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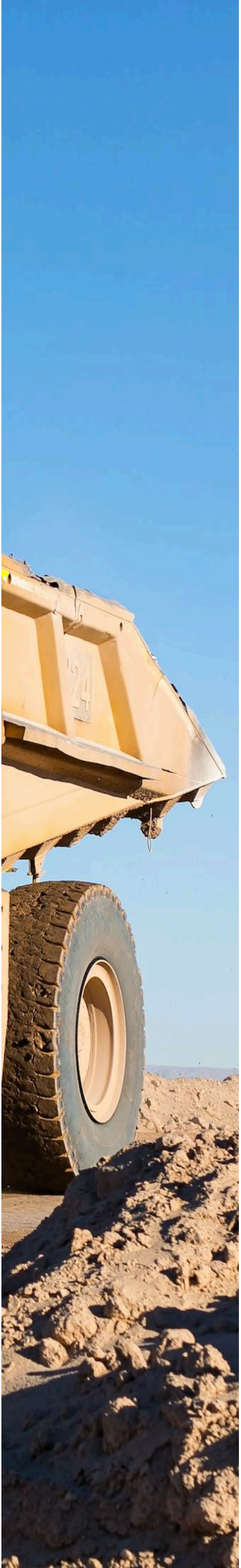
Production Dominated by China is a Problem for the West

Critical Minerals Commodity Report

June 2025



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Front picture: Bauxite – Alunorte

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Executive Summary

Introduction

This report on gallium is the third in our 2025 series on critical minerals. Due to their use in clean energy technologies and semiconductors, critical minerals have gained prominence in government policy agendas and captured the public's interest. Many of these commodities face increased demand, supply chain bottlenecks, volatile price fluctuations, and geopolitical concerns. The markets are also becoming more complex as China has begun to exploit its strong position as a supplier of many critical minerals by imposing certain export restrictions.

While many valuable reports are available on critical minerals more broadly, few focus on the actual market dynamics of individual commodities. This lack of coverage partially reflects the relatively small size of these commodity markets (many are primarily produced as a by-product), the limited number of mining and processing companies, and the limited opportunities for equity investment. Access to data is difficult, and industry facts are hard to find, leading to a general opacity in the supply and demand picture. Our reports will attempt to explore what information is available and analyse some of the key risks to these commodity supply chains.

Critical Minerals

Critical minerals lack a universally accepted definition and are classified based on current technological requirements and the respective supply and demand dynamics applicable to different countries and markets. For example, the United States identifies 50 minerals as critical, the European Union 34, Japan 34, and Australia 31. Seventeen commodities, including gallium, are common to all these countries.

Gallium is prominently featured on the critical minerals lists of most countries because of its reliance on imports from China and its essential role in manufacturing semiconductors, which produce goods vital to regional economies.

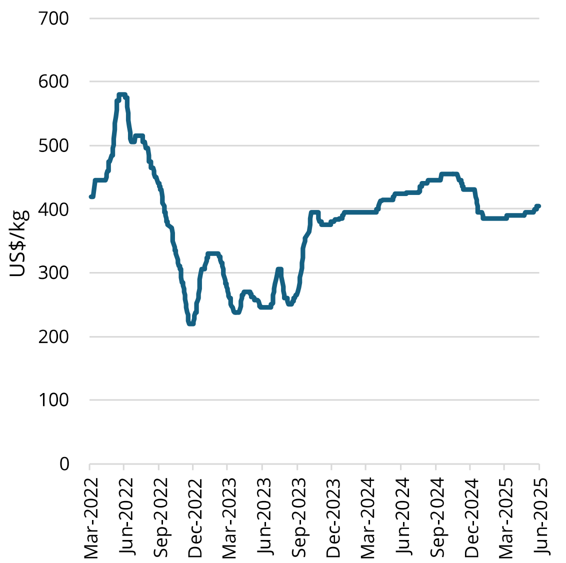
Gallium Output Dominated by China

China dominates global gallium production. In 2024, it accounted for 98% of the world's refined primary (low purity) gallium output, primarily sourced from gallium-bearing bauxite and a minor contribution from zinc ore. Minor amounts of gallium came from other global producers, including Russia, Japan, and South Korea (see Figure 2).

The West relies on China for the manufacture of 55% of the world's gallium-based semiconductors, including those used for light-emitting diodes (LEDs) where gallium is essential. Access to gallium started to become difficult in August 2023 when China implemented export controls on gallium-related items. Subsequently, in December 2024, China imposed a total ban on the export of gallium to the US, a move widely believed to be retaliation for the US's export ban on sales of semiconductor manufacturing equipment to China.

This is a significant problem for Western gallium markets, resulting in the gallium price more than doubling from US$220/kg in December 2022 to a recent peak of US$455/kg in November 2024. Figure 1 shows the gallium price for the past three years.

Figure 1. Gallium Price (US$/kg)



Source: Bloomberg - China Gallium Metal 99.99% FOB.

Gallium Production Focused on Bauxite

Gallium is a relatively rare element typically occurring in bauxite ores at only 57 parts per million (ppm) concentrations. Around 95% of global output is recovered in very small quantities as an inconsequential by-product from some alumina refineries, in the value chain from bauxite to aluminium. The remaining 5% is recovered from zinc ores during the zinc smelting process.

The gallium market is very small and opaque compared with most other metals. Total global primary production of low-purity gallium in 2024 was approximately 762 t, equivalent to about US$167 m at an average 2024 price of US$220/kg (the aluminium market is about US$206 bn, and zinc is about US$33 bn).

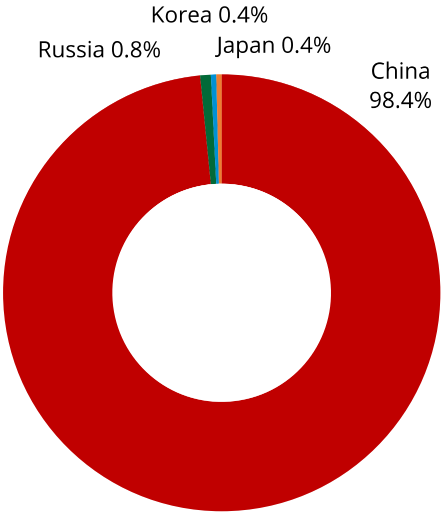
China's output of low-purity gallium increased from 22 to 750 t/y from 2005 to 2024, reflecting the rapid expansion of its aluminium industry. This increase also resulted from the Chinese government mandating many alumina producers to establish processing capabilities to extract gallium to support the country's growing gallium semiconductor industry. China is currently estimated to have a gallium capacity of 1,000 t with production of 750 t, resulting in a utilisation rate of 75%. However, gallium production in China has consistently exceeded demand, and stocks are believed to have accumulated.

The West barely produces any primary gallium and relies on metal exports from China. This is because gallium extraction from alumina has been uneconomic in the West. The few gallium plants operating at alumina refineries in the West closed in the mid-2010s. This was principally because China was rapidly increasing gallium output at that time, which caused the price to fall and made production uneconomic.

Gallium Resources: Theoretically Large

Gallium resources are theoretically large, but globally, little is being recovered. The USGS states that gallium contained in world resources of bauxite is estimated to exceed 1 Mt, and additional gallium is contained in world zinc resources. However, the overall recovery each year is less than 10%. Based on the bauxite resource alone, annual gallium production in 2024 of 762 t, and a 10% recovery, the global resource equates to about 132 years of production. In practice, gallium is almost exclusively extracted from bauxite in the world in China and from only 35% of existing bauxite-alumina operations in China, where the average gallium recovery is 22%.

Figure 2. Low-Purity Gallium Production 2024



Source: USGS 2025.

Manufacturing and Consumption

Gallium consumption has increased dramatically over the past 20 years, rising from about 4 t in 2005 to an estimated 335 t in 2024 (see Figure 5). This growth has come from use in rare earth permanent magnets (REPMs), light-emitting diodes (LEDs), integrated circuits (ICs), and photovoltaics (PV). The increase in demand for LEDs, integrated circuits, and photovoltaics is centred on gallium-based semiconductor substrates and epilayers. China accounted for roughly 62% of the overall gallium consumption in 2024.

The USGS published a breakdown of the material flow of gallium in 2022 (see Figure 6). In that year, low-purity gallium production was 638 t, with 100 t consumed in REPMs in China and 206 t in semiconductor manufacturing. Within the semiconductor market, 92 t of gallium was consumed in China (45%) and 114 t (55%)

worldwide, principally in Canada, China, Japan, Slovakia, and the United States. China exported the low-purity gallium to these countries for secondary refining. This material was used to produce high-purity gallium for semiconductor manufacturing. For example, in the United States, about 99% of the gallium consumed in 2023 was in GaAs, GaN, and GaP wafers for integrated circuits (79%) and optoelectronic devices (20%).

Of the global balance, 101 t was lost in wafer manufacture, 18 t was lost in secondary processing, and 213 t was stored in inventories in China. Other research on Chinese Gallium consumption also observed high stockpiling levels in China.

Demand Growing Strongly

The estimated demand for gallium in 2024 comprised REPMs (46%), LEDs (37%), integrated circuits (9%), and photovoltaics (3%). Demand in these sectors continues to grow strongly.

Recycling of gallium occurs only in part of the manufacturing industry. The primary source of supply for gallium recycling is new scrap, which consists of waste from the semiconductor manufacturing process. This new waste is recovered from what is essentially a closed-loop system. The recycling of gallium-bearing post-consumer scrap (old scrap) is currently unviable due to gallium's highly dissipative nature in consumer products and the challenges in recovering it.

Although gallium can be substituted in many applications, this often comes at the cost of production efficiency or product characteristics.

New Capacity is Limited

The only new project in the West, is the recently announced 50 t/y gallium plant (about 7% of current global output) being constructed by Metlen Energy and Metals at its alumina operations in Agios Nikolaos, Greece. Investigations continue about the potential of producing gallium at the Clarkesville zinc mine in the United States and the Lubumbashi tailings operation in the DRC, but neither of these projects have made visible progress and remain uncertain. The reopening of former production facilities in the West also looks unlikely.

There may be other opportunities to establish new gallium capacity in the West at new or existing alumina refineries or zinc smelters; Rio Tinto announced in December 2024 that it is constructing a demonstration plant in Saguenay, Canada. However, the technological and economic practicalities remain uncertain, especially considering that the amounts of gallium recovered are minimal and hold limited economic significance for alumina and zinc producers. Nevertheless, Metlen's and Rio Tinto's proposed gallium plants are positive indicators that producing gallium from bauxite in the West could once again be viable.

Another potential source of gallium (and other critical minerals) could be the bauxite waste product known as red mud, which is created during alumina production. Every tonne of alumina production generates around 1.25 tonnes of red mud. There are extremely large resources of red mud around the world, although not all of them may contain gallium. This area is currently under research; however, an economically viable and environmentally sustainable process for recycling red mud to recover gallium and other products on a large scale has yet to be implemented.

Conclusion

Gallium is a key component in many semiconductors, and consumption is growing in REPMs. However, China essentially controls the market. It produces 98% of the metal and accounts for around 62% of its consumption. This means that manufacturing in the West is almost entirely dependent on Chinese exports. With only limited new production in the West likely in the foreseeable future, China holds nearly all the cards in this commodity.

This is a significant problem for Western markets, and material availability has become more challenging following China's export restrictions announced in 2023. This was further escalated with China's total export ban to the US announced in December 2024. Prices have risen sharply, and the market is expected to remain tight for the foreseeable future.

1. The Industry Basics

The gallium industry is exceedingly small compared with most other metals. Total global primary production of low-purity gallium in 2024 was approximately 762 t, equivalent to about US$167 m at an average 2024 price of US$220/kg for low-purity gallium.

In 2024, China was the largest producer of low-purity gallium, accounting for 98% of output, having recovered the metal from gallium-bearing bauxite and zinc ore. Other primary low-purity producers include Russia, Japan, and South Korea. Germany, Hungary, and Kazakhstan ceased primary production in 2016, 2015, and 2013, respectively. Ukraine is believed to have ceased primary production in 2022 due to the conflict with Russia.

Most gallium producers are based in China, and much of the information regarding their operations remains confidential. Information within the gallium supply chain is scarce, and the reliability of the available data is questionable.

Gallium Geology

Gallium (chemical symbol Ga) is a relatively rare element, dispersed in the Earth's crust at an average of about 19 parts per million (ppm). It does not occur in nature as a native metal; rather, it substitutes in trace quantities for other elements in minerals. Gallium exists in very small concentrations within the ores of other metals. Gallite ($CuGaS_2$) is the main gallium-bearing mineral. Most gallium (about 95%) is recovered in very small quantities as an inconsequential by-product of alumina production in the value chain from bauxite to aluminium. The remaining 5% is recovered during the smelting of some zinc ores.

Gallium was briefly mined as a primary commodity. In 1986-87, the Apex copper mine in Utah reopened to produce gallium and germanium as primary commodities from jarosite and limonite ores; however, it proved not to be economically viable.

Gallium in bauxite originates from minerals such as feldspar and nepheline. Both aluminium and gallium are concentrated in the bauxite through weathering, with gallium averaging around 57 ppm in bauxite, although it can vary from 5 to 812 ppm. Uniquely, alumina and gallium are extracted directly from the mineral nepheline in Russia.

Gallium is also reported to be present in some fly ash from coal power stations, mine tailings, and claystone, but it is currently not recovered from these sources.

Gallium Resources

There is limited data on gallium resources, and most reports refer to bauxite resources as an indication of gallium resources. The USGS states that gallium contained in world resources of bauxite is estimated to exceed 1 Mt, and a considerable quantity could be contained in world zinc resources, although less than 10% of the gallium in bauxite and zinc resources is recovered [(1)]. Based on the bauxite resource alone, annual gallium production in 2024 of 762 t, and a 10% recovery, the global resource equates to about 132 years of production.

In 2014, the USGS published a report compiling the gallium grades of major bauxite deposits worldwide [(2)]. The summary data from the bauxite provinces is presented in Table 1. The table shows the average bauxite, alumina, and gallium tonnages for deposits within the bauxite provinces and the ranges and averages of gallium concentrations. While the data does not encompass all deposits, it provides an indication of the global distribution of gallium in bauxite deposits.

However, not all bauxite deposits are economically viable for alumina recovery, and others contain low gallium grades. For example, the bauxite deposits in the United States are generally unsuitable for alumina production due to their high silica content despite high gallium grades.

Table 1. Gallium Grades and Content of Major Bauxite Provinces

Bauxite Province	Avg Bauxite Deposit Size Mt	Avg Alumina Content Mt	Avg Gallium Content t	Gallium avg ppm	Gallium ppm range
African	867	462	13,837	43	22–122
Caribbean	367	171	22,797	67	39–145
Central Asian	34	20	-	15	10–19
Chinese	400	208	9,174	25	14–56
East Australian	6	3	1,030	52	29–74
East European	36	4,464	-	74	31–120
Hindustan	111	12	2,454	57	<10–146
Indonesian-Philippine	9	5	115	33	22–47
Mediterranean	61	20	1,307	53	5–812
North American	50	25	12,556	86	50–100
South American	459	94	22,019	63	<10–136
Southeast Asia	45	19	-	72	65–83
Ural	-	-	-	50	41–70
West Australian	437	220		59	30–99
Average	**201**	**385**	**9,477**	**53**	**5-812**

Source: Compilation of Gallium Resource Data for Bauxite Deposits - Schulte and Foley 2014, USGS.

Gallium Recovery

Tropical regions hold approximately 90% of the world's known bauxite resources. Most bauxite occurs near the surface and is mined and processed without beneficiation. Gallium is extracted from bauxite during its conversion to alumina using the Bayer process. In this process, bauxite is dissolved at high temperatures in a caustic soda (sodium hydroxide) solution referred to as Bayer liquor.

About 70% of the gallium is leached out in the Bayer process along with the aluminium. The remaining 30% of the gallium and other impurities form a waste product, a mix of solid and metallic oxide impurities known as red mud [(3)].

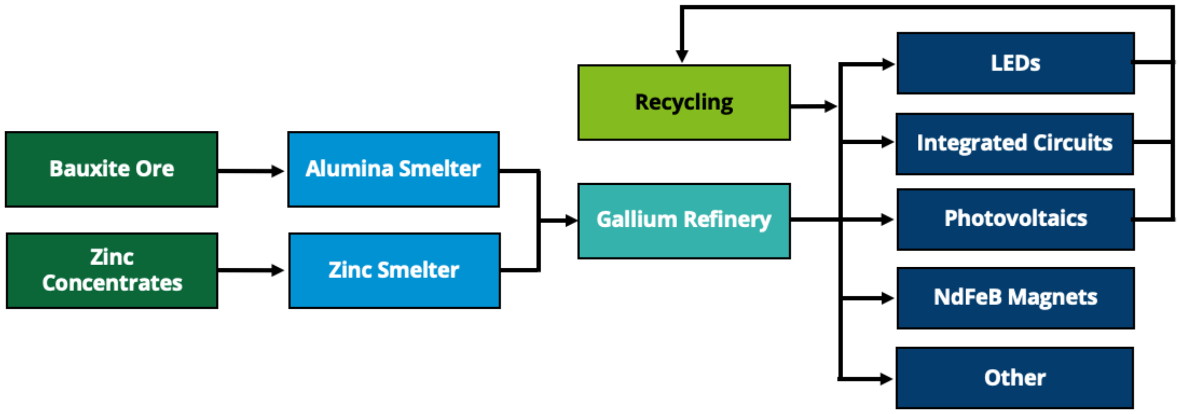
Various options to recover gallium from sodium aluminate solutions include fractional precipitation, electrochemical deposition, solvent extraction, and ion exchange [(4)]. Ion exchange using resins is the main method applied in industry for gallium recovery from the Bayer liquor.

Despite the dominance of gallium extraction from alumina, relatively few alumina producers globally possess gallium extraction facilities. This is due to the fact that not all bauxite deposits contain economic gallium grades, and the additional processing disrupts the closed-loop recycling process of the Bayer liquor, potentially negatively affecting the economics of alumina production.

Gallium is also recovered from zinc smelting during the purification stage, when impurities from the zinc process are removed. These impurities, along with dust and residues, are processed at a primary refinery to separate the various by-products. They are treated in roasters or pressure-leach facilities and refined to produce gallium and other by-product metals. It is reported that the recovery of gallium from zinc smelters can also negatively affect the recovery of the primary metal.

Figure 3 shows a simplified gallium supply chain, and a flow diagram of gallium recovery is shown in Appendix 1.

Figure 3. Simplified Gallium Supply Chain



Source: RFC Ambrian

The red mud residue produced as a waste product from the alumina refining process is hazardous due to its very high pH values. However, this represents a potential resource that could be exploited for gallium, as well as for rare earths, iron, and titanium, although has yet to be proven economic.

Gallium Refining

Finally, the gallium extracted from alumina and zinc production is refined through electrowinning to yield a 4N (99.99%) product, which is considered low purity. Further refining occurs to create high-purity gallium, primarily prepared by fractional crystallisation and directional crystallisation to achieve purities of 6N and 7N, which are predominantly used in the electronics industry. Gallium metal is a soft and silvery-white element with low melting and high boiling points.

World high-purity refined gallium production in 2024 was estimated to be about 320 t, according to the USGS, unchanged from the estimate for 2023. Canada, China, Japan, Slovakia, and the United States were the known principal producers of high-purity refined gallium. The United Kingdom ceased high-purity refined gallium production in 2018. Gallium was recovered from new scrap in Canada, China, Japan, Slovakia, and the United States.

The USGS also reports that the world high-purity refined gallium production capacity was an estimated 340 t/y, and secondary high-purity gallium production capacity was 280 t/y.

Existing literature on the life cycle of gallium is limited. The most recent study (2022), which is the only one that has analysed China's gallium flows, examined the gallium supply chain across its main life cycle stages over a period from 2005 to 2020 in China [(5)]. The yield, loss, and recycling rates in the mining, smelting, refining, and manufacturing stages are reported to be derived from literature and relevant domestic metallurgical standards.

The data from this report indicates a 92% recovery rate from the mining of bauxite, a 52% recovery rate from the smelting of alumina using the Bayer process, and a 46% recovery rate from the gallium refining process. This is an overall gallium recovery of just 22%. The report further highlights that just 35% of China's alumina production has the capacity to recover gallium.

Gallium's primary applications are neodymium-iron-boron (NdFeB) permanent magnets, light-emitting diodes (LEDs), integrated circuits (ICs), and photovoltaics.

Gallium Export Restrictions

In August 2023, the Chinese Ministry of Commerce and the General Administration of Customs implemented export controls on gallium and germanium items to protect national security interests. Export businesses dealing with these items must obtain export licences from the Ministry of Commerce through provincial commerce authorities. The gallium-controlled items include gallium-related materials such as gallium metal, gallium nitride, gallium oxide, gallium phosphide, gallium arsenide, indium gallium arsenide, gallium selenide, and gallium antimonide.

In December 2024, China banned the export of gallium, germanium, antimony, and superhard materials to the US and implemented stricter export control checks on dual-use graphite materials. This action followed the US announcement of new export controls and sanctions designed to prevent the sale of advanced US microchips and semiconductor manufacturing equipment to China.

The export restrictions imposed by China caused the price of gallium to more than double, reaching US$455/kg in November 2024.

The simplified gallium flow chart shown in Figure 6 indicates net exports of about 159 t of wrought and unwrought gallium from China in 2022. The US and other countries report imports of gallium metal, but the trade code includes hafnium, indium, niobium, and rhenium, thereby making the gallium content undifferentiable from the other commodities. This makes tracking gallium imports difficult.

The USGS highlights that China's export controls on gallium illustrate global concerns about the reliability of supplies of mineral commodities that are vital to economic development, national security, and the transition to renewable energy. It reports that a complete disruption of China's net exports of gallium would decrease US GDP by an estimated US$3.1 bn. Nearly half of the decrease would come from the semiconductor and related device manufacturing industry (6).

2. Demand Fundamentals

Gallium consumption has increased dramatically over the past 20 years, rising from about 4 t in 2005 to an estimated 335 t in 2024. This growth has come from four industrial applications, representing about 95% of gallium usage worldwide. These applications are neodymium-iron-boron (NdFeB) permanent magnets, LEDs, integrated circuits, and photovoltaics. The increase in demand for LEDs, integrated circuits, and photovoltaics is centred on gallium-based semiconductor substrates and epilayers. China accounted for roughly 62% of the overall gallium consumption in 2024, excluding stockpiling.

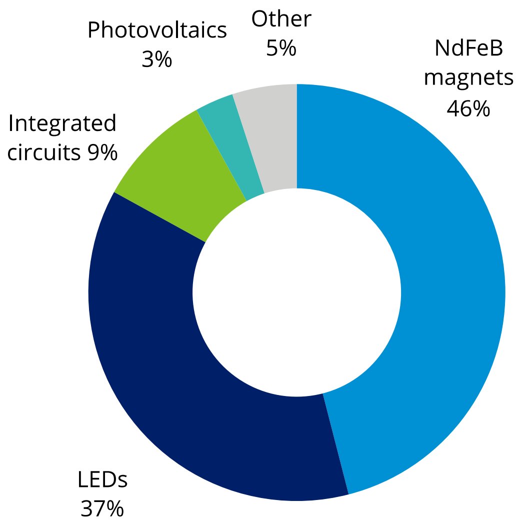
There is no standard industry data for gallium consumption, and only a few commodity specialists cover the metal. Figure 4 displays the estimated breakdown of gallium consumption by end-use in 2024. Figure 5 presents the breakdown of global gallium applications by end-use from 2005 to 2025. Both charts are derived from a research report on Chinese gallium consumption [5], USGS data [6], and estimates from RFC Ambrian.

The flow of material from refined low-purity gallium through to key end products in 2022 is shown in Figure 6, based on data from the USGS [6]. It is worth noting that although low-purity gallium production was 638 t, only 100 t was consumed in permanent magnets and 206 t in semiconductor manufacturing. Of the balance, 213 t was stored in inventories in China, 101 t was lost in wafer manufacture, and 18 t was lost in secondary processing. High stockpiling levels in China are also observed in the research on Chinese gallium consumption [5].

Gallium Intermediaries

Gallium, in the form of refined metal or gallium-containing compounds, is processed to manufacture intermediate products. High-purity gallium is used for the preparation of gallium arsenide (GaAs) and gallium nitride (GaN) semiconductor materials because of its excellent dielectric properties.

Figure 4. Gallium Consumption 2024



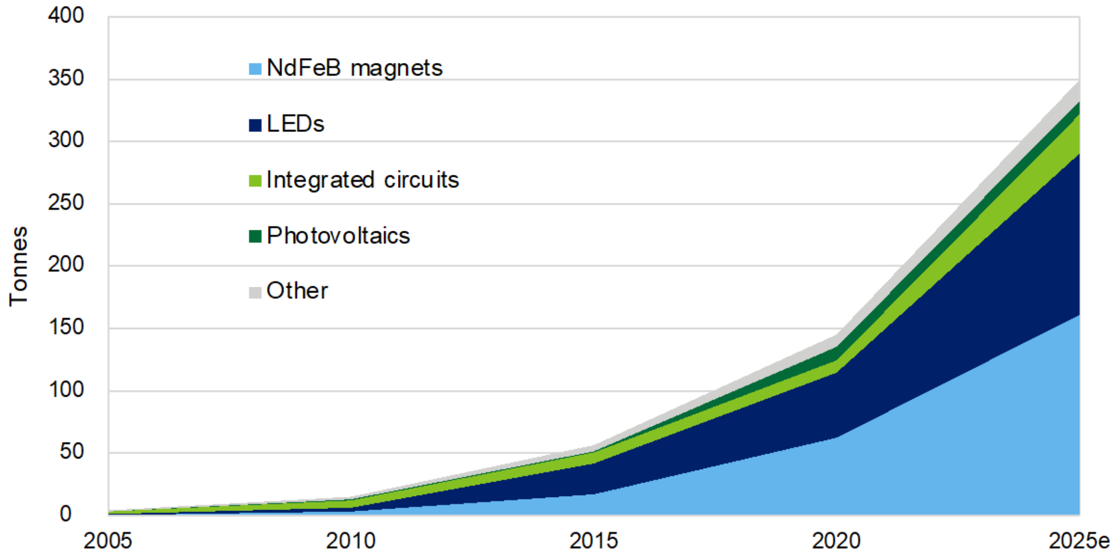
Source: RFC Ambrian estimates

These compounds are necessary ingredients either for the growth of single-crystal ingots that are cut into substrates (wafers) or for preparing epitaxial monocrystal substrate layers grown on an existing substrate. Other common gallium compounds include gallium phosphide (GaP) and trimethyl gallium (TMG).

Rare Earth Permanent Magnets

A permanent magnet (PM) consists of magnetised material that generates its own persistent magnetic field. There are various types of permanent materials, and a rare earth element (REE) permanent magnet (REPM) is one category of permanent magnet formed from alloys of the lanthanide group of REEs. Neodymium-iron-boron permanent magnets (NdFeB) represent the most widely used type of REPM. The inclusion of REE means that REPMs are significantly more powerful than conventional magnetic materials, enabling the use of smaller or more powerful motors and generators in industrial applications. As an alloying element, gallium is incorporated into REPMs in quantities of less than one percent for slight enhancements in magnetic properties and corrosion resistance.

Figure 5. Global Gallium Consumption by End Use



Source: Evolution of the Anthropogenic Gallium Cycle in China (5), RFC Ambrian estimates.

Sintered NdFeB PMs can be classified into high-performance and standard NdFeB PMs. In China, only a few manufacturers can produce high-performance NdFeB PMs. These high-performance NdFeB PMs are primarily utilised in energy-saving and environmental protection products, such as generators for wind turbines and motors for electric vehicles (EVs), while standard NdFeB PMs are mainly employed in magnetic separators and electroacoustic applications. The growth in demand for EVs is expected to increase the demand for gallium.

China is the largest producer of REPMs, the largest consumer, and a net exporter. In 2020, China produced 196 kt of REPMs, 90% of global production, and is expected to produce 284 kt in 2025 (92%) (7).

Light Emitting Diodes (LEDs)

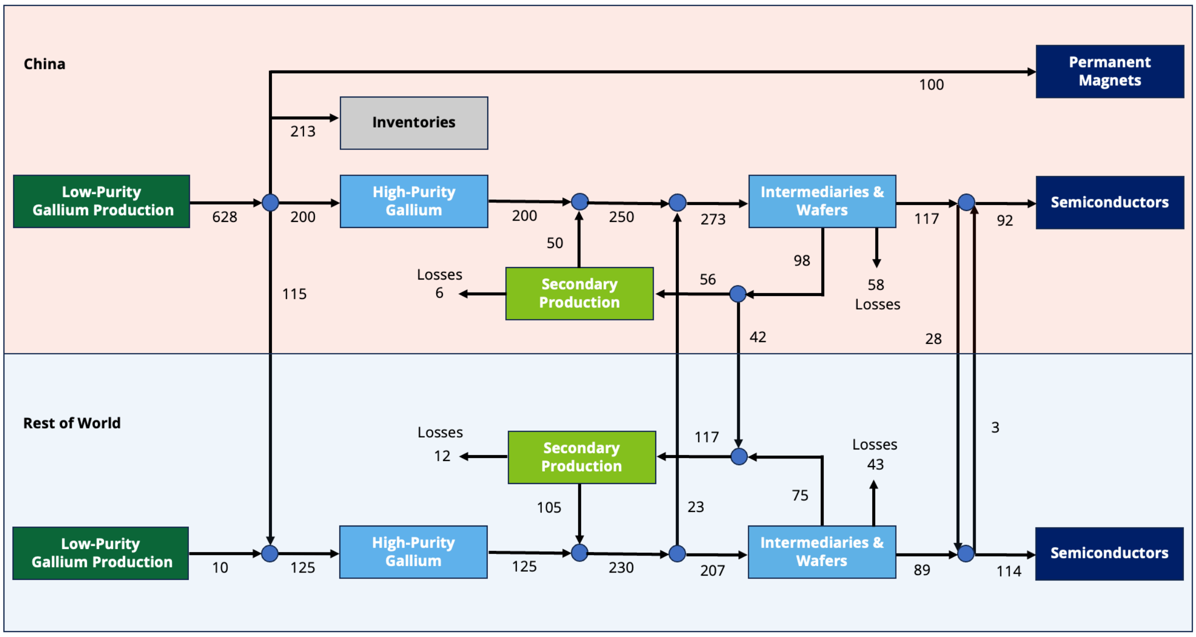
Gallium is an essential element in LEDs. An LED is a solid light-emitting device made of compound semiconductors which can convert electric energy into optical energy. The primary element in the semiconductor is gallium. Gallium nitride (GaN) emits brilliant light when a small electric current is passed through it. Other light colours can be produced by adding indium to the gallium nitride. The addition of aluminium to gallium nitride produces ultraviolet light.

A range of gallium-based technologies can be utilised for LEDs, including gallium arsenide (GaAs), aluminium gallium arsenide (AlGaAs), gallium phosphide (GaP), gallium indium phosphide (GaInP), aluminium gallium indium phosphide (AlGaInP), indium gallium nitride (InGaN), and gallium arsenide phosphide (GaAsP). Most GaN semiconductor devices are grown on a sapphire substrate (heteroepitaxy).

LED lamps and luminaries account for about 70% of all global lighting solutions. GaN technology has been crucial in reducing global energy consumption and carbon emissions from lighting. Growth from new light installations is slowing, and the demand for secondary replacements is becoming increasingly significant. Moreover, in addition to general lighting, LEDs are now being utilised for indoor farming, advanced lighting systems in autos, and LED-based display screens employing mini-LEDs and micro-LEDs.

Mini-LEDs are display technologies that utilise submillimetre-sized LED devices as either the backlight or pixel light source. The use of mini-LEDs as the backlight for liquid crystal display (LCD) panels has gradually increased in high-definition TVs, laptop computers, tablet computers, and other electronic products, significantly enhancing the display quality of LCD panels.

Figure 6. Simplified Gallium Material Flow 2022 (tonnes)



Source: USGS, RFC Ambrian. NB. Semiconductors include integrated circuits and LEDs.

Micro-LEDs are display technologies utilising micron-sized LED devices as the pixel light source for high-density LED arrays. In addition to further enhancing display effects, micro-LED technology can overcome the limitations of mini-LED technology for smaller screens. However, there are currently challenges in manufacturing, encapsulation, and testing technologies for micro-LEDs, necessitating improvements for large-scale production. Nevertheless, once these challenges are addressed, micro-LED display technology is expected to generate significant demand for GaAs substrates.

Figure 7. Light Emitting Diodes

Source: Vexica

Photovoltaics

Gallium arsenide is used to produce solar cells known for their high efficiency. These cells convert a larger percentage of sunlight into electricity than other types of solar cells (20 to 30%) and can also operate at higher temperatures than traditional silicon solar cells. Furthermore, GaAs solar cells are relatively lightweight and highly tolerant to radiation and temperature, making them suitable for various applications. However, producing these wafers is generally more challenging and costly, resulting in their principal use in space-based solar power systems.

Performance can also be tuned by layering for GaAs-based solar cells. One solar cell can contain up to eight thin layers, each absorbing light at a specific wavelength to maximise efficiency. Such photovoltaic cells are called multi-junction or cascade solar cells. Layers commonly used include GaAs, AlGaAs, InP, InGaP, and GaInAs.

However, demand for gallium in this sector is declining. Silicon-based solar technologies are shifting from p-type solar cells doped with gallium, boron or aluminium to the more efficient n-type TOPCon (Tunnel Oxide Passivated Contact) solar cells doped with phosphorus or arsenic [(8)].

Another use of gallium is in thin-film solar cells where a copper-indium-gallium-selenide (CIGS) semiconductor is used. The substrates used for thin film photovoltaics are glass, stainless steel, or polyimide film, and semiconductor materials include cadmium telluride (CdTe), CIGS, and amorphous thin-film silicon (a-Si, TF-Si). However, the market share of thin-film solar cells has declined in recent years. It is now a very small percentage of the total solar market, and global production of CIGS semiconductors is reported to have halted in 2021.

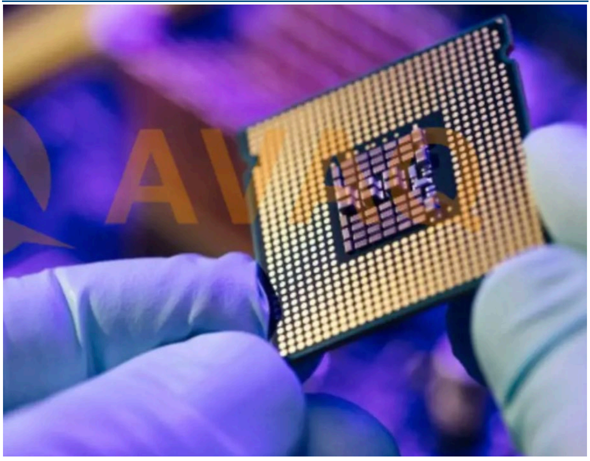
Integrated Circuits

GaAs semiconductors are employed in wireless communication equipment. Their primary application is in radio frequency (RF) signal transmission and reception devices, including power amplification. GaAs substrates are utilised to produce RF devices for base stations and smartphones in 4G and 5G communications. The adoption of GaN in RF devices is also increasing due to its power efficiency, reliability, and space optimisation. It is increasingly being utilised in 5G telecom infrastructure and defence radar applications. Furthermore, GaN RF devices have started to find applications in satellites.

GaAs semiconductors are also employed in laser devices. A laser generates visible or invisible light through stimulated emission. Infrared lasers and sensors made with GaAs substrates possess characteristics such as high-power density, low energy consumption, high-temperature resistance, high luminous efficiency, and high breakdown voltage. They are currently utilised in vertical-cavity surface-emitting laser (VCSEL) devices for 3D sensing technology, such as facial detection in mobile phones.

Third-generation GaN and SiC semiconductors are utilised in wide-bandgap electronics, offering higher voltages and power, elevated operating temperatures, faster switching, improved efficiency, and a smaller form factor. The adoption of GaN in consumer electronics and communications is increasing. However, its high-cost limits it to niche applications in power supply, representing only one percent of the power electronics market.

Figure 8. Gallium Arsenide Integrated Circuit



Source: AVAQ

IGZO Thin Film Displays

Indium gallium zinc oxide (IGZO) is a semiconducting material composed of indium (In), gallium (Ga), zinc (Zn), and oxygen (O). IGZO thin-film transistors (TFT) represent a type of display technology used in the TFT backplane of flat-panel displays (FPDs). This innovative technology results in thinner equipment, compared to traditional display technology, and offers lower power consumption alongside higher resolution and brightness. Consequently, IGZO is anticipated to gradually become mainstream technology for panel displays [9].

Other Gallium Uses

Wide bandgap GaN and gallium oxide (Ga_2O_3) semiconductors are used in photodetectors. A photodetector is an essential device at the front end of an optical receiver that converts incoming optical signals into electrical signals, known as optoelectronic converters. This includes solar-blind ultraviolet (UV) photodetectors employed in various applications such as monitoring ozone holes, detecting flames, space communication, missile guidance, biochemical detection, and inspecting UV leakage.

Gallium trichloride is utilised to create the electrolyte in speciality battery chemistry (lithium thionyl chloride), which enables high-temperature performance. Low melting point alloys, catalysts, optical glasses, dental filling materials, and piezoelectric materials are among the other applications of gallium. The EU banned the use of mercury in thermometers in 2010, which has since been replaced by galistan, an alloy of gallium, indium, and tin that remains liquid at room temperature. This market is expected to expand, increasing the demand for gallium consumption.

Substitution of Gallium

Gallium can be substituted in many of its applications, but usually at the expense of production efficiency or product characteristics. Varying levels of substitutability exist for gallium across different energy applications. Currently, no technology is available to replace gallium in LED compositions; only preliminary technology exists to reduce gallium content. However, liquid crystals made from organic compounds are increasingly being used in visual displays to substitute LEDs (10). Alternative lighting sources, such as incandescent and fluorescent, exist but have lower luminosity, and some utilise rare earth elements.

Si and SiC semiconductors can replace GaN semiconductors in power electronics, although GaN operates at higher frequencies than Si and SiC. Silicon-based complementary metal-oxide semiconductor power amplifiers compete with GaAs power amplifiers in mid-tier third generation (3G) cellular handsets. Indium phosphide components can be substituted for GaAs-based infrared laser diodes in some specific wavelength applications, and helium-neon lasers compete with GaAs in visible laser diode applications.

Silicon is the main competitor to GaAs in solar cell applications. In many defence-related uses, GaAs- and GaN-based integrated circuits are employed due to their unique properties, with no effective substitutes available for GaAs and GaN in these applications. In heterojunction bipolar transistors, GaAs is being replaced in certain applications by silicon-germanium (1).

3. Supply Fundamentals

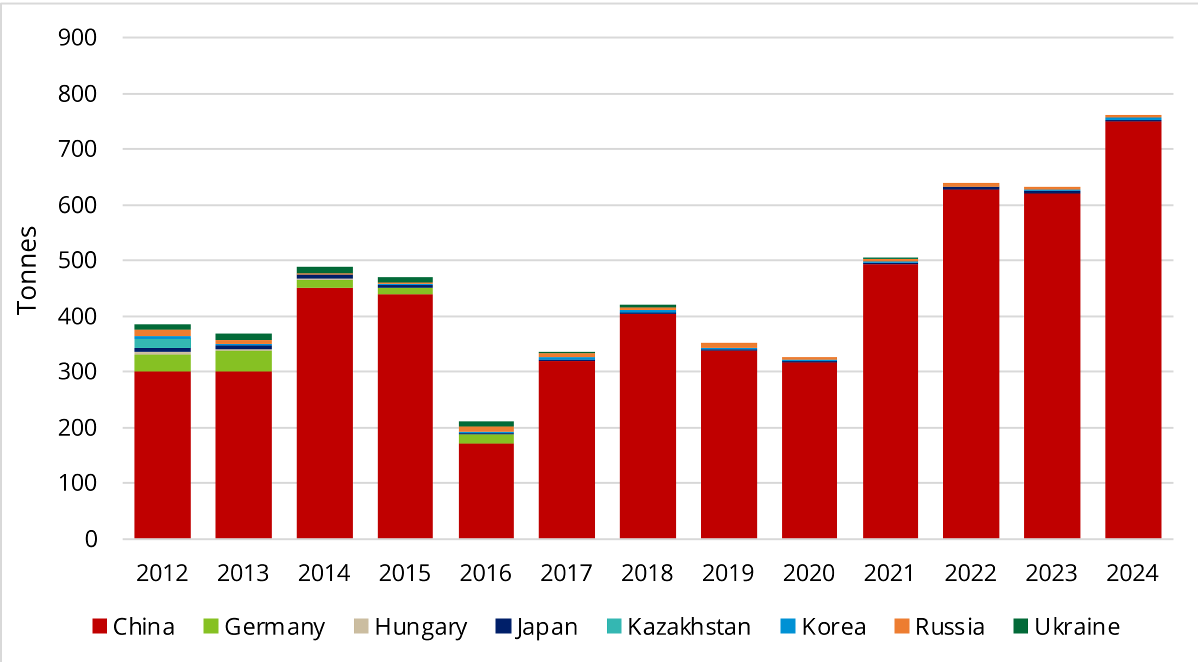
Gallium is extracted solely as a by-product of minor significance from a relatively limited number of operations during alumina refining or zinc smelting, primarily in China. An estimated 95% of output is obtained from refining bauxite into alumina, while around 5% originates from the smelting of zinc ores. Consequently, gallium production estimates are only available at the refinery or smelter production level, resulting in limited data on gallium mine supply.

From 2005 to 2024, global production of low-purity gallium increased from 69 to 762 t/y [(1)]. Figure 9 shows the total global refined production of low-purity gallium from 2012 to 2024 and China's dominance. China's increase in gallium production corresponds to a dramatic increase in aluminium production between 2005 and 2023 (from 7.8 Mt to 41.0 Mt). As part of that expansion, the Chinese government required many aluminium producers to install processing capacity to extract gallium. China's key producing regions of aluminium and gallium are Guangxi, Guizhou, Henan, Shandong, and Shanxi.

The objective was to support a growing gallium semiconductor industry. However, the rapid increase in production during this period created a global oversupply that negatively impacted gallium prices, and operations in the UK, Germany, Hungary, and Kazakhstan found it no longer profitable to produce gallium. They were forced to close capacity from 2013 to 2016, further increasing China's dominance. Production capacity continues to increase in China despite the industry's apparent overcapacity, with two new gallium recovery plants opened in 2023.

In 2024, the USGS estimated a global annual gallium capacity of 1,124 t, compared with global production of 760 t, a utilisation rate of only 68%. China is estimated to have a capacity of 1,000 tonnes, with production of 750 tonnes and a utilisation rate of 75%. However, even with these low utilisation rates, gallium production in China is reported to have consistently exceeded demand; from 2005 to 2020, an estimated 948 tonnes of gallium were stockpiled, according to a recent technical study [(5)].

Figure 9. Low-Purity Gallium Production 2012-2024



Source: USGS 2024

The USGS also reported a high level of stockpiling in China in its recent analysis of the gallium market [6]. The 948 t of stockpiled metal appears high (nearly 1.3 years of 2024 production), and it remains unclear where these stocks may be held, although China's gallium producers likely hold some inventory.

Gallium Midstream Producers

The refining of primary gallium is concentrated in China, with minor production in Russia, Japan, Korea, and Ukraine. Many of the gallium refiners in China are subsidiaries of the parent bauxite mining and alumina refining companies, with some fully integrated. Zhongjin Lingnan Nonfemet in China and Korea Zinc in South Korea are the only two significant producers of gallium from zinc smelting that have been identified.

Some alumina refineries in China process both domestic and imported bauxite, and new refineries mainly process imported bauxite. Bauxite imports into China have risen from about 2 Mt in 2005 to an estimated 160 Mt in 2024, primarily sourced from Guinea (about 65%) and Australia (30%). China's dependence on bauxite imports is now around 65% of the total ore processed. This growing reliance on imported bauxite has reportedly led to issues for some gallium producers, as the gallium content in the imported ore has been lower than that of the domestic ore.

Table 2. Significant Primary Gallium Refiners

Company	Country	Refinery	Capacity t/y Ga estimates	Production 2021 est. tonnes Ga
Xiaoyi Xing'an Gallium Industry	China	Guangxi, Guizhou, Henan, Shandong, Shanxi*	170	153
Aluminum Corporation of China (Chalco)	China	Guangxi, Guizhou, Henan, Shandong, Shanxi*	160	132
Zhuhai SEZ Fangyuan	China	Guangxi, Chongqing, Henan, Shandong, Shanxi*	140	80
East Hope Gallium Industry	China	Henan*	80	65
Beijing Jiya Semiconductor Materials	China	Shanxi*	65	35
Guangxi Debao Gallium Industry	China	Guangxi	50	16
Zhongjin Lingnan Nonfemet	China	Guangdong (zinc)	20	16
Dowa Metals & Mining	Japan	Akita Zinc Iijima (zinc)	20	3
Rusal	Russia	Achinsk, Boksitogorsk	10	2-3
Sual	Russia	Pikalevsky, Ural	11	2-3
Korea Zinc	S. Korea	Onsan (zinc)	16-20	2
Rusal	Ukraine	Nikolaev	12	1
Shanxi Zhaofeng Gallium Industry	China	Shanxi*	25	na
Guangxi Tiandong Jinxin Rare Metals	China	Guangxi*	60	na
Guizhou Qiya Aluminum	China	Guizhou*	24	Started 2023
Guizhou Galuminum Alumina	China	Guizhou*	40	Started 2023
Total			**905**	**508**

Source: Asian Metal, Beijing Tongmei Xtal Technology 2022, UNCTAD - Digital economy growth and mineral resources, DERA, company reports. * Integrated alumina facility.

Xiaoyi Xing'an Gallium Industry is owned by Xiaoyi Xingan Chemicals (60%), a subsidiary of Hangzhou Jinjiang Group, which also owns Sanmenxia Aluminum, a major integrated aluminium producer in China. Other shareholders include Nanjing Jinmei (25%), a subsidiary of a joint venture between Beijing JiYa Semiconductor (see below) and AXT, a US-based semiconductor company, and QI Zeng (15%). The company has production plants in Shanxi province and produced 153 t of gallium in 2021.

The Aluminium Corporation of China (Chalco) has a gallium capacity of approximately 160 t/y, with production facilities located in the Henan, Guizhou, and Guangxi provinces, where it manufactures gallium metal (6N) and gallium oxide. In its 2022 annual report, Chalco disclosed that it produced 146 t of gallium that year. Chalco also adjusts its gallium production in response to market demand, and prices for its gallium are determined through negotiations with its customers.

Zhuhai SEZ Fangyuan operates six gallium refineries in China, located in Yuanping (Shanxi), Lushan (Henan), Dengfeng (Henan), Nanchuan (Chongqing), Zouping (Shandong), and Jingxi (Guangxi). The company acquires gallium concentrate from Chinese alumina refineries and produces gallium metal through alkaline resin adsorption. It has a production capacity of 140 t/y of 4N and 6N gallium metal and holds a patent for a chelating resin used in gallium adsorption. In 2021, the company produced 80 t of gallium.

East Hope Gallium Industry operates in Mianchi County, Henan Province, with a capacity of 80 t/y and produced 65 t of gallium in 2021. The East Hope Group owns and operates two alumina refineries, in Henan and Shanxi Provinces, the latter featuring a dedicated bauxite mine, alongside two aluminium smelters in Inner Mongolia and one in the Xinjiang Autonomous Region.

Beijing Jiya Semiconductor Material is a joint venture between AXT of the US, Consco Group (Hong Kong), and Shanxi Aluminum Plant. The company has two production lines in Shanxi and produces 65 t/y of gallium.

Guangxi Debao Gallium Industry is a wholly owned subsidiary of Beijing ZhuoLongYuan Technology. It has gallium production plants in Guangxi, Shanxi, and Henan with a total capacity of about 50 t/y gallium and produced about 16 t of gallium in 2021.

Zhongjin Lingnan Nonfemet operates the Danxia zinc refinery located in Guangdong Province and produced about 16 tonnes of gallium in 2021.

Dowa Metals & Mining produces gallium at the Iijima zinc smelter, which is part of Akita Zinc, an 81% owned subsidiary in Japan. Akita imports zinc ore primarily from the Taizapa mine in Mexico, as Japan lacks domestic zinc ore production.

In Russia, **Rusal** produces gallium from the Achinskoe and Boksitogorskoe alumina refineries with annual capacities of 1.5 and 5 t, respectively.

Siberian–Urals Aluminium (SUAL) in Russia produces gallium from the Pikalyovo alumina refinery, which has an annual capacity of 9 t of apatite nepheline ore, and from the Urals Aluminum Smelter, which has an annual capacity of 2 t of gallium.

In Russia, the gallium sources are by-products of alumina production: bauxite (60 to 65%) and nepheline (about 35%).

According to the USGS, **Korea Zinc** produces about 2 t/y of gallium from its Onsan zinc smelter in South Korea. Zinc concentrates are sourced from Cannington, San Cristobal, and Red Dog mines, but gallium is not mentioned in the company reports.

In Ukraine, **Rusal** produces gallium from the Nikolaev alumina refinery, which has a reported annual capacity of 15 t. Bauxite is supplied from Rusal's operations in Guinea. It has been reported that the refinery was confiscated from Rusal following Russia's invasion of Ukraine and that the State Property Fund (SPF) plans to privatise it. The alumina refinery has been offline since March 2022.

Shanxi Zhaofeng Gallium Industry is a joint venture of Shanxi Zhaofeng Aluminum (51%) of Yangmei Group, Beijing Jiya Semiconductor Material (29%), and Shanxi Huadin Resin (20%) in China. It has a capacity of about 25 t/y of gallium.

Guangxi Tiandong Jinxin Rare Metals operates a 1.2 Mt alumina refinery with a capacity of about 60 t/y of gallium.

Guizhou Qiya Aluminum began producing gallium from its alumina refinery in October 2023 and has a reported capacity of 24 t/y. The company, situated in southwest China, processes domestic bauxite and imports bauxite from Malaysia and Indonesia.

Guizhou Galuminum Alumina began producing gallium from its alumina refinery in 2023. The refinery has a reported capacity of 40 t/y of gallium.

Secondary Refiners of Gallium

In 2022, China refined 200 t of primary gallium and 50 t of recycled material into high-purity gallium and exported 103 t of low-purity gallium. Most of China's gallium exports are used for secondary refining to produce high-purity gallium with purities of 6N and 7N, which is used to make semiconductor materials.

Above-Ground Gallium Stocks

Large above-ground stocks of gallium metal are believed to exist in China. This includes stocks which were accumulated by the Fanya Metal Exchange (FME) between 2011 and 2015. FME was a state-backed exchange based in Kunming, Yunnan Province, which claimed to be the world's largest rare metals trading platform. The exchange focused on metals, including gallium, used in technologies promoted in China's official strategic plan. In the three years after its establishment, the exchange raised as much as US$6.4 bn.

In 2015, the exchange was exposed as a Ponzi scheme, and the executives were charged with embezzlement and sabotage of financial markets. The exchange's warehouses reportedly held 191.2 t of gallium. Kunming Rongke New Materials (a state-owned company) purchased the gallium stock in September 2019 for ¥173 m (about US$24 m). It then sold it to Vital Materials (a Chinese advanced materials company that produces GaAs wafers), which said it would be consumed within its own business. This is a large amount of gallium for one company to hold as stock, and its consumption will likely take a number of years.

The US government maintains a National Defense Stockpile, which is overseen by the Defense Logistics Agency (DLA), containing key materials critical to national security. The DLA lists gallium as a 'material of interest'; however, the agency's public reports indicate it has not purchased gallium for stockpiling within the past decade. However, the Manufacturing Capability Expansion & Investment Prioritization (MCEIP) office of the US Department of Defense is undertaking investment in support of the National Defense Strategy and investing in major and sub-tier suppliers of strategic raw materials to mitigate supply chain risks. This is reported to include both gallium and germanium.

Gallium Recycling

The primary source of gallium recycling is new scrap, which comprises waste generated during the manufacturing process. At present, a considerable amount of gallium is sourced from recycling new scrap produced during the fabrication of gallium arsenide and gallium nitride semiconductor substrates. This waste arises from the backgrinding of the substrates, deposition of epitaxial layers, and the trimming, etching, and polishing of wafers. This new waste is recovered from a closed-loop system.

Gallium is recovered from new scrap in Canada, China, Japan, Slovakia, and the United States, with secondary high-purity gallium production capacity estimated at 280 t in 2023. Companies involved in recycling gallium scrap include PPM Pure Metals (Germany), Neo Performance Materials (Canada), Rasa Industries (Japan), Nippon Rare Metal (Japan), Indium Corp. (United States), CMK (Slovakia), and Umicore (Belgium).

MTM Critical Metals [ASX: MTM] is advancing a novel metal recovery technology, Flash Joule Heating, which has demonstrated early successes in improving gallium and germanium recovery rates from new scrap. The company entered a strategic partnership with Indium Corp in late 2024.

The recycling of gallium-bearing post-consumer scrap (old scrap) is currently unfeasible owing to the highly dissipative nature of gallium in consumer products and the difficulty in recovering it.

4. New Gallium Projects

As highlighted, primary gallium is only recovered as a by-product of alumina refining and zinc smelting. Consequently, any additional supply of gallium can only come from increasing the production of the primary metals. In addition, the operation must have gallium capture facilities, the gallium grade within the mine concentrate must be economic, and the gallium extraction process should not affect the recovery of the primary metal.

New Production Potential

There is limited visibility on new gallium production capacity. Two new gallium production facilities were started in 2023 at existing alumina facilities in China. In the West, only three projects are known with the potential to produce gallium in the next few years. The most advanced is the Aluminium of Greece plant in Greece, which has recently been given the go-ahead. Discussions continue about the potential of producing gallium at the Clarkesville zinc mine in the US and the Lubumbashi tailings operation in the DRC.

Metlen Energy and Metals (formerly Mytilineos) operates Europe's only vertically integrated bauxite, alumina, and primary aluminium production unit (see Figure 11). The 'Aluminium of Greece' facilities are located at Agios Nikolaos in Greece [(15)]. In January 2025, the company decided to invest in new bauxite production, expand and modernise the existing alumina production capacity, and construct a new 50 t/y gallium recovery plant at a total cost of €295 m. Completion of the works and production start-up for bauxite is scheduled for 2026, with alumina and gallium production beginning gradually from 2027 and full-scale operation by 2028. Metlen mines diasporic type bauxite from underground mines in Greece and recently entered into an agreement with Rio Tinto to import bauxite from Guinea.

Nyrstar, which is majority-owned by the trading and logistics company **Trafigura**, is investigating a US$150 m germanium and gallium plant to process old tailings at the Clarksville zinc operations. The plant aims to produce 30 t/y of germanium and 40 t/y of gallium [(11)]. Construction will likely take two to three years, although little visible progress has been made on this project in the past few years. Nyrstar is also considering germanium and gallium projects in Australia and Europe [(12)].

In the DRC, **STL**, owned by **Gecamines**, operates a smelter at Big Hill in Lubumbashi, which recovers copper, zinc, and cobalt from former mine tailings. STL has constructed a new US$75 m hydrometallurgical and refining plant to recover cobalt hydroxide, copper cathode, and germanium precipitate [(13)]. The plant has the capacity to produce 30 t/y of germanium, with the first production shipped in October 2024. The germanium concentrates will be sent to **Umicore** in Belgium. Gecamines reports that it plans to explore the viability of processing gallium.

In December 2024, **Rio Tinto** reported that it is assessing the potential for extracting and valorising gallium present in the bauxite processed in its alumina refinery in Saguenay–Lac-Saint-Jean, Canada. Rio Tinto plans to build a demonstration plant in Saguenay for extraction technology to produce up to 3.5 t/y of gallium. A commercial-scale plant could eventually reach 40 t/y [(14)]. The bauxite is imported from South America.

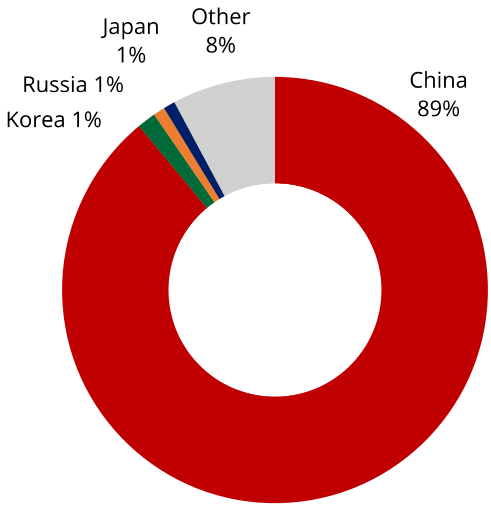
In May 2025, **RareX** [ASX: REE] entered into a strategic collaboration agreement with Australian technology developer Gega Elements to advance Gega's novel gallium refining solutions, coming soon after RareX announced high-grade gallium intercepts from historic drilling at its Cummins Range project in Western Australia. Also in Western Australia, **Nimy Resources** [ASX: NIM] has recently announced high grade near-surface gallium in exploration drilling at its Mons Project.

Previously Closed Operations

The West has idled gallium capacity, comprising previously closed gallium production facilities. Idled capacity included in the USGS' global capacity calculation includes 40 t/y in Germany, 8 t/y in Hungary, 25 t/y in Kazakhstan, and 15 kt/y in

Ukraine (see Figure 10). However, most of these facilities have been closed for a considerable period and may have been decommissioned or require significant investment to reopen. There are no public reports or indications of efforts to reopen any of these former gallium plants, but some are listed below for reference. It is likely that the reopening of any of these plants, if possible, would likely require higher gallium prices for a sustained period of time.

Figure 10. Low Purity Gallium Capacity 2024



Source: USGS 2025.

1. The **Pavlodar** aluminium refinery in Kazakhstan, operated by Aluminium of Kazakhstan JSC, halted gallium production in 2013 because of low prices.

2. Dadco Alumina and Chemicals operated the **Staad** alumina refinery in Germany, which formerly extracted gallium but closed in 2016.

3. Magyar Aluminium operates an alumina facility in **Ajka**, Hungary. The facility formerly extracted gallium but closed in 2015.

4. NALCO owns the **Damanjodi** alumina plant in Odisha, India, which has previously recovered gallium. In 2014, NALCO expressed interest in sourcing technology to establish a 10 t/y gallium extraction plant. No updates have been provided since then.

5. A mothballed gallium refinery is located near Alcoa's **Pinjarra** alumina refining plant in Australia. Originally owned by Rhone-Poulenc, it is now the property of GEO Specialty Chemicals. The plant produced gallium chloride, which was exported to France, but it ceased operations in 1997.

6. The **Renukoot** alumina plant, situated in Uttar Pradesh, India, is owned by Hindalco, which has previously extracted gallium.

7. Slovakia was a primary producer of gallium, but **CMK** stopped production in 2010. It now operates a secondary refinery of gallium.

Existing Alumina and Zinc Facilities

In theory, increased gallium production could be achieved by recovering more gallium from zinc concentrates or bauxite in existing smelters and refineries or by building gallium recovery and refinery capacity at existing alumina refineries and zinc smelters where gallium is not recovered. This is the approach Rio Tinto is taking at its alumina refinery in Saguenay–Lac-Saint-Jean, Canada.

However, recovering gallium from alumina refineries and zinc smelters may negatively affect the recovery of alumina and zinc, thereby reducing the efficacy of the process. A high gallium content in bauxite and zinc concentrates is essential to make gallium recovery economically viable on an industrial scale; yet, even under such circumstances, gallium recovery contributes only a small fraction (a few percent) of the business's total revenue. The negative impact on the recovery and profits of alumina or zinc resulting from gallium recovery could significantly outweigh the value of the gallium profits. The outcome of Rio Tinto's demonstration plant should prove interesting.

New Zinc and Alumina Facilities

Additional gallium capacity could be developed when new zinc smelters or alumina refineries are constructed, provided that the feedstock contains adequate quantities of gallium.

According to S&P Global Intelligence, only two new alumina refineries are currently under construction in Indonesia and Vietnam. A feasibility study has been completed for an alumina project in Brazil, and a pre-feasibility study is ongoing for an alumina refinery in Madagascar.

Figure 11. 'Aluminium of Greece' Integrated Aluminium Plant, Site of a New Gallium Refinery.

Source: Metlen

Nine new zinc smelters are being commissioned, with construction underway at five additional sites. Eight of these smelters are in China, two in Turkey, and one in Russia, Indonesia, Iran, India, and Vietnam.

This data may suggest an opportunity for new gallium capacity to come online at these alumina refineries and zinc smelters. However, no information is available regarding whether these projects will produce gallium, which suggests that it is currently unlikely.

Increasing recoveries or building more gallium refineries involves economic decisions that weigh the capital and operating costs of these actions against the potential revenue they might generate, including losses from alumina and zinc processing inefficiencies. This assessment is also partly influenced by the price of gallium.

Red Mud as a Source of Gallium

As previously highlighted, the red mud residue produced as a waste product from the alumina refining process could be a further resource that could be exploited for gallium (and rare earths) if the recovery technology is developed. Every tonne of alumina production generates around 1.25 t of red mud. Currently, an estimated 150 Mt of red mud are produced each year, and by 2024, an estimated 5.6 bn tonnes of red mud waste had been accumulated globally.

Several processes have been successfully tested in the laboratory, and research papers on the recovery of gallium from red mud are available. However, an economically viable and environmentally sustainable process for recycling red mud to recover gallium at scale has yet to be implemented.

In 2018, the EU financed a 4-year programme to research the valorisation of bauxite residue and to train staff. However, the focus was on recovering iron, aluminium, titanium, and rare earth elements, as well as valorising the residuals into building materials, with gallium not being mentioned.

Wave Aluminium, based in Luxembourg, is a global technology company focused on the sustainable processing of alumina tailings through the use of microwave energy transfer technology. The company is currently constructing a plant at the Hydro Alunorte alumina refinery in Pará, Brazil, which is expected to be operational in 2025 to recover commercially valuable materials. The project will initially process 50 kt/y of bauxite residue but can potentially expand to process 2 to 4 Mt/y of bauxite residue. However, the company does not identify which minerals will be recovered.

5. Gallium Markets & Prices

Gallium Trade

China is the leading producer and exporter of gallium. Global trade in gallium-containing semi-finished goods is difficult to identify and quantify because these goods are generally a subset of broader product categories included in trade statistics. In August 2023, China implemented export restrictions on gallium and other metals, and in December 2024, it introduced a total ban on exports to the United States.

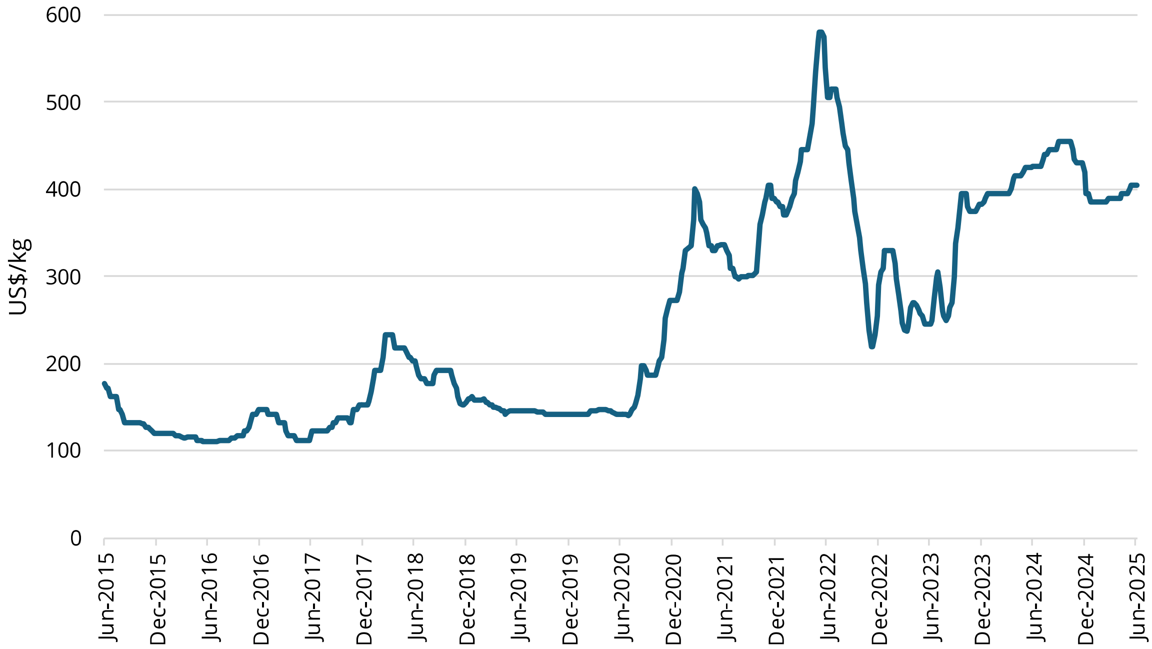
Gallium Prices

There are no official prices for gallium, as it is not traded on a metal exchange. The price is determined solely by negotiations between buyers and sellers. Most contracts between gallium producers and processors are long-term and confidential. Spot prices are obtained from specialist trade magazines such as Argus Media and Asian Metal. Figure 12 illustrates the long-term price of gallium metal.

Primary low-purity gallium prices in China recently peaked at US$580/kg in June 2022 before declining to US$220/kg in November 2022, a decrease of 62%. This was due to reduced gallium demand from the LED and REPM markets and an increase in China's primary low-purity gallium production capacity [16]. Prices subsequently started to recover in August 2023, owing to renewed demand from the REPM market and global concern about reduced gallium availability following China's implementation of export controls.

China's political actions have resulted in the price of gallium metal more than doubling from US$220/kg in November 2022 to US$455/kg in November 2024. Since November 2024, the price has pulled back slightly but remains at elevated levels.

Figure 12. Gallium Price 2015 to 2025 (US$/kg)



Source: Bloomberg - China Gallium Metal 99.99% FOB.

6. The Gallium Market Outlook

Supply Side Issues

The outlook for gallium supply remains uncertain due to the opacity of the market. China currently dominates the industry, producing 98% of primary output, and continues to increase capacity with ample resources to maintain its status as a major producer in the long term. In addition, according to recent studies, it also appears to be overproducing and stockpiling significant quantities of gallium.

Most of the capacity elsewhere in the world closed in the past ten years due to low gallium prices and this capacity appears unlikely to be restarted. The only new project in the West, announced in January 2025, is a 50 t/y gallium plant being constructed by Metlen Energy and Metals at its alumina operations in Agios Nikolaos, Greece (about 7% of current global output). Investigations and discussions continue about the potential of producing gallium at the Clarkesville zinc mine in the US and the Lubumbashi tailings operation in the DRC, but both projects remain uncertain.

There may be other opportunities to establish new gallium capacity in the West at new or existing alumina refineries or zinc smelters; however, the technological and economic practicalities remain uncertain, especially considering that the amounts of gallium recovered are minimal and hold limited economic significance for alumina and zinc producers. Any construction of new capacity would need to be economically justified. Metlen's proposed new gallium plant in Greece and Rio Tinto's planned demonstration plant in Canada are both positive indicators that producing gallium in the West could once again be viable.

Another potential source of gallium (and other critical minerals) could be the bauxite waste product known as red mud, which is created during alumina production. There are extremely large resources of red mud around the world, although not all of them may contain gallium. This area is currently under research; however, an economically viable and environmentally sustainable process for recycling red mud to recover gallium and other products on a large scale has yet to be implemented.

Demand Side Factors

The demand outlook for gallium is equally opaque due to the small size of the market and the limited information available from participants. Over the past 20 years, the composition of the various uses of gallium has changed. with strong growth in REPMs and LEDs in particular. Furthermore, the global expansion of the 5G infrastructure is anticipated to boost demand for gallium-based semiconductors. Some 55% of gallium-based semiconductor manufacturing now occurs in the West. However, these markets remain too opaque to quantify growth in any of these sectors.

Gallium Market Balance

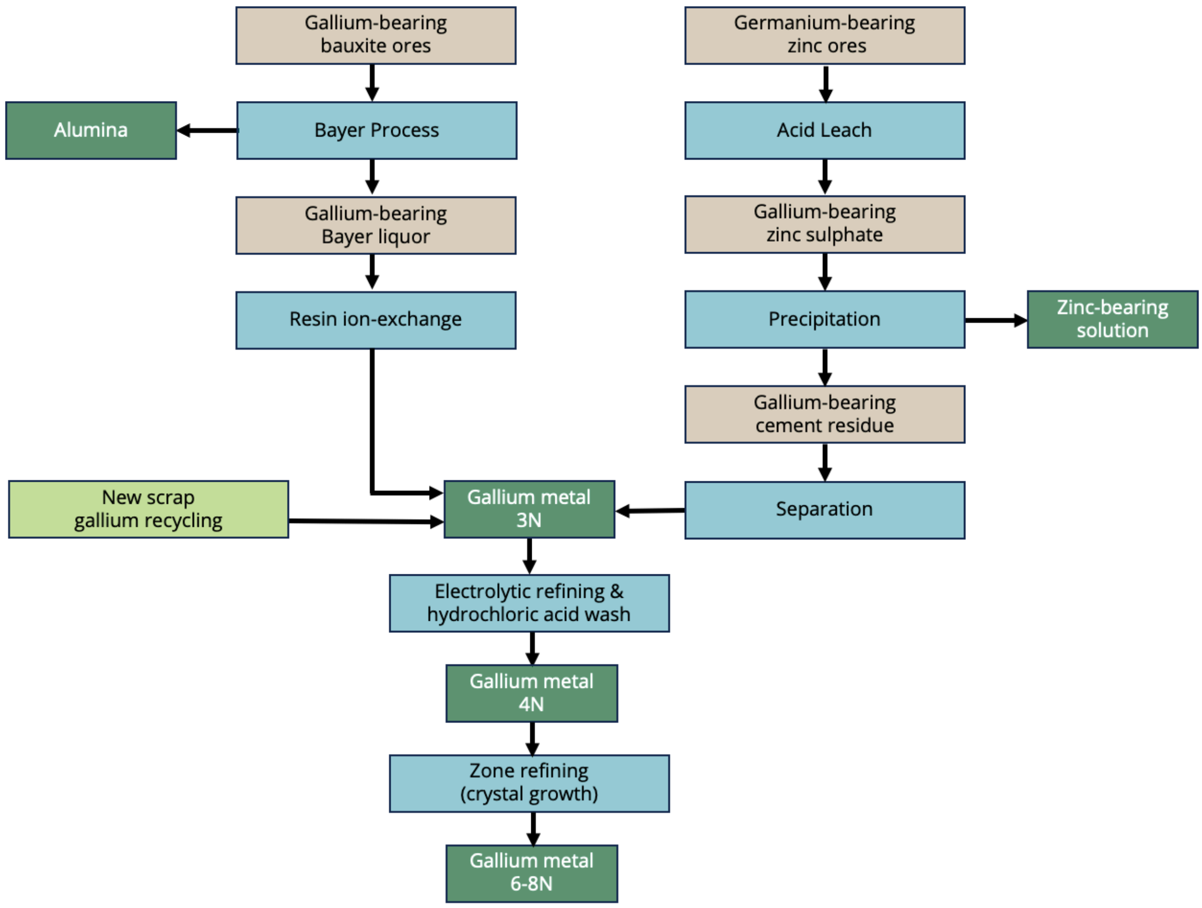
From a global perspective, sufficient gallium production capacity exists. In fact, overproduction is taking place, and excess material is being stockpiled. However, with 98% of gallium output occurring in China and with only limited new production likely in the West in the foreseeable future, China holds nearly all the cards in this commodity.

This is a significant problem for Western markets. The amount of gallium available for the continued manufacture of gallium-based semiconductors in the West will continue to depend on how much gallium China agrees to export. Material availability has become more difficult following China's export restrictions announced in August 2023, and problems have increased further following China's total export ban to the US announced in December 2024. This has already led to a more than doubling of the gallium price, and the market imbalance will continue to maintain pressure on the price.

Appendix 1 – Gallium Processing

Figure 13 shows the simplified processing flow diagram for gallium, highlighting the key products and their end-market uses.

Figure 13. Simplified Gallium Processing Flow Diagram



Source: Critical Minerals Handbook.

Appendix 2 – Gallium Semiconductors

Semiconductors

A semiconductor is a substance that has specific electrical properties that enable it to serve as a foundation for computers and other electronic devices. It is typically a solid chemical element or compound that conducts electricity under certain conditions but not others.

Semiconductor substrates are thin slices of material used as a base for carrying and supporting electronic logic circuitry (chips). The chip is the carrier of the miniature integrated circuit (IC), which has been laid out using photolithography and etching technology. Chip features are measured in nanometres. A nanometre is one-millionth of a millimetre. One micron equals 1,000 nanometres.

Silicon substrates dominate the semiconductor substrate market; however, certain electronic and optoelectronic applications have performance requirements that exceed the capabilities of conventional silicon substrates and often require high-performance compound wafers, many of which contain gallium.

Semiconductor Materials

Semiconductor materials are referred to as first-generation, second-generation, and third-generation to differentiate them. However, there is no strict substitutional relation among the semiconductor materials; different materials are used in specific applications based on their respective advantages.

(i) First generation: Single-element semiconductor materials mainly comprise silicon (Si) and germanium (Ge).

(ii) Second generation: Type III-V compound semiconductor materials, which are mainly comprised of gallium arsenide (GaAs), gallium phosphide (GaP), indium phosphide (InP), and indium antimonide (InSb).

(iii) Third generation: Wide-bandgap semiconductors, including gallium nitride (GaN), silicon carbide (SiC), and zinc oxide (ZnO).

Gallium-based Semiconductors

The fabrication of GaAs and GaN compound semiconductors consists of a few microns' thick epitaxial deposition layers on top of the much thicker substrate. GaAs- and GaP-based LEDs and ICs are mainly processed on GaAs substrates, while GaN-based LEDs are produced on sapphire, SiC or silicon substrates. Gallium metal, triethyl gallium, and trimethyl gallium (TMG) are used in the epitaxial layering process to fabricate epitaxial wafers to produce ICs.

Semiconductor devices made from GaAs substrates demonstrate high power density, low energy consumption, high temperature resistance, high luminous efficiency, radiation resistance, and high breakdown voltage levels. GaAs substrates are widely used to produce LEDs, ICs for radio frequency (RF) devices, photovoltaics, and photonics. The growth in demand is driven by 5G communications, next-generation displays (mini-LEDs and micro-LEDs), autonomous vehicles, artificial intelligence, and wearable devices. The global market for GaAs substrates is highly concentrated. Leading manufacturers in the global GaAs substrate market include Freiberger (28%), Sumitomo (21%), and Beijing Tongmei (13%).

GaN substrates are used in high-power electronic devices. Their high breakdown voltage and electron mobility make them ideal for power amplifiers, switches, and rectifiers. GaN on silicon for power electronics can be applied across a range of industries, from consumer chargers and power supplies, electric vehicles, and data centre power management to military radars and aerospace systems, enabling higher efficiency, smaller form factors, and enhanced capabilities compared to its silicon counterparts.

Approximately 83% of the gallium consumed in the United States in 2024 was used in GaAs, GaN, and GaP wafers.

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