

# Study on the Security of Manganese Resources and Industry Chain in China

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**Abstract:** Manganese is an important strategic mineral resource. China is the world's largest consumer and importer of manganese resources. However, problems such as shortages of manganese ore resources, severe overcapacity, manganese slag pollution, and scattered and disorderly development have created significant pressure on domestic manganese ore resources, threatening the security of the industrial chain. This study reviews the industrial supply chain of manganese ore resources and materials in China from five perspectives: resource, smelting, material, product, and recovery ends, and discusses the development status, prospects, green and low-carbon development, structural adjustment, and manganese resource reserves of China's manganese industry. Based on our findings, we propose the following: (1) implementing a green development path to realize the comprehensive utilization of manganese slags; (2) establishing a safe and easy-to-control resource supply system by guaranteeing the domestic manganese resource reserve; (3) improving industry concentration and optimizing the manganese industry structure; and (4) increasing investment in research on manganese resources while promoting the transformation of scientific and technological achievements.

**Keywords:** manganese resources; industry chain; high-quality development; industry structure; security

## 1 Introduction

Manganese ore is a basic bulk raw material necessary for industrial production—particularly in the iron and steel industry—and for supporting the development of new energy, new materials, and other emerging industries. It is an important strategic material in China's national economic structure [1–4]. China is the world's largest consumer and importer of manganese resources, the largest producer and exporter of electrolytic manganese metal alloys, and the largest producer of manganese alloy such as manganese silicon alloy. The safe and high-quality development of the manganese industry chain has important practical significance and far-reaching influence on the implementation of the new development concept, which involves constructing a new development pattern of “double circulation.” This pattern ensures the safety of national primary products and maintains social stability and ecological security in resource-based areas.

China's cumulative consumption of manganese metal was  $1.2 \times 10^8$  t from 2001 to 2017, and its cumulative demand for manganese metal has been estimated to be  $1.8 \times 10^8$  t from 2018 to 2035. Although the demand for manganese in China will decline slowly in the future, according to the research results of the Strategic Research Center for Mineral Resources of the Chinese Academy of Geological Sciences, both the comprehensive guarantee degree and accumulative guarantee rate of manganese in China in 2025 and 2030 are low, while external dependence is high; therefore, the supply pressure of domestic manganese resources in the future will be greater than at present.

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Whether it will be able to meet the needs of China's economic society and industrial development, remains unknown [5].

In recent years, significant progress has been made in exploring manganese resources in China. For example, four concealed super-large manganese deposits have been discovered in the Tongren Songtao Manganese Mine, a national fully-equipped exploration district in Guizhou Province [6–10]. However, owing to resource characteristics, development policy, processing technology, and other reasons, the development and utilization process is slow, and it is difficult to effectively alleviate the supply pressure of manganese ore in China [11]. China's manganese industry has also long faced serious problems, such as increasingly tight manganese ore resources, overcapacity, severe pollution of production links and manganese slag, and scattered and disordered development. Although several rounds of nationwide manganese pollution control and industrial structure adjustment have achieved certain results, the problems of excess capacity and low industrial concentration are still prominent. Therefore, appropriately addressing the main problems in the manganese industry and improving the security level of manganese mineral resources are strategically significant for promoting the stable and healthy development of the national economy.

Therefore, based on the major consulting project of the Chinese Academy of Engineering, "Strategic Research on the High-Quality Development of Key Minerals and Related Material Industry," we analyzed the present situation of the manganese ore resources supply chain and the related material industry. We also addressed the following issues: how to accelerate industrial transformation and upgrading, how to ensure the green development of the manganese industry, and how to improve the domestic manganese resources reserve. This study discusses the high-quality development of manganese mineral resources and proposes countermeasures and suggestions for the security of manganese mineral resources and industrial chains in China.

## 2 Demand for the secure development of manganese ore resources in China

China should realize the strategic goal of transforming from a large country to a powerful country in terms of mineral resources, adhere to the sustainable development of mineral resources, and strive to make the country powerful in terms of mineral resources [12]. To achieve these goals, the safe development of manganese ore resources is of great significance, and its strategic needs are reflected in the following aspects.

### 2.1 A sound resource management system

A sound resource management system covers ferrous metals, non-ferrous metals, and other minerals, and involves the entire industry chain of exploration, development, utilization, and reserves. It coordinates the development of domestic and foreign mineral resources, and is the basis for the security of manganese mineral resources. The exploration of manganese ore resources has been included in the state's overall plan for geological exploration. Investment in scientific research and exploration of manganese ore has increased, and technical and financial support has been provided for the development of enterprises and mine construction.

### 2.2 Sustainable development of domestic mineral resources

It is necessary to identify domestic resources and develop domestic and foreign supply plans, based on the demand gap. While identifying the status quo of domestic manganese resources, China should predict the demand gap of manganese resources, while considering the future development planning of major manganese application industries, such as steel, new-energy batteries, and chemical engineering, and develop targeted import and export strategies to improve the sustainable development of domestic manganese resources [13].

### 2.3 Diversified industrial structure supply system

Fiscal, tax, land, resources, and other policy levers should be adopted to eliminate backward production capacity, reduce domestic excess capacity, encourage globalization, reduce the output of low-end manganese products and the export of electrolytic manganese, and change the industrial development model of importing resources and exporting low-end products. Further, the demand of domestic electrolytic manganese and manganese series ferroalloy smelting enterprises for manganese ore should be reduced, while key high-tech manganese enterprises must accelerate scientific and technological innovation, develop more manganese series new materials and products, expand production scale, and constantly improve the technological content and added value of the products [4].

### 3 Current status of manganese mineral resources and industrial chain development in China

Manganese ore resources can be divided into four types, according to mineralization, manganese source, and metallogenic conditions; these are marine sedimentary, volcano–sedimentary, metamorphic, and hydrothermal. Among them, marine sedimentary and metamorphic deposits have the largest industrial value, and their reserves account for approximately 90% of the world's total reserves. Volcanic-sedimentary manganese deposits have a certain number of deposits, but their reserves are relatively small. There are also abundant manganese nodules at the bottom of the ocean, but they cannot be exploited on a large scale, owing to the limitations of mining technology and equipment. The main types of manganese mineralization in China are marine sedimentary deposits and a few metamorphic deposits [14–17].

#### 3.1 Overview of manganese ore resources in China

Manganese is widely distributed in China. According to the statistics of the Ministry of Natural Resources [18], the reserves (ore amount) of manganese resources in China in 2020 amounted to  $2.129569 \times 10^8$  t; these resources were concentrated in Guangxi, Guizhou, Hunan, Gansu, and Yunnan. Guangxi ranks first in China, with reserves amounting to  $1.189205 \times 10^8$  t, followed by Guizhou ( $1.99682 \times 10^7$  t) and Hunan ( $1.573667 \times 10^7$  t) (Table 1).

**Table 1.** Statistical table of manganese ore reserves in China in 2020 [18]. (Units:  $\times 10^4$  t)

Area	Reserves	Area	Reserves
China	21 295.69	Hubei	280.60
Guangxi	11 892.05	Shaanxi	277.45
Guizhou	1996.82	Fujian	73.81
Hunan	1537.67	Jiangxi	64.06
Gansu	1421.43	Guangdong	64.03
Yunnan	1231.43	Inner Mongolia	34.02
Liaoning	971.04	Shanxi	11.15
Chongqing	830.73	Sichuan	6.40
Xinjiang	566.70	Jilin	0.30

The overall consumption of manganese ore in China is increasing. The consumption structure includes manganese alloys, electrolytic manganese metal, electrolytic manganese dioxide, and refractory materials, which are mainly used in the iron and steel industries, followed by the battery and chemical industries. During the mining industry transformation in China in recent years, China has issued increasingly strict environmental protection policies, especially the nature reserve mining right exit policy. Therefore, manganese ore production in China dropped dramatically after 2015, far behind the development of the metallurgical industry, resulting in increasing external dependency and making China the world's largest importer of manganese ore. In 2020, China's manganese consumption was  $4.20665 \times 10^7$  t, of which  $1.0319 \times 10^7$  t of manganese ore was produced and  $3.16655 \times 10^7$  t was imported (Table 2).

**Table 2.** Statistical table of China's manganese ore Imports (ore volume) by country in 2011–2020 [17, 19–21]. (Units:  $\times 10^4$  t)

Country/region	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
South Africa	345	332	520	579	633	759	893	1114	1340	1370
Australia	437	420	490	516	430	407	407	522	520	534
Gabon	144	104	170	148	187	125	205	252	360	474
Ghana	85	119	140	106	53	155	203	350	510	187
Brazil	79	80	100	88	118	117	182	183	300	280
Malaysia	67	90	110	92	63	89	79	109	140	86
Cote d'Ivoire	–	–	18	33	19	18	23	66	100	116
Myanmar	56	26	37	22	5	27	10	47	94	56
Total	1297	1237	1670	1631	1535	1759	2053	2702	3420	3166

#### 3.2 China's manganese mineral resources industry chain

China's industrial chain of manganese resources includes resources, smelting, material, product, and recovery

ends (Fig. 1). The resource end includes ore resources such as manganese oxide and manganese carbonate ores. The smelting end includes manganese metallurgy and manganese chemical processing. The material end includes electrolytic manganese, electrolytic manganese dioxide, silicon-manganese, and ferromanganese. The product end includes steel, new-energy batteries, and catalysts. The recovery end mainly comprises manganese slag.

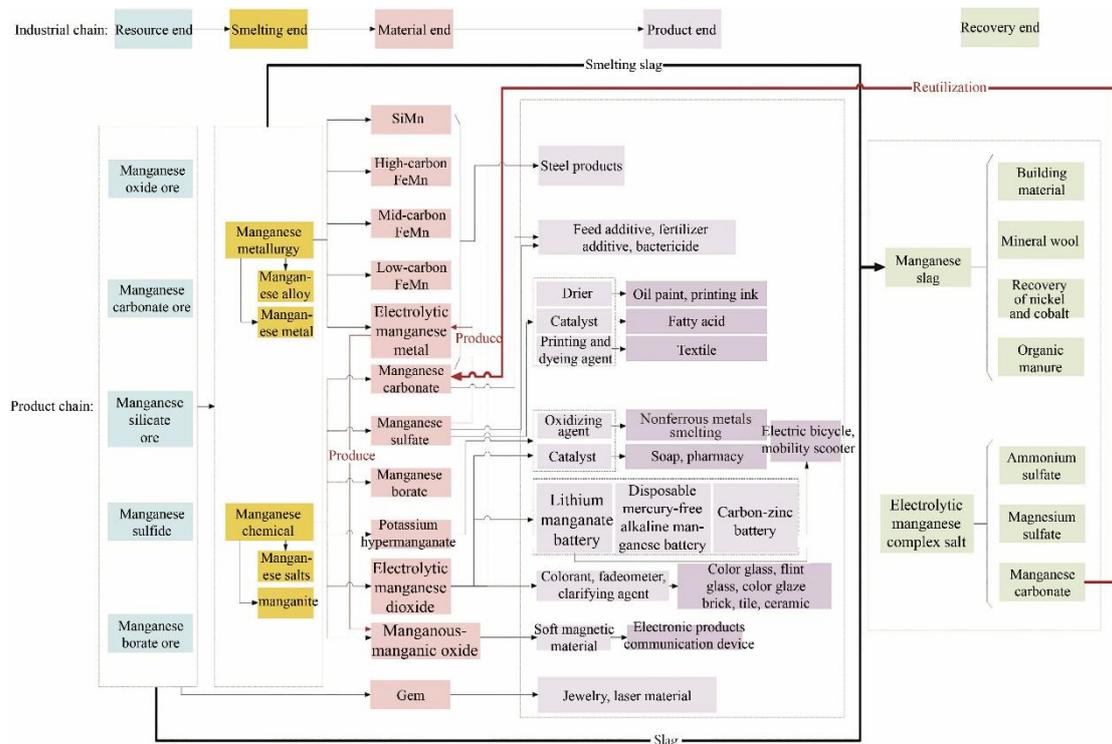


Fig. 1. Schematic representation of manganese mineral resources and the material industry chain.

### 3.2.1 Resource end

There are four main types of manganese ore in China: manganese carbonate, manganese oxide, mixed ore, and other types of ore. Manganese carbonate ore is the major type, while manganese oxide and other types of ore (such as manganese silicate, manganese sulfide, and manganese borate ore) are less abundant. Manganese ore resources in China are primarily lean ores. The manganese ore grade in China is only 22% on average, and there are few rich ores according to international standards. Lean ore with medium and lower grades can only be used after dressing for grade improvement, while the grade of manganese oxide ore and manganese carbonate ore should be more than 30% and 25%, respectively. The manganese ore material composition in China is complex; mineral particles are generally fine and difficult to select; technical processing performance is poor; and the phosphorus, sulfur, iron, silicon, cobalt, and nickel contents in the ore are high.

### 3.2.2 Smelting end

The smelting and processing of manganese resources in China are at a relatively high level, owing to the low-grade manganese ore. Low-grade ore cannot be directly used, and its value can only be realized after the grade is improved by smelting and processing. Currently, China has relatively efficient independent intellectual property rights to obtain electrolytic manganese and electrolytic manganese dioxide using the electrolytic method. China also has a technological advantage in smelting high-carbon manganese alloys. The main manganese series alloy products in China are ferromanganese alloy, silicon-manganese alloy, and manganese metal, which are the main products of deep processing of manganese ore. China's silicon-manganese production is mainly concentrated in Inner Mongolia, Ningxia, and Guangxi, with outputs of approximately  $4.53 \times 10^6$  t,  $2.16 \times 10^6$  t, and  $1.68 \times 10^6$  t, respectively. Ferromanganese is concentrated in Inner Mongolia, Shandong, Guangxi, and Henan, with outputs of approximately  $5.8 \times 10^5$  t,  $5.2 \times 10^5$  t,  $2.1 \times 10^5$  t, and  $1.5 \times 10^5$  t, respectively [19].

### 3.2.3 Material end

The manganese ore resources in China are mainly electrolytic manganese and electrolytic manganese dioxide, which are widely used in the iron and steel industry with silicon-manganese alloys, low-, medium-, and high-carbon

ferromanganese, and manganese carbonate. In addition, lithium manganate, manganese sulfate, and manganese phosphate are important in the field of new-energy batteries.

Electrolytic manganese is widely used in iron and steel smelting, non-ferrous metallurgy, electronic technology, chemical industry, environmental protection, food hygiene, electrode industry, and the aerospace industry. The domestic electrolytic manganese supply is stable and can meet domestic and foreign demands. From 2017 to 2020, the domestic production of electrolytic manganese remained stable, declining slightly in 2020; however, the overall production remained at  $1.5 \times 10^6$  t. In terms of demand, electrolytic manganese in China is exported, while domestic demand is also met. In 2020  $3.2 \times 10^5$  t was exported, and its apparent consumption was approximately  $1.18 \times 10^6$  t.

China is the world's leading producer of electrolytic manganese dioxide, accounting for 70% of the global production capacity. According to statistics from the China Economic Information Network, there are approximately 30 electrolytic manganese dioxide manufacturers in China, Japan, the United States, Europe, India, and other countries. In terms of capacity, the total global capacity in 2018 was approximately  $5 \times 10^5$  t, of which China's capacity reached  $3.5 \times 10^5$  t. By 2020, the electrolytic manganese dioxide output was  $3.1 \times 10^5$  t.

Lithium manganate is a type of cathode material used in lithium batteries. In recent years, the output and shipment of lithium manganate have been on the rise, reaching  $9.29 \times 10^4$  t and  $6.6 \times 10^4$  t, respectively, in 2020. Lithium manganate is mainly used in electric bicycles, low-speed electric vehicles, small-power-type power tools, digital electronic products, and energy storage; the rapid development of the electric bicycle industry and low-speed electric vehicle market shows that it has the potential to replace lead-acid batteries.

Ternary batteries have driven the growth of manganese sulfate demand. Most ternary batteries use electrolytic manganese dioxide or high-purity manganese sulfate monohydrate cathode materials. High-purity manganese sulfate is primarily used in the preparation of lithium manganese, manganese tetroxide, and nickel cobalt manganese materials. With the development of lithium-ion battery technology, its field of application is gradually expanding, driving the market development of high-purity manganese sulfate and other materials.

The lithium iron manganese phosphate battery is regarded as an achievement in the upgrading of lithium ferromanganese phosphate batteries, with good stability and high safety. Compared to lithium iron phosphate batteries, lithium iron manganese phosphate batteries can increase the energy density by 15%–20% under the premise of increasing the cost by approximately 6%. However, it can increase manganese consumption by approximately 0.4 kg/kW·h.

#### 3.2.4 Product end

There are many products of manganese mineral resources, and the downstream application fields are very wide, including iron and steel metallurgy, battery manufacturing, chemical processing, medicine, electronics, construction, and agricultural feed. At present, 85% to 90% of China's manganese consumption is by the steel industry and 5% to 10% by the battery and chemical industries. The rapid development of green manufacturing, such as new materials and electric vehicles, will provide a broad market for cathode materials, such as electrolytic manganese dioxide, lithium manganate, and high-purity manganese sulfate.

The steel industry accounts for 90% of the manganese demand. Manganese is an irreplaceably important element in the iron and steel industry, as it can improve the strength, toughness, wear resistance, and corrosion resistance of alloys, eliminate the influence of sulfur and oxygen on the thermal brittleness of steel, and does not reduce the plasticity and impact toughness of steel. The manganese content in the low-alloy steel is approximately 1%–2%. Steel and stainless steel are the largest downstream consumers of manganese.

According to the World Iron and Steel Association, global crude steel production reached  $1.878 \times 10^9$  t in 2020, up by 0.48% annually; moreover, China's crude steel production was ranked first in the world, with  $1.065 \times 10^9$  t, up 11.52% annually, accounting for 56.7% of global production. It was followed by India, with an output of  $1.0 \times 10^8$  t, accounting for 5.3% of global production. Japan was third, producing  $0.83 \times 10^8$  t, or 4.4% of the global production. From January to July 2021, China produced  $8.09 \times 10^8$  t steel,  $5.34 \times 10^8$  t pig iron, and  $6.49 \times 10^8$  t crude steel, respectively.

#### 3.2.5 Recovery end

The recovery end is mainly composed of manganese slag, including slag from the resource and smelting ends. Green landfill treatment of manganese slag can be carried out, and manganese slag can be reused in construction materials, mineral wool, fertilizer, and metal recovery.

## 4 Major problems in the development of the manganese industry in China

### 4.1 The development and utilization cost of domestic manganese ore resources is high, the cycle is long, and the security of resource supply is low

China's manganese ore resources are primarily manganese carbonate ores. The ore grade is approximately 15%–25%, and the ore body is a thin multilayer, gently inclined, and buried deep. The depth of the ore body is approximately 1000–1500 m, which requires deep underground mining; therefore, the mining cost is high. Manganese carbonate ore has a fine particle size and high impurity levels, and is relatively difficult to dress. In addition, the mine construction cycle was long. For example, the Lijiawan Manganese mine in Wuling, Guizhou Province, took five years from the project filing in 2014 to obtain a safety license in 2019, which is a long period to fill the gap.

### 4.2 High degree of external dependence and low degree of security of manganese resource industry chain

China's iron and steel industry, electrolytic manganese dioxide for batteries, high-purity manganese sulfate, and other industrial sectors have formed an industrial chain system that relies on high-grade imported manganese oxide ore, with an external dependence of nearly 90%. Once supply problems occur, these industrial chains are bound to be destroyed, seriously threatening the security of the domestic manganese resource industry chain. In addition, manganese carbonate ore is currently used only to produce electrolytic manganese and stainless steel. Manganese ore consumption in this field accounts for approximately 10% of total manganese ore consumption. Therefore, the existing domestic manganese industry chain layout does not match the resource endowment of manganese carbonate ore in China, which is not conducive to improving the diversification and security level of the domestic manganese resource industry.

### 4.3 The safety degree of production capacity and industrial structure is low

Owing to resource endowment, industrial structure, and other reasons, the domestic manganese industry has excess capacity and output, and the phenomenon of scattered and disorderly development is severe. Domestic manganese production enterprises are large in number and small in scale, and some small mining enterprises have backward technologies, aging equipment and facilities, a low degree of automation, high energy consumption, large ore consumption, and high pollution emissions. Some small mining enterprises rush when the market performs well and stop production once the situation turns grim. Their general profitability is low, and they lack the ability and capital to invest in upgrading, safety, and environmental protection.

### 4.4 The safety degree of environmental protection and sustainable development is low

China's electrolytic manganese industry has high energy and resource consumption and causes serious environmental pollution. Most electrolytic manganese production enterprises are built by mines, deep in green mountains, with clear waters. There are problems such as obsolete technologies and equipment, high pollution emissions, small investments in environmental protection, and low resource recovery rates. Moreover, the contradiction between the pollution and sustainable development of solid wastes, such as manganese slag produced in the production process of electrolytic manganese, is becoming increasingly prominent. Manganese slag contains large amounts of harmful substances such as soluble manganese and ammonia nitrogen, which easily dissolve and pollute the surrounding underground and surface water bodies.

## 5 Development strategy and path of manganese ore resources in China

China is a large producer, consumer, and mineral resources trader. Considering a new development pattern that emphasizes domestic economic circulation and integrates international and domestic dual circulations, investment and construction of new infrastructure, new urbanization, and major projects will be coordinated, and the supporting role of black metal mineral resources represented by manganese will be increasingly prominent. This not only poses a challenge, but also offers an opportunity for the development of manganese mining enterprises. It is necessary to abandon the extensive operation mode; accelerate the construction of an industrial structure and production mode with high scientific and technological content, low resource consumption, and less environmental pollution; and promote the safe and high-quality development of the manganese industry [22].

## 5.1 Development goals

The next 15 years will present an important opportunity for China to develop into a powerful country in terms of mineral resources. Research indicates that China can build itself into a powerful country in terms of mineral resources by 2025, and it is expected to fully build itself into a powerful country in terms of mineral resources by 2030. Currently, domestic manganese ore reserves must be increased, international mining cooperation strengthened, and secondary resource utilization improved. While improving the comprehensive supply capacity of manganese ore resources in China, the environmental access threshold should be improved and the intensity of resource development should be moderately reduced, to thereby improve the sustainable development and utilization of manganese ore resources and improve the static guarantee life of manganese ore resources in China [12].

By 2025, it is necessary to establish a flexible management system for manganese ore resources, greatly improve the guarantee ability and static guarantee period of manganese ore resources, continue to improve the concentration and diversification level of the manganese ore industry, and significantly increase the reserves and output of international rights and interests of manganese ore resources.

By 2030, it is necessary to fully develop China into a powerful country in terms of mineral resources represented by manganese ore, and fully realize the centralization and flexibility of the manganese resource management system. As mining concentration and diversification continue to improve, influential transnational manganese mining enterprises should be built to enhance the security of international rights and strategic reserves and production.

## 5.2 Development path

### 5.2.1 Accelerating the transformation and upgrading of the manganese industry to solve overcapacity

In July 2021, the National Development and Reform Commission, Ministry of Industry and Information Technology, Ministry of Natural Resources, and Ministry of Ecology and Environment jointly issued the *Notice on Strengthening Manganese Pollution Control and Promoting Adjustment of Manganese Industry Structure*, proposed to optimize and adjust the policies of the electrolytic manganese metal industry, and gradually eliminated electrolytic manganese metal single production line below  $1 \times 10^4$  t/a and electrolytic manganese metal production enterprises with scales below  $3 \times 10^4$  t/a.

Production overcapacity in the manganese industry should be addressed from the perspectives of manganese ore resource development and utilization patterns and mine mergers. Industrial clusters that prioritize large- and medium-scale mining and integrate dressing, smelting, processing, and comprehensive management should encourage merging and reorganization. Thus, the industrial development pattern of importing resources and exporting low-end products should be changed.

It is necessary to strictly control the new electrolytic manganese metal and manganese silicon alloy projects, strictly approve or put on record projects, improve industry standards, remove overcapacity by eliminating small, energy-intensive, and polluting enterprises that fail to meet national requirements, and increase the industrial concentration and scale of enterprises.

### 5.2.2 Exploring new ways for green transformation by adhering to low-carbon and circular development

Green development is the only way to achieve high-quality development in the manganese industry. The newly revised *Law on the Prevention and Control of Environmental Pollution by Solid Waste* in 2020 has established “reduction, recycling, and harmlessness” as the basic principles of solid waste management in China. A circular economy and green development have become the new themes of the manganese industry transformation and upgrading, high-quality development, and solutions to the problem of manganese residue treatment.

It is necessary to conduct strict comprehensive treatment of water, gas, and slags, formulate strict emission standards, optimize production technology, promote harmless treatment and recycling of manganese slags, and ultimately achieve the goal of zero emissions and the construction of green and beautiful mines.

Environmental protection should be strengthened in the development of manganese resources. By relying on scientific and technological progress, we should promote clean production, improve the level of exploitation and utilization of manganese resources, develop a low-carbon circular economy, build green mines, and promote the coordinated development of the exploitation and utilization of manganese resources and the environment.

### 5.2.3 Increasing manganese resource reserves to guarantee national resource security

Resource security is an important component of the state’s overall security. To ensure supply security, we should combine international and domestic markets to optimize resource allocation and improve the reserves of manganese

resources. Moreover, a strategic material reserve system that is guided by the government, participated in by enterprises, and that combines manganese ores and manganese metal should be established.

Attaching importance to the exploration and development of domestic manganese resources and the construction of manganese ore product bases; improving the guaranteed capacity of domestic manganese ore resources; resolutely resisting projects with high energy consumption, high emissions, and low level; avoiding blind development by all means; and ensuring the secure supply and price stability of national manganese ore resources and mineral products are recommended.

## **6 Countermeasures**

In the face of China's excessive dependence on foreign manganese mines, domestic manganese mining enterprises constantly improve their exploration, mining, dressing, and smelting technologies and rationally make use of the policies issued by the governments at all levels, to increase the cooperation opportunities of overseas manganese mines. In addition, further opening-up and the Belt and Road initiative also bring new opportunities for China's manganese industry to participate in global resource allocation and international production capacity cooperation.

### **6.1 Practicing green development to achieve comprehensive utilization of manganese slags**

We will adhere to the principle that "lucid waters and lush mountains are invaluable assets," promote high-quality development, ensure a coordinated development of mining and ecological protection, and improve the mining investment environment. The relevant departments should simultaneously take multiple measures. We should strictly enforce the requirements of manganese slag pollution control by issuing technical specifications for manganese slag pollution control in the electrolytic manganese industry and carrying out special law enforcement inspections related to the ecological environment and clean production of electrolytic manganese enterprises. Additionally, it is necessary to recycle manganese slags, increase investment in and guidance for the comprehensive utilization of manganese slag research and development, improve the added value of electrolytic manganese industry products, extend the electrolytic manganese industry chain, and improve the technological content of the products.

### **6.2 Improving industry concentration and optimizing manganese industry structure**

China should strengthen the manganese industry; encourage large enterprises to carry out mergers and reorganizations of assets, resources, brands, and markets; and promote the scale and intensification of the industry, to thereby achieve industrial upgrading and high-quality development.

The focus will be on cracking down on illegal construction and production without approval, and local governments will be held accountable. We should also implement policies and standards that have been formulated, strengthen supervision of the implementation of existing industry standards, and raise access thresholds for industries. For example, we will implement an evaluation index system for cleaner production in the industry and set a deadline for rectification of enterprises that fail to meet cleaner production standards.

### **6.3 Enhancing China's ability to ensure resource security to establish a secure resource supply system**

The new round of prospecting strategies will continue to prospect and explore manganese ore resources, especially manganese oxide- and manganese carbonate-rich resources, strengthening the exploration of domestic manganese ore metallogenic belts, key resource bases, and large- and medium-sized mines, and search and increase reserves in peripheral areas, to constantly enhance the ability to guarantee the security of domestic resources.

Adopt supply policies such as "exploring but not mining," "buying more and mining less," and "not mining with low quality," carefully mining domestic manganese ore, forbidding disorderly mining of manganese ore, and severely cracking down on illegal mining activities. In addition, strict environmental protection policies should be implemented that are focused on reducing mining volumes and improving domestic manganese mining standards as far as possible to reserve limited resources and establish a controllable resource supply system.

### **6.4 Increasing investment in scientific research on manganese resources and promoting the transformation of scientific and technological achievements**

First, state-level scientific research projects must be established. Technologies for the exploration, development, and utilization of deep concealed manganese-rich ore resources should be applied, such as big data, artificial intelligence, cloud computing, and other modern information technologies, to realize high-quality development and

utilization of deep manganese ore and to guide the development and utilization of other deep resources. Second, grade improvement and low-cost utilization of manganese carbonate ores should be implemented to build an industrial chain system with manganese carbonate ores as the core.

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## References

- [1] Zhou C Y. Producing Ferromanganese from Oxidation Manganese ore based on Solid Phase Reduction with Carbothermic Method[D]. Changsha: Central South University, 2012.Chinese.
- [2] Liu Z N, Xu H, Wang Q S, et al. CHINA'S MANGANESE SUPPLY-DEMAND ACTUALITY AND ITS SUSTAINABLE DEVELOPMENT[J]. Resources & Industries, 2015, 17(6): 38-43.Chinese.
- [3] Zhu Z G. Exploitation and Utilization of Resources of Mn Ore[J]. China Mangagese Industry, 2016, 34(2):1-3.Chinese.
- [4] Huang Y, Chen G Y, Tian Y M, et al. Main problems and countermeasures suggested for the manganese industry of China[J]. Geology and Exploration, 2021, 57(2): 294-304.Chinese.
- [5] He H. Analysis of the law of manganese consumption and a prediction about China's manganese demand[J]. China Mining Magazine, 2020, 29(5): 7-11.Chinese.
- [6] Zhou Q, Du Y S, Yuan L J, et al. Major progress and potential prediction of geological exploration in Songtao manganese national fully equipped exploration district in Tongren, Guizhou[J]. Guizhou Geology, 2016, 33(4): 237-244.Chinese.
- [7] Zhang S, Zhou Q, Zhang P Y, et al. Geological characteristics and prospecting prediction of Xixibao super-large manganese deposit in Songtao, Eastern Guizhou[J]. Geological Science and Technology Information, 2015, 34(6): 8-16.Chinese.
- [8] Zhang S, Zhou Q, Zhang P Y, et al. Geological characteristics and prospecting practice of Pujue super-large manganese deposit in Songtao, Guizhou[J]. Guizhou Geology, 2018, 35(4): 304-313.Chinese.
- [9] Yuan L J, Zhou Q, Yao X C, et al. Main geological characteristics of Songtao Gaodi extra-large manganese-rich deposit in Guizhou[J]. Guizhou Geology, 2018, 35(4): 314-318.Chinese.
- [10] Shen H Q, Zhang S, Zeng F, et al. New research progress and potential prediction of Lijiawan-Gaodi-Daotuo graben located in Songtao area, Wuling manganese ore belt in Nanhua Period, South China[J]. Guizhou Geology, 2021, 38(2): 129-138.Chinese.
- [11] Ren H, Wu H, Wang Z G, et al. Country's autonomous and controllable manganese industry supply chain building rely on domestic superhuge manganese ore[J]. Coal Geology of China, 2021, 33(11): 1-3.Chinese.
- [12] Chen Q S, Gan Y, Yan J L, et al. Transition from a large to a powerful country in mineral resources: Objectives, Measures, and Proposals[J]. Strategic Study of CAE, 2019, 21(1): 49-54.Chinese.
- [13] Sun H W, Wang J, Ren J P, et al. Current situation of global manganese resources and suggestions for sustainable development in China[J]. Conservation and utilization of mineral resources, 2020, 40(6): 169-174.Chinese.
- [14] Fu Y, Xu Z G, Pei H X, et al. Study on Metallogenic Regularity of Manganese Ore Deposits in China[J]. Acta Geologica Sinica, 2014, 88(12): 2192-2207.Chinese.
- [15] Cong Y, Dong Q J, Xiao K Y, et al. Characteristics and predicted potential of Mn resources in China[J]. Earth Science Frontiers, 2018, 25(3): 118-137.Chinese.
- [16] Deng W B, Zhang Y W, Kong L H, et al. Current status of manganese ore resources in China and selecting for national physical geological data of manganese ore deposits[J]. China Mining Magazine, 2019, 28(9): 175-182.Chinese.
- [17] Cheng X, Hu P, Zhang H K, et al. The main types, distribution and current development of manganese ore deposits[J]. Geology in China, 2021, 48(1):102-119.Chinese.
- [18] Ministry of Natural Resources of PRC. Statistics on Mineral Resources and Reserves of China in 2020[R/OL]. China: Ministry of Natural Resources, 2021. [http://www.mnr.gov.cn/sj/sjfw/kc\\_19263/kczycltjb/202111/P020211122581854693756.pdf](http://www.mnr.gov.cn/sj/sjfw/kc_19263/kczycltjb/202111/P020211122581854693756.pdf).Chinese.
- [19] Qin D L, Chen N X. 2020 global manganese ore and the production brief in China's manganese products[J]. China Mangagese Industry, 2021, 39(4):10-12.Chinese.
- [20] IMnI. 2019 Annual Market Research Report. [R/OL]. France: IMnI, 2020. <https://www.manganese.org/market-research/annual-reports/imni-2019-annual-market-research-report.pdf>.
- [21] D'Harambure A., Yang Y F, Yang J. An analysis of the status quo and development trend of global manganese ore industry[J]. China Mangagese Industry, 2021, 39(4):1-4.
- [22] Yang Q L. 2020 China manganese Industry Development Strategy Seminar held[J]. China Nonferrous Metals News, 2021-12-19.Chinese.