Original Article

Indium use, resource, market and ore deposit type

JZ Yin[1,2,3] ©

Abstract

With the continuous advancement of science and technology, rare dispersed elements that have long been dormant in rocks and ignored by humans have become increasingly important. Indium is one of these rare dispersed elements, although most people know little or nothing about it. In fact, indium has a wide range of important uses in many aspects. Given the unique physical and chemical properties of indium, some uses are even irreplaceable. Therefore, many countries have included some rare elements, including indium, in the list of national strategic resources or critical metals for protection. This article not only popularizes the main uses of indium in modern society, briefly describes the distribution and current status of natural indium ore resources around the world, but also explores its market status in the past 10 years and future development trends. Finally, the main genesis types of associated or symbiotic indium ores around the world are summarized and briefly discussed. Because indium does not exist as an independent deposit and can only exist as a by-product of non-ferrous metals such as copper, lead, zinc and tin, it is very important to research and develop new sources of indium, including recycling and reuse. These new sources include but are not limited to waste rock piles and tailings from related abandoned old mines, etc.

Key words: Rare dispersed metal indium; use; global resource distribution; market and trend; origin type

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Affiliation Info: [1] Orient Resources Ltd., Canada; [2] Wuhan Institute of Technology, Wuhan 430205, China; [3] College of Earth Sciences, Jilin University, Changchun 130061, China

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Authors' Contact Info: Yin, JZ: jimyin7@yahoo.ca

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Corresponding Aurhor©: Yin, JZ, PhD, PGeo, Professor; Email: jimyin7@yahoo.ca

1 Introduction

With the rapid development and continuous progress of science and technology, many metals that were not noticed by people, especially those rare metals have been constantly entering people's sight, gaining more and more attention, and playing an indispensable and important role in modern industries. Most of the rare dispersed elements that ordinary people don't know about are an important category of these metals.
Most people are familiar with bulk mineral products such as steel, aluminum alloys and various copper alloys that are closely related to their daily lives, but few people know about rare metals such as indium (In), gallium, rhenium, etc. In fact, the indium mentioned here is one of the many rare dispersed elements.
This article will analyze the distribution and production status of global indium resources on the basis of introducing the main uses of indium, a rare metal in modern life, and then explore the market and future trends of indium products, and then classify its deposit genesis types. In the future, another article will discuss its formation conditions, etc.

2 Use

Indium is a soft, silvery-white metal with a slightly bluish tint. Pure indium metal is highly plastic and will leave marks if you squeeze it gently. It can also be easily pressed into slices or cut into blocks, just like the tofu we often see in our daily lives. Indium metal has a low melting point and electrical resistance, but a high boiling point. It has excellent ductility, plasticity, and corrosion resistance. In addition, indium has excellent light permeability and electrical conductivity, making it one of the best semiconductor materials[1-3].

Indium is located in the fifth period and group IIIA of the periodic table. It has an atomic weight of 114.818 and is the 49th element. The average abundance of In in the continental crust is 0.052 ppm where it is nearly always found as a trace element in other minerals4. Obviously, the content of In in the earth's crust is low and very dispersed, and it only exists as an impurity in metal deposits such as zinc and lead. Therefore, people classify indium as a rare metal together with elements with similar characteristics such as gallium, thallium, germanium, selenium, tellurium and rhenium. The chemical properties of indium are between those of gallium and thallium. In 1863, Ferdinand Reich and Hieronymus Theodor Richter discovered indium through spectroscopy and named it indium because of its indigo spectral line. However, it was not until the following year that indium was successfully isolated. The special physical and chemical properties of indium determine that there is no elementary substance indium in nature. Indium generally exists in combination with other elements to form related compounds.

Due to its low melting point, high boiling point, good ductility, strong plasticity, low resistance, good superconductivity and corrosion resistance, as well as good light permeability and conductivity, indium is widely used in high-tech fields such as radio and electronic industry, aerospace, alloy manufacturing, new materials for solar cells, medical, national defense and military, high-tech, nuclear industry, modern information industry and energy. Indium is also commonly found in the display screens of computers and smartphones that modern humans almost cannot live without. ITO targets used in the production of liquid crystal displays and flat-panel screens are the main consumer of indium ingots, accounting for about 70% of global indium consumption. The second largest consumer is the electronic semiconductor field, which accounts for about 12% of global consumption. Indium consumed in the solder and alloy field accounts for about 12%. The scientific research industry consumes about 6% of indium (Figure 1)[1-3, 5].

Metal indium was originally used to manufacture industrial bearings and has been used ever since. After the surface of the bearing is plated with indium, its service life is extended by 5 times that of the bearing with ordinary coating. The alloy of indium and gallium can lubricate the sliding elements, so it is used in electric vacuum instruments.

Indium is easy to form a firm coating on the metal surface and has good corrosion resistance. Especially, it can prevent the corrosion of alkaline solution to the metal. The coating of indium not only has a bright color but also is easy to polish. In addition to pure indium coating, alloys such as indium and zinc can also be used as coatings. Indium coating is also used in decorative crafts. When the surface of various mirrors, retroreflectors and reflectors is plated with indium, its reflective performance will be greatly enhanced and resistant to seawater erosion. Therefore, this coating is often used in the reflectors of ships. In addition, bronze mesh with indium coating on the surface can be used to remove mercury vapor in vacuum instruments.

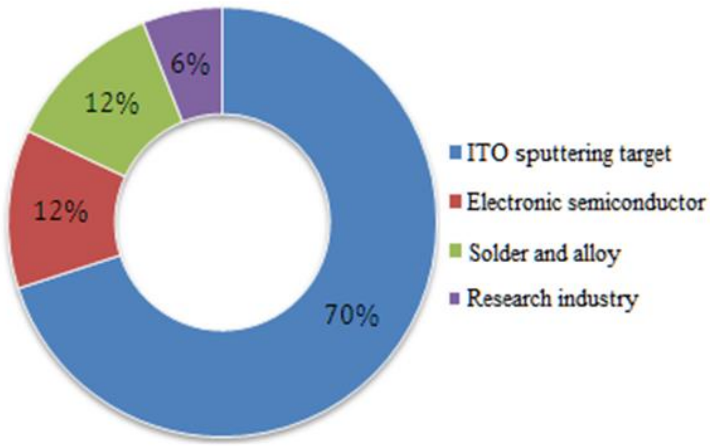


Figure 1. The main uses of indium and their proportion[2]

Because indium has a low melting point, it can be used to manufacture a variety of fusible alloys. This type of indium-containing alloy with a melting point in the range of 47 to 122 °C is mostly used to manufacture various types of fuses, fuse cutouts, thermostats and signal devices.

Many fusible alloys of indium can be used as brazing materials. Indium and its alloys can firmly weld parts made of piezoelectric materials together. When making multi-layer integrated circuits, it is crucial to choose brazing materials containing indium.

The glassy composite of high-purity indium oxide and tin oxide (ITO) is used to make transparent conductive electrodes in the plasma TV and LCD TV screen industries, and is also used as a sensitive element for measuring certain gases. In the radio and electronics industries, indium and silver oxides are mixed and pressed into special contact devices. Many alloys can improve their strength, ductility; wear resistance and corrosion resistance after adding a small amount of indium. Indium has also earned the reputation of "vitamin of alloys", and some people call it the "wonderful indium effect".

Indium alloys can be used to produce solar cells. The new generation of copper-indium-gallium-selenium (CIGS) thin-film solar cells has the characteristics of low production cost, low pollution, no decay, and good weak light performance. More importantly, the photoelectric conversion efficiency of this cell ranks first among various thin-film solar cells, close to crystalline silicon solar cells, but its cost is only one-third of the latter. Therefore, it is called "a very promising next-generation new thin-film solar cell" by the international community. This cell also has a soft, uniform black appearance, which is an ideal choice for places with high requirements for appearance, such as glass curtain walls of large buildings.

Indium is also the core material for manufacturing computer chips and indium tin oxide (ITO). Adding a very small amount of indium can greatly improve the performance of related products.

Indium is also one of the important basic materials that are indispensable for modern high-tech weapons and equipment. Since the 1980s, the U.S. Defense Logistics Agency (DLA) has included indium in the list of national defense reserve materials. In modern military high technology, indium is mainly used in electronic and information equipment. From military command to weapon guidance, from television to electronic countermeasures, components containing rare metals such as indium are used. The infrared imager that relies on the different thermal radiation of the target and the background to form an image is an infrared photoelectric system. When combined with other devices, it becomes a multi-sensor intelligent system and an all-weather, all-day combat tool. According to relevant materials, the United States has equipped the military with at least more than 100 types of thermal imagers. The "eyes" of the infrared thermal imager are infrared detectors, and the main materials used are CdSb, InSb, and InAsSb/Si, etc. The newer generation of infrared detectors under development will use InSb components. This component has higher sensitivity and resolution, and a longer use distance[1-3, 5-7].

Because indium is an indispensable rare resource in many high-tech fields such as the above, it has been listed as a critical mineral by China, the European Union, the United States, Japan and other countries. The so-called critical mineral means that foreign investors cannot get involved in the exploration and development of this mineral resource. The import and export of related mineral products are also strictly controlled by relevant countries.

Due to its good ductility and plasticity, low vapor pressure, and ability to adhere to a variety of materials, indium is also widely used as a gasket or lining material in high-altitude instruments and aerospace equipment. Indium foil is often used as a contactor for ultrasonic linear blocking. In the atomic energy industry, indium is used to make neutron indicators. Many indium alloys are often used to make control rods in nuclear reactors. Indium is also an excellent material for making neutron detectors, comparable to metallic gallium.

In addition to the above application fields, one of the more promising application fields of indium is the field of oral medicine. It is known that alloys used for dentures are basically alloys with gold, silver and palladium as main components and 0.5% to 10% indium added. Adding a small amount of metallic indium to the material of dental prostheses can significantly improve the corrosion resistance and hardness of these prostheses, and this alloy material will not turn black[1-3, 5-6].

According to relevant analysis, the amount of indium used in new applications is still increasing at a rate of 10 % - 20 % per year[2-3, 5-10].

In German, some resources are called Gewürzmetall (spice metals) because, like spices such as cinnamon or saffron, they only account for a small proportion of the production process of electronic devices, but are essential for certain functions.

Indium is one of these spice metals.

3 Resource

Similar to many other mineral resources on the earth's surface, the distribution of indium ore deposits on this planet is also extremely uneven (Figure 2). Not only is the overall resource volume of indium ore relatively small, but it is also mainly concentrated in a few countries such as China, Peru, the United States, Canada and Russia. Among them, China has the richest indium ore resources, accounting for about 72.0 % of the global total. Peru has the second largest indium resources in the world, accounting for about 3.3% of the world's total. The United States ranks third, accounting for about 2.5% of the global total (Figure 3)[8-10].

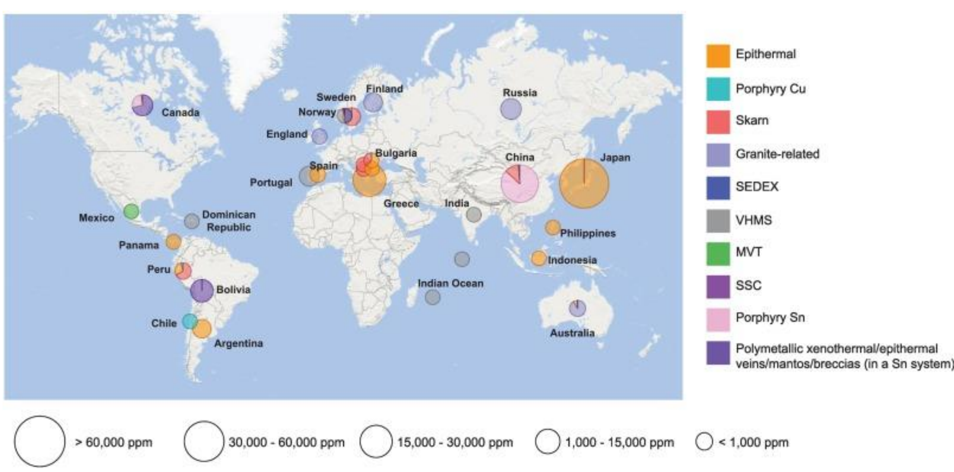
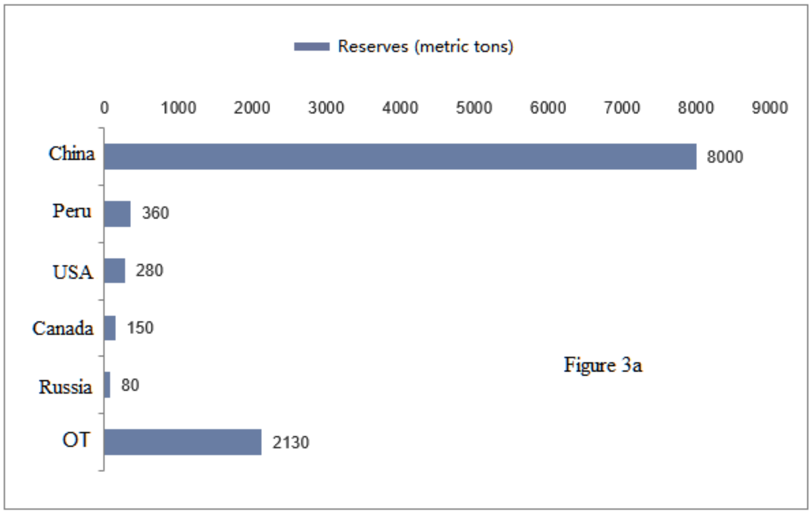


Figure 2. Map of the average indium content of indium-bearing minerals per mineralization style and by country[11]

The bubble size corresponds to the visual representation of the relative indium content in ppm measured by EPMA or LA-ICP-MS Abbreviations VHMS: volcanic-hosted massive sulfide deposits; SEDEX: sedimentary exhalative mineral deposits; SSC: sediment-hosted stratiform Cu; MVT: Mississippi Valley-type Zn-Pb



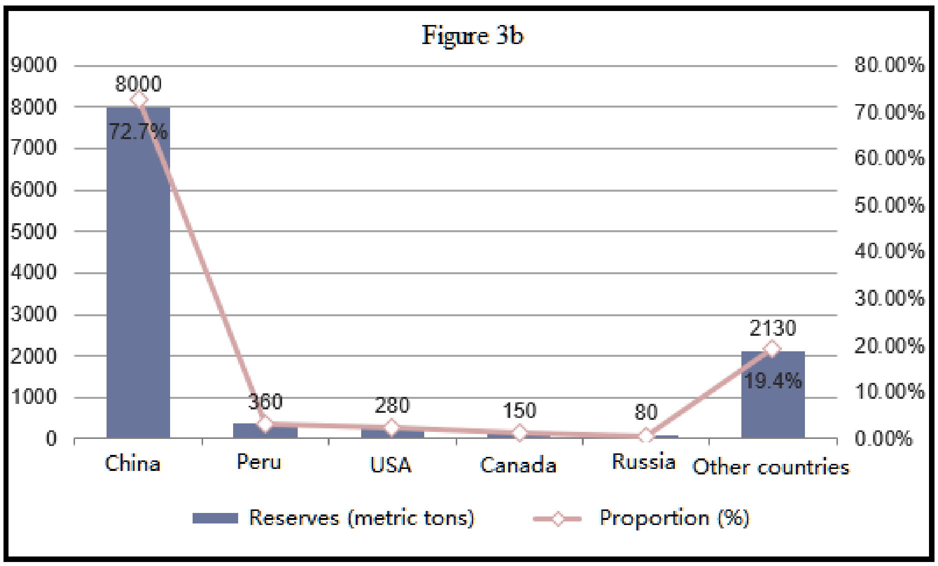


Figure 3a & 3b. Indium reserves (a & b) and percentages (b) of major countries around the world[8-10]

According to statistics from relevant departments of the China Ministry of Natural Resources, China's indium reserves in 2021 were 1,998.7 tons, an increase of 11.5% from 1,792.77 tons in 2020. From the perspective of administrative divisions, China's indium resources are mainly concentrated in the following provinces (Figure 4): In 2021, the indium reserves in Guangxi accounted for 68.9% of the country's total, or 1,377.38 tons. Other provinces such as Inner Mongolia, Jiangxi, Yunnan and other places also have relatively high indium reserves.

For a long time, all rare dispersed elements, including indium, have been sentenced to death by traditional geochemistry and mineral geology theory: because their abundance in the earth's crust is too low, they cannot form their own independent primary deposits, and can only appear as associated elements in traditional bulk ores such as copper, lead and zinc.

It was not until the first half of the 1990s that this death sentence on rare dispersed elements was broken by the discovery of the Dashuigou independent tellurium deposit on the southeastern edge of the Qinghai-Tibet Plateau. It turns out that under special geological settings, some rare elements can form independent primary deposits[12-19].

But the musty old death sentence of conventional mineral deposit geology still applies to all other rare dispersed elements except tellurium, including the subject of this article, indium. The fact is that almost all the indium in the world today comes from zinc minerals. To date, no isolated and independent indium deposit has been discovered.

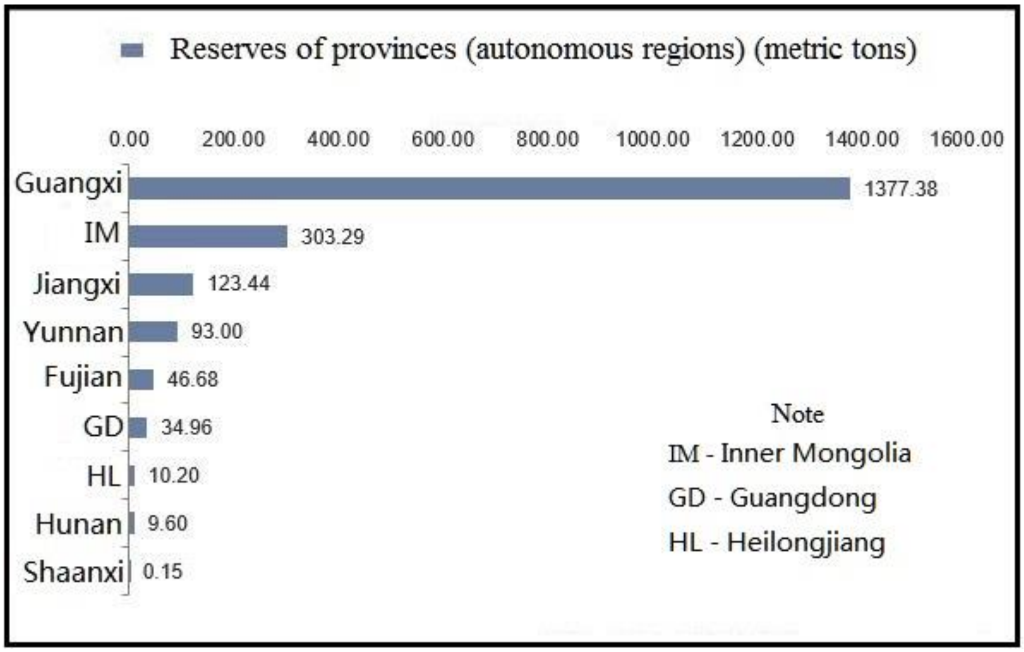


Figure 4. Statistical ranking of indium ore reserves in China's provinces (autonomous regions) in 2021[8-10]

4 Market

At present, there are two main sources of refined indium products. According to different extraction sources, refined indium products can be divided into primary indium and recycled indium. The main raw materials of primary indium are crude zinc, crude lead, slag, smoke, alloy, anode mud, leached slag and related solutions obtained after smelting of indium-containing concentrates such as sphalerite and galena. Recycled indium is recovered and refined from discarded ITO targets and indium-containing semiconductor waste, discarded parts, alloy processing waste, waste catalysts and other materials. In addition, it also includes the recycling and refining of discarded indium-containing terminal products.

At present, the main extraction process and mainstream extraction process technology for refined indium production in the world is extraction-electrolysis. Its principle process flow is: indium-containing raw materials → enrichment → chemical dissolution → purification → extraction → stripping → zinc (aluminum) replacement → sponge indium → electrolytic refining → refined indium.

China not only has the world's largest amount of primary indium resources, but is also the world's largest producer and exporter of primary indium products, accounting for more than 30% of the world's total indium production. The so-called primary indium products refer to refined indium ingots derived from primary indium ore with a purity of 99.995% or more[8-10].

According to Mineral Commodity Summaries released by the U.S. Geological Survey in January 202321, China, the leading producer and exporter of indium globally, exported 421 tons of indium in the first 8 months of 2022, a 13% increase compared with exports in the same period in 2021 (Table 1). Exports were primarily sent to the Republic of

Korea, 55%; Singapore, 14%; and Hong Kong, 12%. Some zinc smelters in Sichuan and Yunnan Provinces in China temporarily cut production during the year in response to power supply issues, according to news sources; however, the extent of the cuts and their effect on related byproduct metal production, including indium, could not be quantified.

Table 1. Estimated world refinery production of indium[21]

Country/Year	2021	2022
United States	n/a	n/a
Belgium	20	20
Canada	60	55
China	540	530
France	38	20
Japan	66	66
Republic of Korea	190	200
Peru	12	n/a
Russia	5	5
Uzbekistan	1	1
World total (rounded)	932	900

An indium-producing zinc smelter in Auby, France, was placed on care-and-maintenance status in January owing to high power prices. The smelter resumed production at a reduced rate in March. Annual indium production at the smelter was last reported in 2018 at 43 tons[21].

In this concise summary of indium, USGS emphasizes that indium is most commonly recovered from the zinc-sulfide ore mineral sphalerite. The indium content of zinc deposits from which it is recovered ranges from less than 1 part per million to 100 parts per million. Although the geochemical properties of indium are such that it occurs in trace amounts in other base-metal sulfides-particularly chalcopyrite and stannite-indium recovery from most deposits of these minerals was not economic. This seems to imply that indium ore resources are indeed limited and not inexhaustible. Humans are urged to use and cherish them.

Finally, USGS specifically said this in a short paragraph about indium substitutes: Antimony tin oxide coatings have been developed as an alternative to ITO coatings in LCDs and have been successfully annealed to LCD glass; carbon nanotube coatings have been developed as an alternative to ITO coatings in flexible displays, solar cells, and touch screens; poly (3,4-ethylene dioxythiophene) (PEDOT) has also been developed as a substitute for ITO in flexible displays and organic light-emitting diodes; and copper or silver nanowires have been explored as a substitute for ITO in touch screens. Graphene has been developed to replace ITO electrodes in solar cells and also has been explored as a replacement for ITO in flexible touch screens. Researchers have developed a more adhesive zinc oxide nanopowder to replace ITO in LCDs. Hafnium can replace indium in nuclear reactor control rod alloys[21].

This is obviously good news. It means that we are encouraged not to lose confidence because of the limited natural indium resources mentioned above. After all, science and technology have been developing and scientific and technological workers will always find substitutes for natural rare substances such as indium to make human life and future better.

Thanks to the substantial increase in indium production in China and South Korea, global primary indium production has gradually increased since 2010, reaching a peak of 844 tons in 2014. Then it gradually declined. In recent years, production has gradually recovered and reached 760 tons in 2019, a year-on-year increase of 2.6%[8-10].

In terms of specific national production, Japan's primary indium production in 2019 was 75 tons, a year-on-year increase of 7.1%. Canada's primary indium production was 60 tons, a year-on-year increase of 3.5%. Belgium, Peru and Russia's primary indium production was 20, 10 and 5 tons respectively[8-10, 22].

South Korea is one of the countries that is worthy of attention in producing primary and recycled indium. In recent years, South Korea has maintained a high production capacity of refined indium. Relying on its status as one of the world's major consumers and the world's second largest zinc smelting capacity, South Korea's production of recycled and primary indium has grown rapidly. As of 2019, South Korea's primary indium production was 240 tons, a year-on-year increase of 2.1%. The raw materials for primary indium in South Korea mainly come from refined zinc ore in Bolivia.

China is not only the country with the richest indium reserves in the world, but also the world's largest producer of primary indium. From 2010 to 2014, China's primary indium production increased at an average annual rate of 8.8%. In 2015, due to the bankruptcy of the Pan Asia Nonferrous Metals Exchange, China's indium market showed a serious oversupply situation, and the price of indium plummeted, causing a sharp decline in indium production, a year-on-year decrease of 23.9%. After that, it continued to decline year by year, and it did not rise until 2018 to 300 tons, accounting for 39.5% of the world. As of 2019, China's primary indium production remained at 300 tonnes, the same level as in 2018[8-10, 22].

As far as global indium production is concerned, with the continuous growth of demand for downstream panels from 2015 to 2019, global indium production continued to grow. In 2020-2021, due to the overall demand and the impact of the epidemic on global trade, the overall indium supply fell slightly, with production in 2020 and 2021 being 957 tons and 920 tons respectively.

As for the overall consumption of indium, although the United States has a certain amount of indium reserves, its overall indium consumption comes from imports. Data show that the United States imported 115 tons of indium in 2020. According to USGS estimates, the country's consumption in 2021 is about 170 tons (Figure 5). In terms of the main sources of imports, the United States mainly imported from China, Canada, South Korea and France from 2017 to 2020, accounting for 31%, 23%, 20% and 9% respectively (Figure 6). It is not ruled out that the strategic United States will temporarily cover up the development of domestic indium deposits and consume foreign indium products first. After all, non-renewable mineral resources will only become less and less and more expensive, not more and more cheap. Even if there are more and more alternative products to indium in the future, they cannot completely replace indium itself with unique chemical and physical properties.

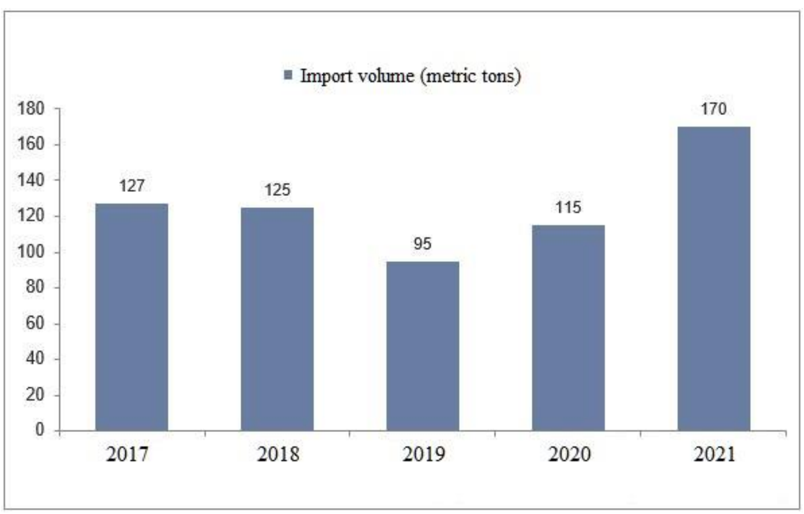


Figure 5. Trend of U.S. indium imports from 2017 to 2021[8-10]

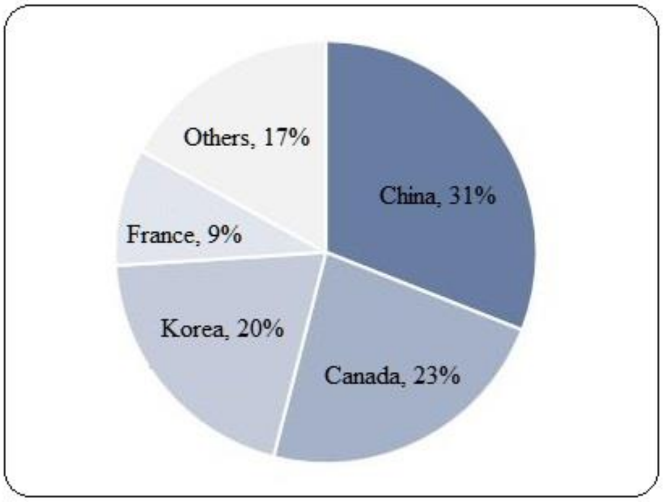


Figure 6. Source countries and proportions of U.S. indium imports from 2017 to 2020[8-10]

Driven by both exports and domestic demand, China's overall indium production has shown a steady growth trend. It reached 540 tons in 2020 and fell slightly to 530 tons in 2021.

From January to November 2022, China's indium product exports totaled 542,364 kilograms, a year-on-year increase of 13.99%. Among them, unwrought indium was 537,052 kilograms, a year-on-year increase of 13.51%; wrought indium was 5,312 kilograms, a year-on-year increase of 100.83% (Figure 7). In 2022, China exported the largest number of indium products to South Korea, Hong Kong of China, Singapore, Japan and the United States, accounting for 56.05%, 12.79%, 10.77%, 4.90% and 4.67% of the cumulative exports from January to November of that year, respectively, accounting for a total of 89.18% (Figure 8). The reason why South Korea has become the largest trading country for China's indium product exports is mainly due to China's Guangdong Province's processing trade, general trade and imported processing trade with South Korea.

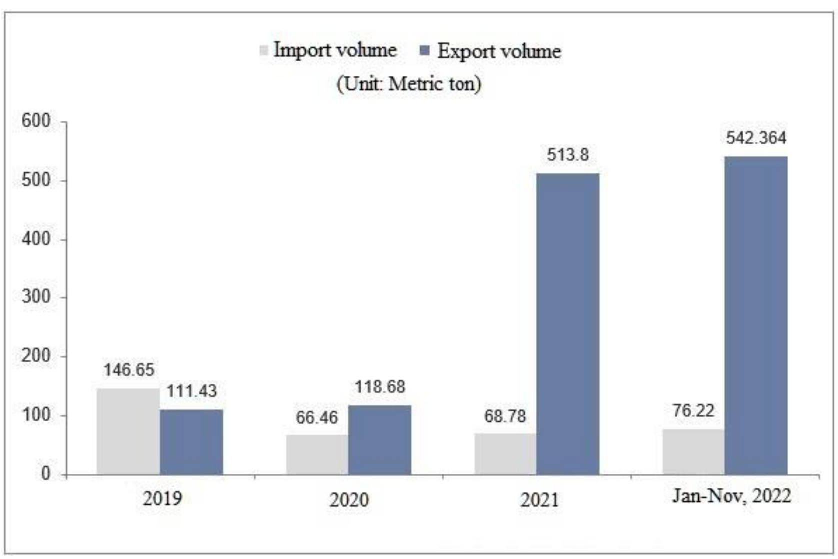


Figure 7. China's indium product import and export trends from November 2019 to November 2022[9-10]

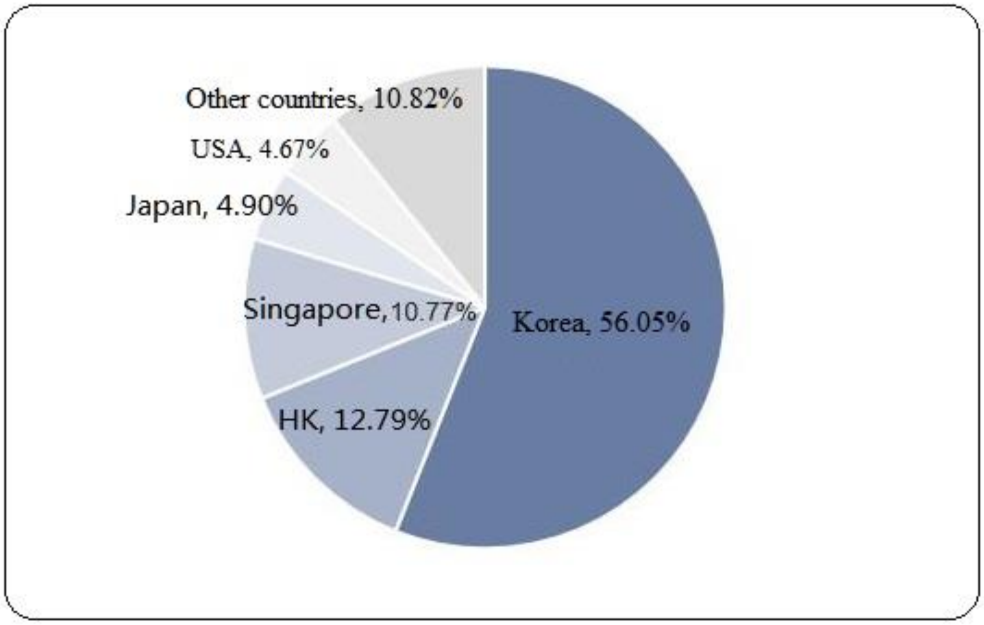


Figure 8. Proportion of China's indium product export destinations from January to November 2022[9-10]

In terms of imports, China imported a total of 76,222 kg of indium products from January to November 2022, an increase of 18.55% year-on-year. Among them, unwrought indium was 72,271 kg, a year-on-year increase of 35.17%; wrought indium was 3,951 kg, a year-on-year decrease of 63.51%8-10. Among them, China imported the largest number of indium products from Japan, South Korea, Germany and the United States, and the five countries accounted for a total of 99.07%. The largest share of this is from Japan, which accounts for 44.6%, and the main importer is Yunnan, China, which imports unwrought indium from Japan (Figure 7).

Since 2022, the production space of refined indium products in China has not changed much. Hunan, Guangxi, Guangdong and Yunnan are still the main production areas, but the ranking of enterprises has changed greatly. During this period, China's refined indium production increased to 667 tons, an increase of 12.1% in 2022 compared with 2021. Among them, primary indium increased by 3% and recycled indium increased by 35.5%[8-10, 22].

In 2022, China's domestic refined indium consumption was about 496 tons, an increase of 6.2% over 2021. This increase in indium consumption is mainly due to the breakthrough in indium target manufacturing technology and the expansion of mass production scale. In 2022, China's domestic ITO target consumption reached 436 tons, an increase of 5.6% over 2021, accounting for about 87.9% of the overall domestic refined indium consumption.

Some studies believe that with the continuous improvement of the degree of localization, the growth rate of China's target production will continue to accelerate, and it is expected that the indium consumption in this field will exceed 500 tons in 2023. At present, indium targets are mainly used in the panel industry.

Since 2018, due to the overall sluggish demand, the domestic indium price in China has generally shown a downward trend (Figure 9). By the end of 2019, it was only around RMB 900 per kg.

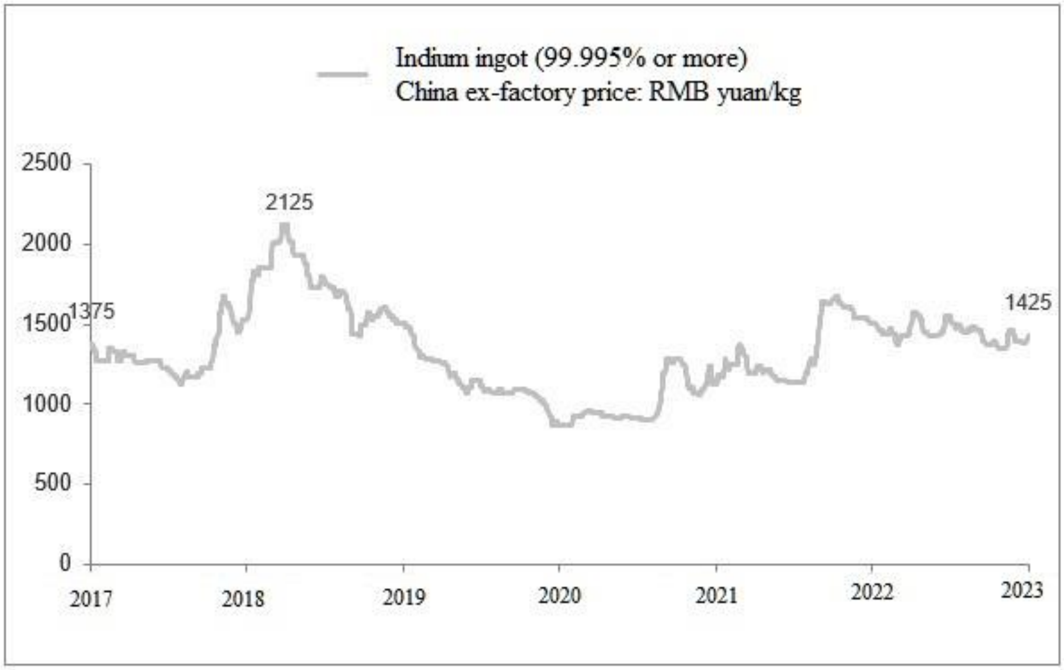


Figure 9. China's indium ingot price trend chart from 2017 to 2023[8-10]

Before the 2020 Spring Festival holiday, the successful auction of Pan Asia's indium inventory boosted market confidence to a certain extent. However, market demand is weak, industry pessimism is spreading, and prices are difficult to recover. From January to August 2020, the domestic indium price in China remained around RMB 900/kg. In September of the same year, the price of indium began to rise, but the market supply was large, and the holders were very motivated to ship. In addition, the market continued to grab market share due to tight funds, and the supplier had to lower the quotation again in December (Figure 9).

In 2021, due to the contraction of the supply side, a new round of downstream procurement, and the rise in electric board prices, market confidence was consolidated to a certain extent, leading to a slight increase in prices in March. But the good times did not last long, and prices fell again in April of the same year. In August, the domestic indium price in China gradually came out of the trough, and the growth rate accelerated in September. In the fourth quarter, the indium price remained at RMB 1,667/kg (Figure 9).

In 2022, the domestic indium price in China fell rapidly in the first quarter. In the second quarter, affected by speculative funds, the price of indium rose rapidly and then fell rapidly again. Entering the third quarter, due to continued weak demand, it stabilized slightly to RMB 1,528/kg in July and then fell back. In the fourth quarter, the price of indium remained bleak. In 2022, the average price of refined indium in China was RMB 1,495/kg, a year-on-year increase of 7.8% (Figure 9).

At present, China's indium production is in a state of oversupply, and the growth of domestic consumption is still insignificant compared with the potential for production growth. However, long-term large-scale export trade and abnormal trade behavior have always kept the country's indium market in a delicate balance. In addition, the pressure brought to the market by the 3,600 tons of inventory left by the Pan Asia Exchange still needs time to digest. Market fluctuations may be needed to provide opportunities for relief.

In the long run, against the background of steady growth in global indium consumption and accelerating domestic consumption, it is inevitable that prices will return reasonably from the low-cost area. But this takes time. Judging from the current situation, the indium product industry will still endure a period of low prices. But in terms of market sentiment, trading confidence will gradually recover in the next two years, and trading will also tend to be active, and it is an inevitable trend to push up indium prices overall.

The reason is that indium is considered a critical element worldwide due to its specific function in low-carbon technology and its vulnerability to supply disruption[11]. As the world is actively advocating low-carbon life, the price of indium products still has a lot of room to rise. The demand for In is expected to increase over the next several decades, with projections of up to 231 % by 2050 compared to 2018 production levels[23].

5 Deposit type

As mentioned earlier, most rare dispersed elements, including indium, do not have independent primary deposits, at least for now. The reality is that most rare elements are by-products of other bulk minerals, namely, so-called associated, symbiotic or parasitic deposits. Mejías et al. (2023)[11] showed that the highest indium content has been commonly described in Cu-rich parts of polymetallic deposits related to magmatic-hydrothermal sources, in contrast with lower indium content in deposits formed at low temperatures and involving diagenetic processes. Sphalerite is the main In-bearing mineral phase incorporated indium through couple substitution, involving Cu, Ag, Ge, Ga, and Sn. Magmatic-hydrothermal sphalerite tends to be characterized by higher In, Cu, Sn, and Fe, and lower Ge contents and is associated with chalcopyrite, stannite, kësterite, cassiterite, and magnetite, which involve exsolution processes.

Based on the previous research data[11, 22-34], especially the latest research results of Mejías et al.[11], the genetic types of associated indium deposits known to humans are summarized in Table 2. The global spatial distribution of these associated indium deposits of different genetic types is shown in Figure 2 of this article.

Table 2. Genetic types and representative deposits of indium deposits around the world[11, 22-34]

Deposit type	Primary ore mineral	Main In-bearing minerals	Representative deposit
Skarn	Sn, Zn, Cu, Ag, Bi, As	sphalerite, chalcopyrite and andradite garnet	Dachang, Dulong, Yejiwei, and Qibaoshan in China
V(H)MS	Cu, Zn	sphalerite and chalcopyrite	María Teresa deposit in Peru, Gaiskoye deposit in Russia, Neves-Corvo in Portugal, and the Geco deposit in Canada
(Sn)PXV	Cu, Zn, Sn, Ag	Fe-rich sphalerite and stannite	Toyoha deposit in Japan; the Huari Huari, Potosi, and Bolivar mines in Bolivia
SEDEX		galena, sphalerite, chalcopyrite, and pyrite	Broken Hill in Australia; Dabaoshan mine in China
Epithermal vein	Zn, Pb, Cu, Au, Ag	gold, enargite, covellite, pyrite, sulphide, rhodonite, chalcopyrite and stannite	epithermal deposits in Argentina & Peru; Ayawilca in Peru; Ashio and Ikuno mines in Japan
Granite-related	Sn, Zn, Cu,	sphalerite, chalcopyrite, stannite, kësterite,	Tigrinoe & Pravourmiiskoe in Russia; Isabel and Baal Gammon deposits in Australia; Cho Don in China; Colquiri in Bolivia
Porphyry Sn	Sn, Zn, Cu	sphalerite, stannite	Central Andean Sn belt from southern Peru through Bolivia to northwest Argentina; the Mount Pleasant deposit in Canada
Porphyry Cu	Cu, Co, Au, Re, Ag	chalcopyrite	The Bingham Canyon/Kennecott Copper mine, and the Santa Rita mine in USA
MVT	Pb, Zn	sphalerite, galena, pyrite, and marcasite	the Lisheen Zn-Pb deposit in Ireland
SSC	Cu	chalcocite, bornite, chalcopyrite, digenite, djurleite, anilite, galena, and sphalerite	the Waterloo mine in Australia
IOCG	Cu, Au, Fe, Ag, Co, Ni, Bi, Se, Te, U, REE, F, Ba, Mo	pyrrhotite, pyrite, chalcopyrite, bornite, chalcocite, sakuraiite	the Copper Blow Project in NSW, Australia; the Chaparra IOCG, Peru
MSCD	Cu, Pb, Zn, Ag	sphalerite, pyrite, Chalcopyrite, galena,	the Waterloo, Queensland, Australia

Note: V(H)MS - Volcanic-hosted massive sulphide; SEDEX - sedimentary exhalative mineral deposits; (Sn)PXV - (Sn) polymetallic xenothermal/epithermal veins; MVT - Mississippi valley-type Zn-Pb; SSC - Sediment-hosted stratiform Cu; IOCG - Iron-oxide copper gold; MSCD - Metamorphosed sandstone-shale copper deposits

It should be noted that among the many genetic types of the above-mentioned associated indium deposits, skarn, massive sulfide and similar deposit types are the most important associated deposit types of indium, accounting for 29.2% and 28% of the world's potential indium resources, respectively. The second is epithermal and sedimentary lead-zinc deposits, accounting for 19.9% and 18.0% of the world's indium resources, respectively.

Werner et al. (2017) counted 101 deposits[34], and the total indium resources of these deposits included in the statistics were 76,183 metric tons.

The world's most representative skarn-type associated indium deposits include the Dachang tin deposit in Guangxi, and the Dulong tin-zinc polymetallic deposit in Yunnan, China; the Ayawilca deposit in Peru, the Tellerhauser and Pohla-Globenstein deposits in Germany, and the East Kemptville deposits in Canada.

The epithermal and polymetallic vein-type associated indium deposits mainly include the Toyoha, Ashio, Akenobe and Ikuno deposits in Japan; the Potosi and Bolivar deposits in Bolivia, etc.

VMS and SEDEX type associated indium deposits are represented by VMS deposits such as Kidd Creek, Geco/Manitouwadge and Heath Steele in Canada; Gaiskoye, Podolskoye and Sibaiskoye in Russia; and SEDEX deposits such as Broken Hill in Australia, Malku Khota in Bolivia, Rammelsberg in Germany, and Filizchay in Azerbaijan.

6 Discussion and conclusions

Rare dispersed metals, including indium, are extremely rare in the earth's crust and have long been ignored by humans. However, with the development of modern science and technology, they play an increasingly important role and have increasingly wide applications on this earth.

Although people can find substitutes for these rare metals, in many ways, the inherent physical and chemical properties of these natural rare metals determine that they cannot be completely and perfectly replaced.

Because of the important role of rare dispersed metals such as indium, its future market will be more and more optimistic, and its prospects will be infinitely bright. Of course, it is not ruled out that its market will fluctuate to a certain extent due to unpredictable international situations, complex relations between countries and other factors.

The extraction and beneficiation technology of indium ore must also be continuously updated and upgraded in order to recover large amounts of waste rock from ancient mines with special but high-grade indium occurrence, including huge stocks of tailings from related abandoned mines.

As indium products play an increasingly important role and position, its secondary recycling not only deserves further attention, but also needs to be strengthened. Obviously, secondary recycling is cheaper and more economical than developing mines.

As far as humans know, all indium deposits in the world are associated with certain bulk primary mineral products. In other words, indium is a trace parasitic mineral that appears in bulk non-ferrous metal deposits such as copper, lead and zinc.

In terms of genetic type, the potential of indium ore resources is huge. Almost all endogenous non-ferrous metal deposits have indium ore as an important byproduct. Among all indium-containing minerals, sphalerite is undoubtedly the most important and the one from which humans currently obtain the most indium.

In the near future, it is not ruled out that new genetic types of associated indium ore will be discovered, such as pure sedimentary indium deposits with higher grades formed after weathering, denudation and sedimentation of other primary associated indium ores. At the same time, it cannot be ruled out that the world's first primary independent indium deposit will be discovered under special geological settings.

In this complex and ever-changing society, everything is possible.

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Data availability

The data that support the findings of this study is available from the author upon reasonable request.

Declaration of competing interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Use of AI tools declaration

The author declares that he has not used Artificial Intelligence (AI) tools in the creation of this article.