude steel output in 2020." China Steel News. http://www.csteelnews.com/qypd/ywjx/202106/t20210602_50758.html.
7. "Jianlong announced steel green low-carbon development roadmap", March 18, 2022. China Steel News, 2022. http://www.csteelnews.com/qypd/jnhb/202203/t20220318_60909.html
8. "Implementing energy-saving and carbon reduction concepts – review of energy-conservation and emission reduction actions in Baotou Steel." Baotou Steel Union Company. https://www.baoganggf.com/newsinfo/2973516.html.

Citations for Table 21. Decarbonization goals of major aluminum companies in Inner Mongolia and the World:

1. "China's Chinalco targets reaching carbon emission peak before 2025." SP Global. https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/electric-power/060921-chinalco-targets-reaching-carbon-emission-peak-before-2025.
2. "Chinese aluminium giant spells out steps to carbon neutrality by 2055." Fast Markets. https://www.fastmarkets.com/insights/chinese-aluminium-giant-spells-out-steps-to-carbon-neutrality-by-2055.
3. "Rusal raised USD 200m under new sustainability-linked pre-export financing." Rusal. https://rusal.ru/en/press-center/press-releases/rusal-raised-usd200m-under-new-sustainability-linked-pre-export-financing/.
4. "Rio Tinto's climate change strategy." Rio Tinto. https://www.riotinto.com/en/sustainability/climate-change.
5. "Alcoa announces 2050 net-zero ambition." Alcoa. https://www.alcoa.com/global/en/stories/releases?id=2021/10/advancing-sustainably-alcoas-2050-net-zero-ambition.
6. "EGA and GE release world-first aluminium products with carbon free power certification." EGA. https://www.ega.ae/en/media-releases/2021/november/ega-and-ge-release.
7. "Norsk Hydro: Hydro Capital Markets Day 2021 - Sustainable value creation." GlobeNewswire. https://www.globenewswire.com/news-release/2021/12/13/2350405/0/en/Norsk-Hydro-Hydro-Capital-Markets-Day-2021-Sustainable-value-creation.html.
8. "China's SPIC aims to cap domestic carbon emissions by 2023." Reuters.

https://www.reuters.com/article/china-spic-climatechange/chinas-spic-aims-to-cap-domestic-carbon-emissions-by-2023-idUSL4N2IQ0R4.

Citations for Table 22. Decarbonization goals of major chemical companies in Inner Mongolia and the World:

1. Kane, E. 2021. "Many global chemicals companies trail on carbon-transition goals." January 27. Bloomberg Intelligence. https://www.bloomberg.com/professional/blog/many-global-chemicals-companies-trail-on-carbon-transition-goals/.
2. Sinochem Corporation. "Sinochem Corporation." Sinochem.com.cn. http://www.sinochem.com.cn/s/1375-4638-143892.html.