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Exploitation and Utilization Status and Safe Supply Strategy of Copper, Aluminum, Lead, and Zinc Resources in China

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Abstract: Copper (Cu), aluminum (Al), lead (Pb), and zinc (Zn) are important raw materials for national economic development and have the highest consumption rate among non-ferrous metals. China's production and consumption of these metals has consistently ranked first globally for more than a decade. However, its output of mining resources is far from meeting domestic consumption, which has led to a high degree of dependence on imports. Based on an exploitation and utilization status study and a future demand forecast for Cu, Al, Pb, and Zn in China, this study analyzes the guarantee level of domestic, imported, and secondary resources to meet consumption demands and formulates a safe supply strategy for Cu, Al, Pb, and Zn mineral resources. The safety guarantee target for these metals in the next 20 years will be quantitatively constructed from the three sources of domestic supply, overseas development, and international trade, and from mineral products, recycled metals, and refined metals. Various strategic measures should be implemented to ensure the uninterrupted supply of these metal resources, such as increasing domestic exploration and development, improving domestic supply capacity, adhering to green and sustainable development of domestic resources, strengthening secondary resource recovery, and actively utilizing overseas resources.

Keywords: mineral resources; non-ferrous metal; safe supply; copper, aluminum, lead, and zinc

The non-ferrous industry is an important component of China's economic development and its safe supply is crucial to ensure China's sustainable economic growth. As important raw materials, copper (Cu), aluminum (Al), lead (Pb), and zinc (Zn) account for more than 95% of the total consumption of non-ferrous metal resources in China; there has been a problem with this sector for many years because of the inadequate domestic supply and high degree of dependence on imported resources. Therefore, this study emphasizes research on the exploitation and utilization status and supply and demand of Cu, Al, Pb, and Zn resources in China, striving to provide a reference for the supply safety of these resources.

1 Exploitation and utilization status of China's Cu, Al, Pb, and Zn resources

1.1 Production and consumption ranked first globally, while imports and exports maintained rapid growth

China is the world's largest producer and consumer of non-ferrous metals. Table 1 and Table 2 list the production and consumption of Cu, Al, Pb, Zn, and other non-ferrous metals in China and the rest of the world from 2011 to 2016 [1–6]. Respectively, in 2016, China's output accounted for 35.9%, 56%, 41.6%, and 45.6% of

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worldwide production, with its consumption representing 49.9%, 54.5%, 41.3%, and 48.1% of the global total of the consumption of these resources.

Table 1. China's and worldwide production of Cu, Al, Pb, and Zn resources. $\times 10^4$ t (by metal reserves)

Year	Refined Cu		Virgin Al		Refined Pb		Zinc ingot	
	China	World	China	World	China	World	China	World
2011	516.3	1981.8	1813.5	4479.0	460.4	1033.6	521.2	1312.0
2012	587.9	2035.8	2025.1	4633.0	459.1	1037.8	488.1	1263.5
2013	666.7	2118.0	2315.5	4861.5	493.5	1068.8	528.0	1324.3
2014	764.9	2248.0	2831.7	5310.9	470.4	1092.5	580.7	1350.8
2015	796.9	2308.3	3151.8	5662.1	442.2	1059.4	611.6	1393.2
2016	845.5	2354.5	3269.8	5837.4	460.4	1105.2	619.6	1357.2

Table 2. China's and worldwide consumption of Cu, Al, Pb, and Zn resources. $\times 10^4$ t (by metal reserves)

Year	Refined Cu		Virgin Al		Refined Pb		Zinc ingot	
	China	World	China	World	China	World	China	World
2011	788.1	1956.6	1770.2	4267.3	430.0	1032.2	546.0	1255.3
2012	889.6	2011.8	2025.8	4553.4	461.8	1040.0	539.6	1222.7
2013	983.0	2098.1	2195.5	4606.4	446.7	1039.1	599.5	1315.1
2014	945.0	2288.6	2700.0	5310.0	490.0	1089.8	635.0	1373.1
2015	1135.3	2261.6	3106.8	5708.4	381.6	1002.6	648.8	1385.0
2016	1164.2	2333.1	3161.5	5800.8	465.5	1126.6	669.3	1390.7

China's consumption intensity has consistently ranked the highest globally for many years. Its consumption per unit of gross domestic product (GDP) is even higher than that of the advanced industrialized countries, which is in addition to it having the highest consumption per unit of GDP and per capita consumption of Cu, Al, Pb, and Zn resources. Table 3 presents China's consumption intensity of these metals in 2015 [5,7].

Table 3. China's consumption intensity of Cu, Al, Pb, and Zn in 2015.

Product (s)		Consumption ($\times 10^4$t)	Population (10 000 people)	GDP (USD 100 million)	Consumption per capita (tonnes per 10 000 people)	Consumption per GDP (tonnes per USD 100 million)
Refined Cu	World	2261.56	726 231	740 000	31.14	30.56
	China	1135.31	137 462	99 863	82.59	113.69
	U.S.	178.9	32 310	185 690	55.37	9.63
Virgin Al	World	5708.43	726 231	740 000	78.60	77.14
	China	3106.81	137 462	99 863	226.01	311.11
	U.S.	532.5	32 310	185 690	164.81	28.68
Refined Pb	World	1002.57	726 231	740 000	13.81	13.55
	China	381.62	137 462	99 863	27.76	38.21
	U.S.	159	32 310	185 690	49.21	8.56
Zinc ingot	World	1384.97	726 231	740 000	19.07	18.72
	China	648.74	137 462	99 863	47.19	64.96
	U.S.	93.1	32 310	185 690	28.81	5.01

Imports of non-ferrous metals are escalating, while that of Cu, Al, Pb, and Zn including copper concentrate, refined and scrap copper, bauxite, aluminum oxide, lead concentrate, and zinc concentrate, also rank first globally. China is also an important exporter of mined Cu, Al, Pb, and Zn, with its total exports growing every year. However, as exported products mainly consist of primary processed or smelted commodities, the value added is low.

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1.2 The excessive intensity of domestic resource exploitation and high degree of dependence on imported resources

China's production of Cu, Al, Pb, and Zn resources is growing fast and the exploitation of these is highly intensive. Table 4 presents the proportion of China's Cu, Al, Pb, and Zn reserves and mineral output compared to the 2016 global total [8,9]. The data in Table 4 show that China's exploitation intensity of these resources is higher than that of the world total, and above the world average level.

Table 4. Proportion of China's Cu, Al, Pb, and Zn reserves and mineral output to the global total. ($\times10^4$ t, by metal reserves)

Mineral species	Reserves		Output		Reserves proportion	Output proportion
	China	World	China	World	(%)	(%)
Copper	2,800	72,000	185.1	2,074.7	3.9	8.9
Lead	1,700	8,800	233.8	480.1	19.3	48.6
Zinc	4,000	22,000	471.1	1,230.2	18.2	38.3
Bauxite*	98,000	2,800,000	6,861.6	27,497.0	3.5	25.0

* Bauxite is calculated based on ore reserves.

Although it is in the middle and late stages of industrialization, China has significant demand for mineral resources. Despite yearly growth in output, the production from non-ferrous metal mines still falls short of consumption, and the shortfall in Cu, Al, Pb, and Zn resources continues to increase, which is in addition to the higher degree of dependence on imported resources [9]. Table 5 [9,10] shows China's degree of dependence on imported Cu, Al, Pb, and Zn resources from 2011 through 2016.

Table 5. Degree of dependence on imported Cu, Al, Pb, and Zn resources from 2011–2016. (%)

Metals	2011	2012	2013	2014	2015	2016
Copper	64.0	62.4	58.4	71.4	65.8	64.1
Aluminum	56.5	52.8	78.6	40.3	47.6	40.4
Lead	18.5	13.4	16.2	8.7	12.9	12.7
Zinc	30.6	9.8	11.9	14.3	24.4	25.0

Note: The degree of dependence is equal to net metal imports (excluding scrap metals) divided by metal consumption.

1.3 Equity production and exploitation capacity has improved but there is insufficient control over overseas mineral resources

A high degree of dependence on imported mineral resources drives many Chinese enterprises to engage in import resource development and exploitation. According to incomplete statistics, they have obtained a number of valuable mining rights and mineral deposits overseas, including 1×10^8 tonnes of Cu resources, 2×10^9 tonnes of Al resources, and more than 5×10^7 tonnes of lead and Zn resources. On this basis, China is scaling up its equity production capacity of Cu, Al, Pb, and Zn resources, to a certain extent. However, there are also significant differences between Chinese mining companies and those of the other major exporters in terms of their resource asset allocation, type, endowment, and total reserves [11,12]. In addition, China also has weak control over world mineral resources, and its overseas equity resource production is low in proportion to imports, which threatens the safety of China's sustainable socioeconomic development.

1.4 The significant increase in recycled non-ferrous metal production still does not approach the recovery rate of other developed countries

In recent years, China has maintained sustained growth in the production of recycled non-ferrous metals, especially in the recycling of Cu, Al, and Pb, which to a large extent compensates for the shortage of domestic non-ferrous metal resources. Table 6 lists the output of recycled Cu, Al, Pb, and Zn in China from 2010 to 2016 [1–6]. By 2016, the output of recycled Cu, Al, and Pb accounted for 26.1%, 19.3%, and 36.0% of the total amount, respectively, which makes some contribution to meeting the domestic consumption demand for non-ferrous metals. At present, the recovery rate of Cu, Al, Pb, and Zn in the United States and other western developed countries has exceeded 60%, and some countries have no smelting plants for processing primary mineral resources. In terms of the recycling of non-ferrous metals, China lags far behind developed countries. This is not only restricted by the

depth of the industrialization process and China's social development stage but also by the recycled non-ferrous metal industry itself.

Table 6. Production of recycled Cu, Al, Pb, and Zn in China. (× 10^4 t)

Year	2010	2011	2012	2013	2014	2015	2016
Cu	162.0	180.0	190.8	215.6	225.5	229.7	220.9
Al	400.0	440.0	482.6	527.3	447.8	577.6	629.8
Pb	136.3	140.4	136.6	150.7	153.1	155.2	166.3
Zn	17.5	17.3	11.5	21.5	21.3	23.2	21.4

1.5 The Cu, Al, Pb, and Zn industry needs further restructuring

China has long been challenged by its irrational structures in the Cu, Al, Pb, and Zn industry and its "inverted triangular" procedures of processing, smelting, separation, and mining. Striving to realize industrial structure adjustment, transformation and upgrade, and benefit growth in recent years, relevant national authorities have implemented a series of control policies at the macro level to control the expansion of production capacity strictly and to accelerate the phasing out of excessive and outdated production capacity. However, the industrial structure is yet to be improved and the exploitation scale of domestic Cu, Al, Pb, and Zn mineral resources still falls short of the demand created by the smelting and processing capacity, while a proportion of primary products is used for export.

2 Demand forecast and availability analysis of Cu, Al, Pb, and Zn in China

2.1 Demand forecast

After examining the law of mineral consumption followed by major industrialized countries over the past century, the Research Center of Global Mineral Resources Strategy, under the Chinese Academy of Geological Science (CAGS), has suggested an S-curve model of the relationship between per capita mineral consumption and GDP per capita [13]. China's economy has shifted from the high-speed growth stage to a high-quality development stage. According to the S-curve theory, China's total consumption of non-ferrous metals will continue to increase over a period of time and as important raw materials, Cu, Al, Pb, and Zn will continue to contribute to high-priority consumption demand in the future. It is estimated that China is likely to experience a demand peak for non-ferrous metals around 2025 through 2030, before which its demand for non-ferrous metals will be consistent but with slower growth.

The Research Center of Global Mineral Resources Strategy, the China Non-ferrous Metals Industry Association, and other organizations have utilized the S-curve forecasting, consumption intensity forecasting, and other methods to estimate China's future consumption demand for Cu, Al, Pb, and Zn mineral resources; the predicted peak values are shown in Table 7 [14,15]. Despite the varying predicted values according to different organizations and methods, the general consensus is that the consumption of these resources will remain at a high level over the long term.

Table 7. Predicted Peak Values and Years of Cu, Al, Pb, and Zn Consumption Demand in China. (× 10^4 t)

Forecasting method (s)	Refined Cu	Refined Al	Refined Pb	Refined Zn
S-curve forecasting	1500 (2025)	3300 (2025)	820 (2030)	1050 (2030)
Consumption intensity forecasting (2030)	1300	4300	550	770

Considering the environmental bearing capacity and the current production situation of non-ferrous metal mines in China, the production capacity of the Cu, Al, Pb, and Zn mining and dressing industry is expected to maintain its size at the current level or increase slightly in the coming 10 to 15 years. The predicted peak demand and guarantee level for non-ferrous metals, including the production of Cu, Al, Pb, and Zn, metallurgical products, and secondary metals, is shown in Table 8 [14–16]. At that time, there is still expected to be a gap between consumption and output, and the shortfall needs to be made up by international procurement, overseas exploitation, industrial transfer, and other means.

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Table 8. Analysis of guarantee level for peak demand of Cu, Al, Pb, and Zn in China.

Metal	Time (Year)	Mine output ($\times10^4$ t)	Secondary metal (domestic) ($\times10^4$ t)	Predicted demand ($\times10^4$ t)	Guarantee level of primary resources (%)	Guarantee level of domestic secondary resources (%)	Total guarantee level (%)
Cu	2025	200	300–400	1500	13.3	20.0–26.7	33.3–40.0
Al	2030	900	600–900	4300	20.9	14.0–20.9	34.9–41.8
Pb	2030	300	200–300	820	36.6	24.4–36.6	61.0–73.2
Zn	2030	530	30–60	1050	50.5	2.9–5.8	53.4–56.3

2.2 Analysis of resource availability

2.2.1 Domestic resource availability

China has a relatively low static guarantee period for the aforementioned resources (see Table 9), which makes it difficult to meet the needs of economic and social development. This period of guarantee is even shorter when calculating in actual consumption terms. Table 9 lists the calculated results of the static guarantee period [6,17]. China has potential in prospecting Cu, Al, Pb, and Zn ores. With the increase of geological exploration, the availability of Cu, Al, Pb, and Zn resources in China may experience a significant increase. However, it is still difficult to meet domestic consumption demands and a portion of these ores therefore needs to be imported.

Table 9. China's static guarantee period of Cu, Al, Pb, and Zn resources.

Mineral species	Unit	Basic reserves	Mine output	Static guarantee period*
Copper	10 000 t	2621.0	185.1	14.2
Lead	10 000 t	1808.6	233.7	7.7
Zinc	10 000 t	4439.1	471.0	9.4
Bauxite	Million tonnes of ore	10.1	0.69	14.6

* Calculated based on output in 2016.

2.2.2 Availability of international and secondary resources

In general, the world reserves of Cu, Al, Pb, and Zn resources are abundant, and highly guaranteed [18]. With the development of mineral exploration technology and the increase in geological exploration investment, the growth of proven reserves will accelerate. As previously mentioned, China's control over imported resources is weak, despite the abundance of world reserves.

With the steady growth of the global consumption of non-ferrous metals, their social stock is also increasing. Therefore, more scrap metals will be available for recycling at the end of the service life of end products made from these metals. However, unlike other developed countries, China cannot realize large-scale recycling and utilization of non-ferrous metals in the short term as it is restricted by economic development and recycling technologies. According to the life cycle of Cu, Al, Pb, Zn, and other products, the output of recycled non-ferrous metals such as these is predicted to continue to increase in the next 15 years. Renewable resources will play an increasingly important role after 2020.

3 China's safe supply strategy for Cu, Al, Pb, and Zn

Considering China's economic and social development outlook, and in combination with the consumption forecast, the safety guarantee target for Cu, Al, Pb, and Zn metals in the next 20 years will be quantitatively constructed from domestic supply, overseas development, and international trade, and from mineral products, recycled metals, and refined metals. Meanwhile, various strategic measures should be implemented to ensure the safety of the Cu, Al, Pb, Zn metal resources supply, such as increasing domestic exploration and development, improving domestic supply capacity, adhering to green and sustainable development of domestic resources, strengthening secondary resource recovery, and actively utilizing overseas resources. The specific strategic measures that China should engage in are:

(1) Strengthen domestic resource exploration and establish new bases for mineral exploitation, utilization, and

reservation. Continuously increase investment in mineral exploration, and further prospect and explore the domestic key metallogenic belts so as to raise the proportion of proven reserves and those of backup non-ferrous resources. A second round of prospecting in and around existing large mines will be conducted to increase the available resources and extend the service life of the mines. The degree of detailed survey on high-level resources in key mining areas of Cu, Al, Pb, and Zn will be improved, so as to increase the proven reserves and the economically available resources.

(2) Deepen the win-win cooperation and development with resource-rich countries and increase the proportion of overseas resource exploitation. Research on the world distribution and supply capacity of Cu, Al, Pb, and Zn mineral resources is required. Attention needs to be paid to those countries and regions with resource advantages regarding their complementarity, reciprocity, and optimal allocation of resources, striving to establish a stable strategic partnership with them. A network integrating storage, production, transportation, trade, distribution, supply and demand, and market information of global resources is to be established for the purpose of developing a diversified channel for mineral resource imports.

(3) Accelerate technological innovation, and improve the practical exploitation and utilization of domestic resources. An internationally competitive engineering technology innovation system, which is in line with China's development demands and characteristics of Chinese mineral resources, is to be established. It aims to boost industrial adjustment, transformation, and upgrade through technological innovation, thereby promoting the development of intelligent production in the Cu, Al, Pb, and Zn mining industry and improving the sustainable development and supply capacity of this sector.

(4) Attach more importance to environmental protection in mining processes and promote green development of resource industry. Environmental impact assessments should be conducted during the exploitation period, and rational and sequential mining of the mineral resources in ecologically vulnerable areas is required. A comprehensive and complete process measure based on the principle of "source control and prevention, clean production, and end treatment" should be taken. Land reclamation, ecological restoration, contaminated soil remediation, and ecological environment reconstruction are to be strengthened in mining areas.

(5) Push forward the development of the industry for recycling and reutilizing secondary resources and establish and improve the resource circulation economy system. To increase the proportion of recycled metals as well as the recovery rate of waste and scrap metals, China's dependence on imported resources should be significantly reduced, and a non-ferrous metal resources recycling economy constructed; the advanced production technology for recycling waste and scrap metals will be developed and industrialized.

(6) Foster large-scale mineral resources enterprise groups with international competitiveness and integrate exploration, mining, dressing, and smelting. Support the combination between mineral resource companies of different types, the mineral resource company and the financial company, the mining resource company and the exploration company, as well as the upstream enterprise and the downstream company. Encourage mergers, acquisitions, and reorganizations under the market mechanism, so as to improve its control over the worldwide Cu, Al, Pb, and Zn resources as well as its influence on the relationship between supply and demand in the international market, in particular on the price.

(7) Establish and improve China's capital market system for Cu, Al, Pb, and Zn mining industry. The combination of mining and capital markets will be facilitated, the traditional trading mode of mining rights will change and the number of financing channels for risk exploration is to be increased. Increase China's influence over the global mining capital market by developing a mature market system.

(8) Give full play to the role of state macro-control. It is suggested that relevant authorities should formulate incentive policies concerning the development and exploration of domestic resources, the recycling and utilization of secondary resources, as well as the exploration and capacity cooperation of imported resources.

4 Conclusion

As important raw materials, China's Cu, Al, Pb, and Zn production and consumption have consistently ranked first globally for more than a decade, but the output of mining resources is far from meeting domestic consumption, which has led to a high degree of dependence on imported resources. It is estimated that China will face a continuous increase in its total consumption of non-ferrous metals and a difficulty in satisfying its consumption demands from domestic mineral resources alone; the high dependence on imported resources is expected to continue. To meet the demands of China's demand for Cu, Al, Pb, and Zn resources to achieve economic development, various strategic measures may be implemented to ensure the safety of non-ferrous metal resources,

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such as increasing domestic exploration and development, improving domestic supply capacity, adhering to green and sustainable development of domestic resources, strengthening secondary resource recovery, and actively utilizing overseas resources.

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