

REVIEW ARTICLE

Current situation of global manganese resources and suggestions for sustainable development in China

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ABSTRACT

As an important metal mineral, manganese is widely used in metallurgy, chemical industry, national defense industry and other fields. Global manganese resources are characterized by extremely uneven distribution, highly concentrated production capacity, and serious separation between supply and demand. China's manganese resources are characterized by extensive distribution but insufficient reserves, low grade and poor quality, high external dependence, and imperfect resource guarantee system. In recent years, China's manganese industry has developed rapidly, and China has become the world's largest consumer of manganese resources. With the growth of new energy market, the contradiction between supply and demand of manganese resources in China will further increase in the future. Based on the actual situation that manganese ore is still in short supply and in great demand in China, in order to ensure the strategic safety of national manganese ore resources and promote the healthy development of China's manganese industry, this paper puts forward sustainable development suggestions such as formulating long-term supply planning, strengthening overseas layout, promoting capacity cooperation and establishing a diversified security system.

Keywords: Manganese Ore; Resource Distribution; Supply and Demand Situation; Resource Potential; Development Suggestions

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1. Introduction

The average content of manganese in the earth's crust is about 0.1%, which is one of the important basic bulk raw material minerals for industrial production. More than 90% is used in the metallurgical industry. It is the element with the largest consumption in steel except iron, and is known as "no steel without manganese"^[1,2]. In addition, it is also used in various fields of the national economy, such as light industry (used for batteries, printing paint, etc.), chemical industry (manufacturing all kinds of manganese salts), agriculture and animal husbandry (chemical fertilizers, fungicides, etc.), building materials industry (fading agents and colorants for ceramics and glass), and national defense industry. Therefore, manganese resources are important strategic materials for China's national economic construction. The most important non metallurgical use of manganese is as a depolarizer in dry batteries in the form of manganese dioxide. In the future, with the rapid growth of China's new energy market, the demand for manganese ore resources, especially battery grade manganese ore, will continue to increase.

In recent years, the output of manganese and manganese

containing alloys in China has ranked first in the world^[3], and it is expected that the demand for manganese resources will further increase in the future. At the same time, the price of manganese in the international market has been fluctuating greatly. Since the outbreak of novel coronavirus, the price of manganese ore has risen rapidly due to the obstruction of mining in some areas^[4]. How to ensure the safety of manganese resources in China has become an urgent problem to be solved. This paper will analyze the distribution characteristics, occurrence, supply and demand pattern and resource potential of global manganese resources, and on this basis, put forward measures and suggestions to ensure the strategic security of China's manganese resources.

2. Global resource distribution characteristics

2.1 Overview of global manganese resource distribution

The world's manganese resources are characterized by relatively rich total amount, but uneven distribution^[5]. According to the statistical data^[6], the global terrestrial manganese ore reserves in 2019 were 810 million tons, of which South

Africa, Ukraine, Brazil and Australia accounted for more than 75% of the total global manganese ore reserves out 300 million tons of manganese resources (**Figure 1**). However, Ukraine's manganese ore grade is poor, and it has withdrawn from the ranks of major manganese ore producers in recent years. The world's high-grade manganese ore resources (with manganese content of more than 35%) are mainly concentrated in South Africa, Australia, Brazil and Gabon. In addition, the bottom of the ocean also contains ab in the form of modern manganese nodules, but due to technical reasons, a large number of manganese resources have not been exploited yet^[7].

2.2 Distribution characteristics of manganese resources in China

China's manganese ore reserves are small, accounting for only 6.67% of the world's total reserves. Manganese ore deposits are characterized by small scale, low grade, complex co-associated components and high mining costs, resulting in low availability of manganese resources in China, and manganese ore has also become one of the scarce minerals in China^[2,8,9].

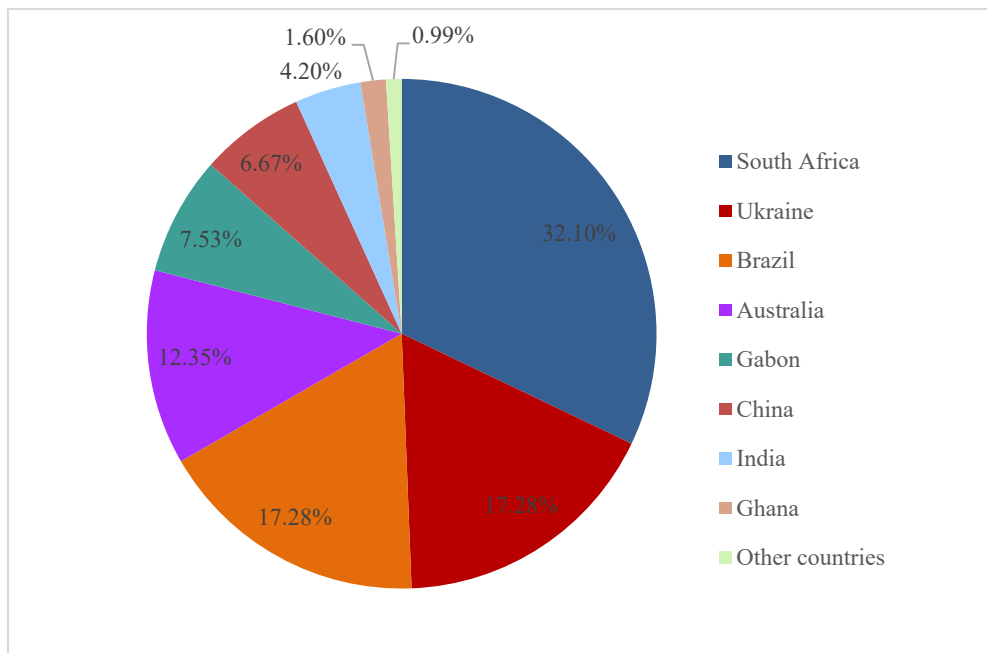


Figure 1. Proportion of global manganese reserves distribution. Source: USGS^[6].

Manganese resources in China are widely distributed in 24 provinces, cities and autonomous

regions across the country. However, the distribution of resource reserves is extremely

uneven. According to the statistical data^[5,10], China's manganese ore is mainly distributed in Guizhou, Guangxi, Hunan, Hebei and Yunnan provinces, of which the identified manganese ore resource reserves in Guizhou and Guangxi account for more than 60% of the total reserves in the country (Figure 2).

3. Production of global manganese resources

3.1 Major manganese producing countries

In recent years, the total annual output of manganese metal in the world has basically remained between 16 and 19 million tons (Figure 3), of which South Africa, Australia and Gabon are the world's major manganese resource producers and exporters, accounting for more than 60% of the world's total output. China, Brazil, Ghana and India

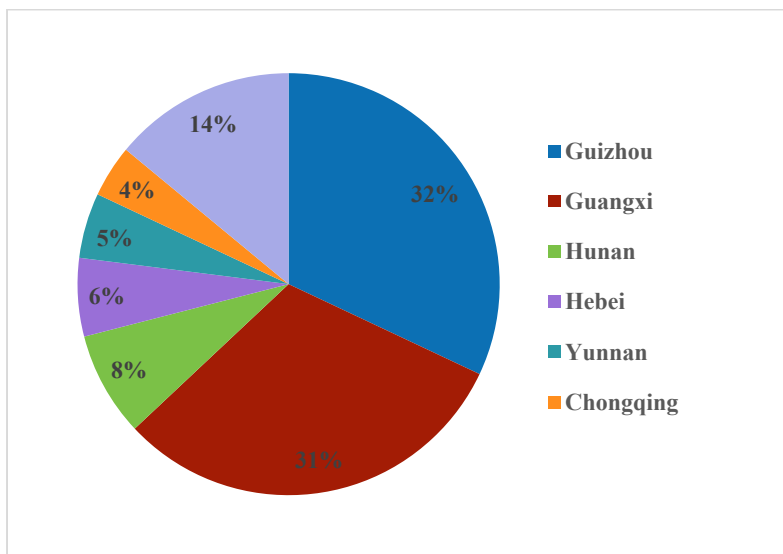


Figure 2. Distribution proportion of reserves of manganese resources in China. Source: Data are from Lei *et al*^[5], Yin and Xiao^[10].

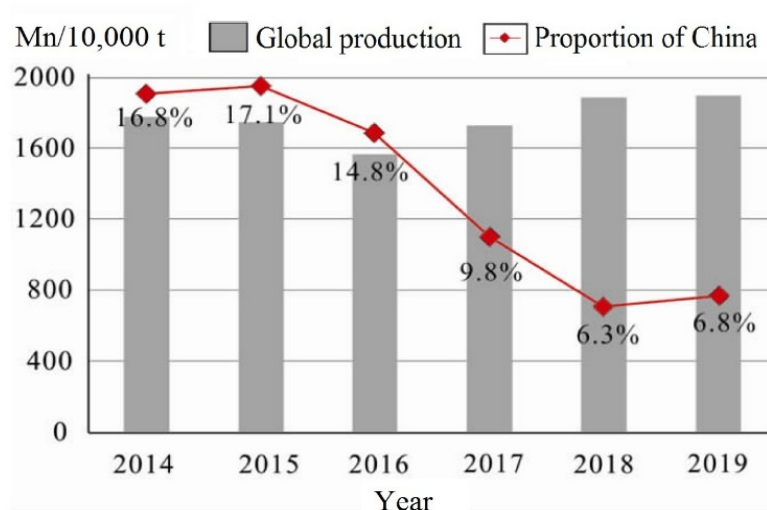


Figure 3. Global production of manganese metal from 2014 to 2019. Source: RTE^[17].

are also the world's major manganese resource producers. However, with the increase of domestic mining costs and strict environmental protection requirements in China, since 2015, China's manganese ore production has been declining, and its share in the world has also continued to decline

(Figure 3).

3.1.1 South Africa

South Africa has the largest reserves of manganese ore in the world, and is dominated by high-grade manganese ore. In 2019, South Africa's manganese metal reserves were 260 million tons,

accounting for 32.1% of the total global reserves, ranking first in the world (**Table 1**). Manganese deposits in South Africa are widely distributed, mainly concentrated in Kalahari postmasburg manganese ore concentration area, especially the metamorphic sedimentary manganese deposits hosted in the Paleoproterozoic Transvaal supergroup^[12,13].

3.1.2 Australia

Australia is the world's major producer and exporter of high-grade manganese ore. In 2019, Australia's manganese metal reserves were 100 million tons, accounting for 12.35% of the total global reserves (**Table 1**). Its manganese ore resources are mainly distributed in northern and western Australia, mostly open-pit mining, with high grade and easy sorting. Groote manganese ore

is the largest primary manganese oxide deposit in Australia. Manganese ore occurs in marine sedimentary deposits in sandy clay, and the manganese content of the ore is about 40%–50%^[14,15].

3.1.3 Brazil

Manganese resources in Brazil are widely distributed, and manganese is found in most states of the country. By the end of 2019, Brazil's manganese metal reserves were 140 million tons, accounting for 17.28% of the world's total reserves (**Table 1**). Azul manganese ore area in Carajas area is the main manganese mine in Brazil at present, which mainly produces high-grade manganese ore with manganese content of 40% and high-grade battery manganese ore^[15,16].

Table 1. Annual production data of the world's major manganese producers from 2014 to 2019

Serial number	Countries	Yield						Reserves
		2014	2015	2016	2017	2018	2019	
1	South Africa	520	590	530	540	580	550	26,000
2	Ukraine	42	41	42	73	51	54	14,000
3	Brazil	104	109	108	116	131	120	14,000
4	Australia	305	245	224	282	348	320	10,000
5	Gabon	186	202	162	219	233	240	6,100
6	China	300	300	233	170	120	130	5,400
7	India	94	90	74	73	96	100	3,400
8	Ghana	42	42	55	81	136	140	1,300
9	Other countries	187	131	142	176	195	246	800
10	Total	1,780	1,750	1,570	1,730	1,890	1,900	81,000

Note: The data in the table are manganese (unit: Mn/10,000 t).

Source: USGS^[6].

3.1.4 Gabon

Gabon is the second largest manganese ore resource country in Africa, and is famous for its rich manganese ore (manganese content 50%–60%) and battery grade manganese ore. In 2019, Gabon's proven manganese (metal) reserves totaled 61 million tons, accounting for 7.53% of the world's

total (**Table 1**). Gabon's manganese resources are relatively concentrated, mainly in the Moanda area in the southeast of Gabon. Manganese ores are mostly hosted in the Paleoproterozoic (2.3–2.3 Ga) Francevillian supergroup, and the deposit type is mainly metamorphic sedimentary^[13,15].

Table 2. The production of the world's leading manganese mining companies

Corporate name	Country	Main mines and locations	Ore output in 2018/t
South32 Ltd.	Australia	Groote in Australia, Hotazel in South Africa	4,983,300
Consolidated Minerals Ltd.	Australia	Nsuta, Ghana	4,100,000
Anglo American Plc	UK/South Africa	Hotazel in South Africa, Groote in Australia	3,322,200
CITIC Dameng Holdings Limited	China	China Daxin Manganese Mine, Gabon Bembele	2,989,040
ERAMET S.A.	France	Moanda in Gabon	2,763,740
Vale S.A.	Brazil	Azul, Urucum in Brazil	1,831,000
African Rainbow Minerals Ltd.	South Africa	Nchwaning, Gloria in South Africa	1,794,500
Jupiter Mines Ltd.	Australia	Tshipi Borwa in South Africa	1,757,609
Kudumane Manganese Resources	South Africa	Kudumane, South Africa	1,700,000

Source: RTE^[17].

3.2 Major manganese mining enterprises

In 2018, there were 9 enterprises and 12 manganese mines in South Africa, Australia, Brazil, Gabon, Ghana and China, the world's major manganese ore producing countries, with an annual output of 25.2 million tons. See **Table 2** for details. Major ore miners account for about 56% of the world's output, and are the main controllers of the world's high-quality manganese rich resources, and play a leading role in the allocation of manganese resources.

4. Supply, demand and import of manganese ore in China

In recent years, with the rapid development of domestic metallurgical industry, China's demand for manganese ore, especially rich manganese ore, has increased sharply, while the domestic manganese ore resource endowment is poor, which makes the contradiction between supply and demand more prominent. China has become the world's largest importer of manganese ore for many consecutive years.

4.1 Highly concentrated importing countries

At present, the source countries of China's overseas manganese ore are mainly South Africa,

Australia, Gabon, Ghana and Brazil, which account for about 90% of China's total imports (**Table 3**), while the import volume from South Africa and Australia accounts for more than 60% (**Figure 4**). In order to ensure the strategic security of China's manganese resources, China has been trying to expand the import sources of manganese resources in recent years, but the import proportion of Australia and South Africa remains above 50%. There is a high supply risk.

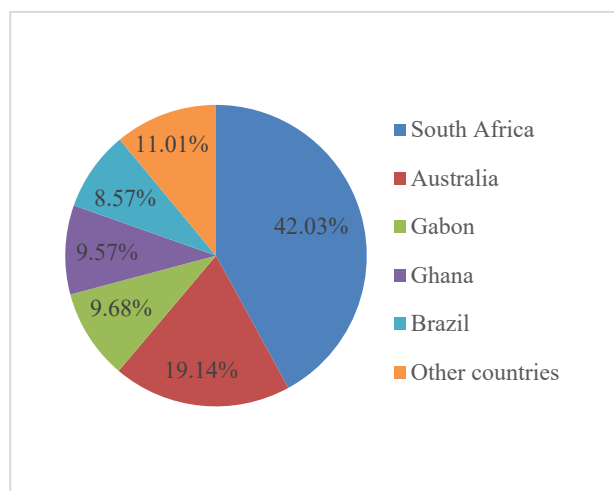


Figure 4. Proportion of China's manganese ore import sources in 2017. Source: RTE^[17].

Table 3. China's manganese ore import volume and source in 2014–2018

Ranking	2014	2015	2016	2017	2018
First place (import volume)	South Africa 5,794,476	South Africa 6,329,742	South Africa 7,591,901	South Africa 8,935,753	South Africa 11,141,791
Second place (import volume)	Australia 5,162,516	Australia 4,297,605	Australia 4,073,938	Australia 4,069,536	Australia 5,221,954
Third place (import volume)	Gabon 1,478,570	Gabon 1,876,216	Ghana 1,548,971	Gabon 2,057,086	Ghana 3,508,550
Fourth place (import volume)	Ghana 1,059,407	Brazil 1,183,085	Gabon 1,256,172	Ghana 2,034,067	Gabon 2,524,817
Fifth place (import volume)	Brazil 880,039	Ghana 537,177	Brazil 1,169,042	Brazil 1,822,121	Brazil 1,827,402
Total	14,375,008	14,223,825	15,640,024	18,918,563	24,224,514
Proportion in total	88.55%	90.12%	91.71%	88.99%	70.88%

Note: The data in the table is manganese concentrate data (unit: Manganese concentrate/t), which is derived from RTE^[17].

4.2 The price fluctuates greatly

From the perspective of the average price of imported manganese ore in China (**Figure 5**), the lowest price was only 104.0 USD/t in 2006 and the highest was 458.2 USD/t in 2008. This is mainly due to the shortage of manganese ore products and the sharp rise in prices due to the financial crisis.

Since then, due to the implementation of China's domestic steel capacity reduction policy in 2014, China's demand for manganese ore has slowed down, falling back to 122.4 USD/t in 2015. However, after 2017, due to the continuous increase of domestic mine environmental protection requirements and mining costs, domestic production

has plummeted, external demand has increased, and the price of manganese ore in the international market has risen again. In 2018, the import price of manganese ore in China reached 212.2 USD/t, and since the outbreak of the epidemic in 2020, the global manganese ore price has increased rapidly. Even if the epidemic is stable, under the monopoly control of the world's manganese rich countries and giant manganese ore companies, the manganese ore price will not have much room for decline.

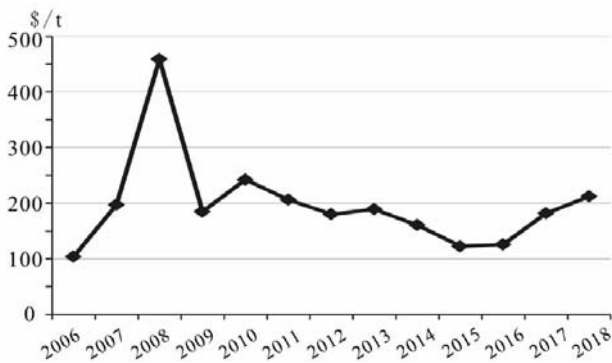


Figure 5. Import prices of Chinese manganese ores, 2006–2018. Source: RTE^[17].

Statistics show that^[4] the global manganese resource reserve production ratio has exceeded 40 years, but the effective exploration activities for manganese ore have increased rapidly in recent years (**Figure 6**), which may be related to the continuous growth of the global new energy market. Battery grade manganese ore is one of the main materials for producing power batteries (lithium manganate). With the further expansion of the new energy vehicle market, the demand for manganese ore will be very strong, which may push up the price of manganese ore.

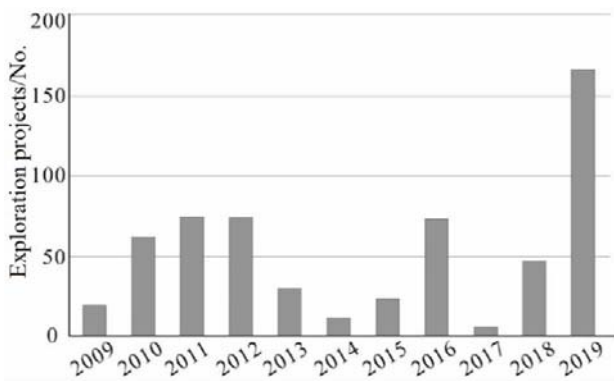


Figure 6. Statistics of global manganese ore exploration projects from 2009 to 2019. Source: Data are from SNL^[4].

At present, the reasons for the fluctuation of

China's manganese ore import price mainly include the following aspects: first, the distribution and production capacity of rich manganese ore resources are very unbalanced, and countries and multinational companies rich in manganese ore resources almost monopolize the pricing power of manganese ore; secondly, there is less investment in the development of overseas manganese-rich mine resources in foreign countries, and there is a lack of international giant manganese ore groups; in addition, the change of ocean transportation cost will also affect the import price of manganese ore in China.

4.3 External dependence

After entering the 21st century, due to the rapid development of the iron and steel industry, China has become the world's largest importer of manganese ore. The import volume of manganese ore and manganese concentrate has increased year by year, and has maintained an external dependence of more than 50% since 2010^[9]. The imported manganese ore is mainly rich manganese ore with a grade of more than 40%. In recent years, the degree of external dependence has exceeded 60% (**Figure 7**), and the contradiction between supply and demand is very prominent.

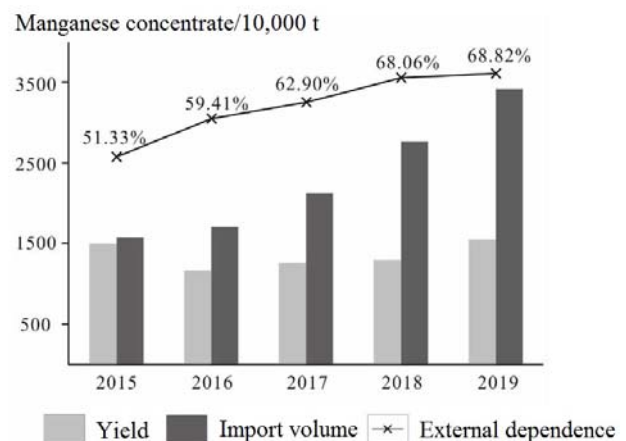


Figure 7. Yield and import of Chinese manganese ores, 2015–2019. Source: USGS and RTE^[6,17].

5. Resource potential analysis

Limited by the metallogenic conditions^[2,10,18], the current situation of the shortage of domestic manganese rich ores is difficult to change in the short term. Making full use of overseas manganese rich resources will help to realize resource

complementarity in China. With the application of some sophisticated exploration technologies^[19,20], deep and peripheral exploration of the deposit will be conducive to achieving new breakthroughs in prospecting and providing technical support for China's manganese enterprises. However, with the rise of trade protectionism and unilateralism, the overseas market is also full of challenges. Identifying manganese potential areas will help domestic manganese enterprises go global.

At present, Africa and Oceania are the main sources of manganese resources overseas in China, and also the main concentration of manganese rich ores in the world. Especially, Africa has superior metallogenic geological conditions, and has become the largest source of imported manganese in China for many consecutive years. South Africa, Ghana and Gabon have large-scale and high-grade manganese mines, which are easy to realize industrial mining, and these countries account for a high proportion of mining investment, which is suitable for national manganese enterprises to settle in. The manganese mines in the Democratic Republic of Congo, Zambia and Namibia are small in scale, but there are many ore spots with high grade, and the investment is small and effective, which is conducive to the involvement of small and medium-sized private enterprises. In Australia and Brazil, because their manganese resources are firmly controlled by international mining giants, it is very difficult for large state-owned enterprises to enter, while small and medium-sized enterprises are trapped in environmental protection, human costs and other factors, which are difficult to make profits, which is not conducive to China's control of its manganese resources. Therefore, Africa will be the most important potential area of China's overseas manganese resources.

Through the comprehensive analysis of manganese ore-forming conditions and exploration and development degree in southern Africa^[6,12,13,21-27], the exploration and development of manganese ore in southern Africa should focus on Kalahari-Postmasburg manganese ore concentration area in North Cape Town, South Africa, the central part of Limpopo Province, Haut-Ogoue and Moyen-Ogoue provinces in Gabon,

North Central Namibia, the adjacent area between southern Botswana and South Africa, Tete Province in Northwest Mozambique, Mansa-Mkushi-Kabwe area in central Zambia and Kisenge-Kamata area in Katanga Province in Southern Democratic Republic of Congo.

6. Conclusions and suggestions

6.1 Conclusion

The distribution of global manganese resources has the following characteristics: (1) the distribution of resources is extremely uneven, and South Africa, Australia and Gabon retain more than 60% of the global resource reserves; (2) the production capacity is highly concentrated, and the main ore producers account for more than 50% of the world's output, controlling the world's main high-quality manganese rich ore resources; (3) there is a serious separation between supply and demand. As the world's largest demander of manganese resources, China's reserves account for only about 5% of the world. Characteristics and demand trend of manganese resources in China: (1) widely distributed but insufficient reserves; (2) low grade, poor quality and limited manganese ore resources; (3) the external dependence is too high, the overseas channels are limited, and the manganese resource guarantee system is not perfect; (4) in the future, the contradiction between supply and demand of manganese resources in China will still exist, and southern Africa can be used as a key area for the exploration and development of overseas manganese resources in China.

6.2 Thoughts and suggestions

With the growth of domestic new energy market, the contradiction between supply and demand of manganese ore in China will become more prominent. In order to ensure the strategic safety of China's manganese resources and the healthy development of the manganese industry, domestic enterprises should seize the historical opportunities brought by the "going global" and the "the Belt and Road" initiatives, and promote a multi-level and multi-channel manganese resource utilization and guarantee system facing the world as

soon as possible. Specific suggestions are as follows:

Identify domestic assets and formulate domestic and foreign supply plans according to the demand gap. While finding out the current situation of domestic manganese resources, combined with the future development planning of major manganese application industries such as steel, new energy batteries and chemical industry, predict the demand gap of manganese resources, and make targeted import and export planning to ensure the sustainable development of domestic manganese industry.

Strengthen overseas layout and improve controllable manganese resource reserves. While increasing the investment in domestic manganese geological exploration, we should enter the manganese-rich resource countries with low degree of mining exploration and lack of technical personnel, such as southern Africa, where the metallogenic conditions is superior and the resource potential is huge. Relying on high-precision and cutting-edge technology, we should strengthen the exploration of manganese rich resources at home and abroad, and constantly seek new manganese resources. Promote production capacity cooperation, extend the industrial chain of resource development and processing in manganese resource countries, and increase the synergy of manganese development conditions. In the process of guiding domestic manganese mining enterprises to go global, there should be both a “national team” composed of large enterprises and a “self-employed” composed of small and medium-sized enterprises. The “national team” can actively participate in the development projects of manganese mines in the source countries, establish long-term strategic investment and cooperation relations with the target countries, and take acquiring world-class mines as the core strategy through various cooperation methods such as resource exploration, equity purchase and engineering for resources. We will do our utmost to ensure the safety of manganese resources supply in China. As a “self-employed” small and medium-sized enterprises, they cannot limit the size of the deposit, with the purpose of quickly and directly obtaining manganese rich

ores, blossom at multiple points, and constantly improve China’s controllable manganese ore reserves. In addition, the beneficiation and smelting technology and the mining technology of marine manganese resources should be further improved to realize the comprehensive development and utilization of manganese resources.

Establish a diversified resource supply system and gradually gain the right to speak by using the scale of the domestic market. China is highly dependent on international manganese ores, but the manganese product suppliers and pricing power in the international market are mainly in the hands of several major foreign manganese miners, which has potential risks. In order to cope with the supply risks that may be caused by the great changes in the international situation, China should establish a multi-level and multi-channel manganese resource supply guarantee system facing the world as soon as possible, share trade risks, reduce the adverse impact of market fluctuations on the entire manganese industry, and further compete for the right to speak by using the scale of the domestic market.

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Conflict of interest

The authors declared no conflict of interest.

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