The risks associated with the global supply chain for critical/ strategic minerals

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The growing importance of critical minerals

Critical minerals are essential for manufacturing a number of significant technology products, including batteries (for EVs for example), clean energy components such as solar panels and wind turbines (and the magnet-based motors that drive them), and of course semiconductors and other electronic components. The National Research Council (NRC) describes an essential mineral as having specific chemical and physical properties, such as metallurgical, chemical, catalytic, electrical, magnetic, and/or optical properties, with no substitute able to provide a similar function at a comparable cost.

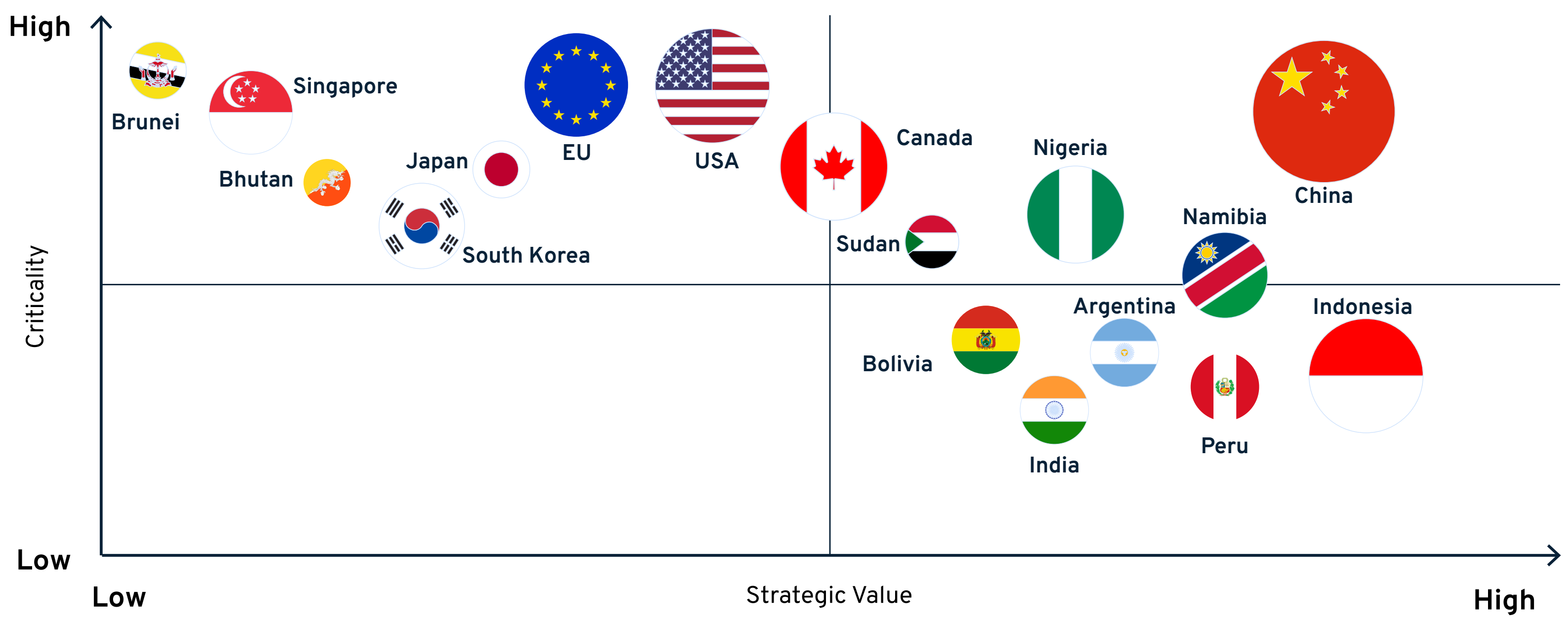
However, these resources are often concentrated in specific regions throughout the world, and as such their distribution represents supply chain risks. Any disruption in the supply chain by a particular country – through the exhaustion of natural resources, regional wars, trade disputes, environmental concerns, or geopolitical tensions, for example – could have a significant impact on the supply of these products and could even impact the global economy. Notably, another term for critical minerals is ‘strategic minerals’.

A rare mineral or critical element supply chain includes extraction (the removal of mineral resources from the surface), processing (which involves the chemical modification of the raw mineral or the use of byproducts), components, end-use technology, and recycling and reuse. At each point, there may be specific suppliers or countries that could disrupt this supply. With demand expected to increase over the coming years, there is valid concern about the resilience and/or security of the supply chain for critical minerals.

While there is a factual basis for terms such as ‘rare earth elements’ i.e. the Periodic table, the term ‘critical’ is based on a number of factors, which can be country- and context-specific, particularly with respect to mineral resources, their importance to the manufacture of technologies, regional economic and strategic development, and supply chain risks and volatility.

Criticality perspectives for different countries

Source: Intergovernmental Forum on Mining, Minerals, Metals, and Sustainable Development (IGF)



These considerations then determine the mineral strategy of each country and/or region. below shows an assessment of the perceived ‘criticality’ by a number of countries.

According to the IGF minerals are considered critical if they are of high economic or strategic importance, particularly if they are rare or concentrated in a specific region and others rely on their import for the production of important technologies. This definition is largely adopted by European countries, the United States, and Japan.

They are also considered critical if one country has an over-abundance of them, and so can use them for gaining competitive or economic advantage in the global supply chain through the ability to restrict their supply or hike prices. Countries using this definition include Canada, Australia, and China. This definition is also suited to countries with significant reserves of minerals that are important to de-carbonization and the transition to clean energies.

Countries to be considered include Bolivia (Lithium, and Gallium), Gabon (Copper, and Manganese), Indonesia (Nickel, and Bauxite), Kazakhstan (Copper-Lead-Zinc), Mozambique (Graphite, and Bauxite), Namibia (Rare Earth Elements, and Tantalum), and Nigeria (Manganese, and Lithium).

There are a number of key risks to consider, including: supply risks (from a concentration of mineral resources or processing capabilities, depletion of supplies, and the discovery of alternative materials); price volatility due to lack of stock or geopolitical tensions; or global economic fluctuations.

This report will highlight the critical minerals that are used for important technologies, global supply chain risks, the concentration of resources and those nations that are heavily reliant on imports of them.

Critical Minerals Overview

Arsenic

Arsenic is a poisonous substance used in miniscule amounts in a range of technologies. Notably, Arsenic is a fundamental component of silicon-based, high-speed semiconductors. Gallium Arsenide (GaAs) is also a vital component of semiconductor production and is also used in the manufacture of components such as infrared emitting diodes, laser diodes, integrated circuits at microwave frequencies, and photovoltaic cells. It is also used in batteries to prevent corrosion, and as an alloy mixed with lead or copper in lead acid batteries.

High-purity arsenic metal (99.9999%) is used to produce GaAs (which is used in semiconductors, solar cells, space research, and communications), and InGaAs (Indium-gallium-arsenide, which is used in shortwave infrared technology and in semiconductors for biomedical, mobile, electronics, optical, and photovoltaic applications).

Peru, China, and Morocco, in that order, were the leading global producers of arsenic trioxide in 2023, accounting for nearly 97% of estimated world production. China and Morocco supplied around 91% of U.S. imports of arsenic trioxide in 2023. China supplied around 98% of U.S. arsenic metal imports as of September 2023 – the U.S. has not produced arsenide since 1985[1].

Cobalt

Cobalt is a major critical element in a broad range of technological applications. It is an essential component in the cathodes of Lithium-ion batteries, which are used in EVs and the rechargeable batteries that power most electronic devices, such as smartphones and laptops. It helps batteries achieve a longer lifespan and higher power density. Its price is increasing due to demand for EV batteries. Its magnetic properties also make it useful in applications related to wind turbines and clean energy technologies, hard disk drives, motors, sensors, actuators, and magnetic resonance imagery. Cobalt offers high-temperature resilience, a melting point (over 1,000°C), thermal stability, hardness, and is easy to process, making it useful not only for energy storage, but also for applications such as aerospace, and defense. As a result, Cobalt-based superalloys are used in aerospace and high-temperature environments such as jet engines and gas turbines.

It's also a vital part of the circuitry of semiconductors. As a result, it's classified by the European Union and the U.S. as a Critical Raw Material. According to the World Economic Forum, global demand for Cobalt is expected to grow four-fold by 2030, largely driven by demand for EVs[2]. Global Cobalt mine and refinery production increased to record highs in 2023, mainly due to the Democratic Republic of Congo (Kinshasa), which accounted for 74% of world cobalt mine production[3] Indonesia, accounted for a further 7%, Russia (just under 4%), and Australia (around 2%).

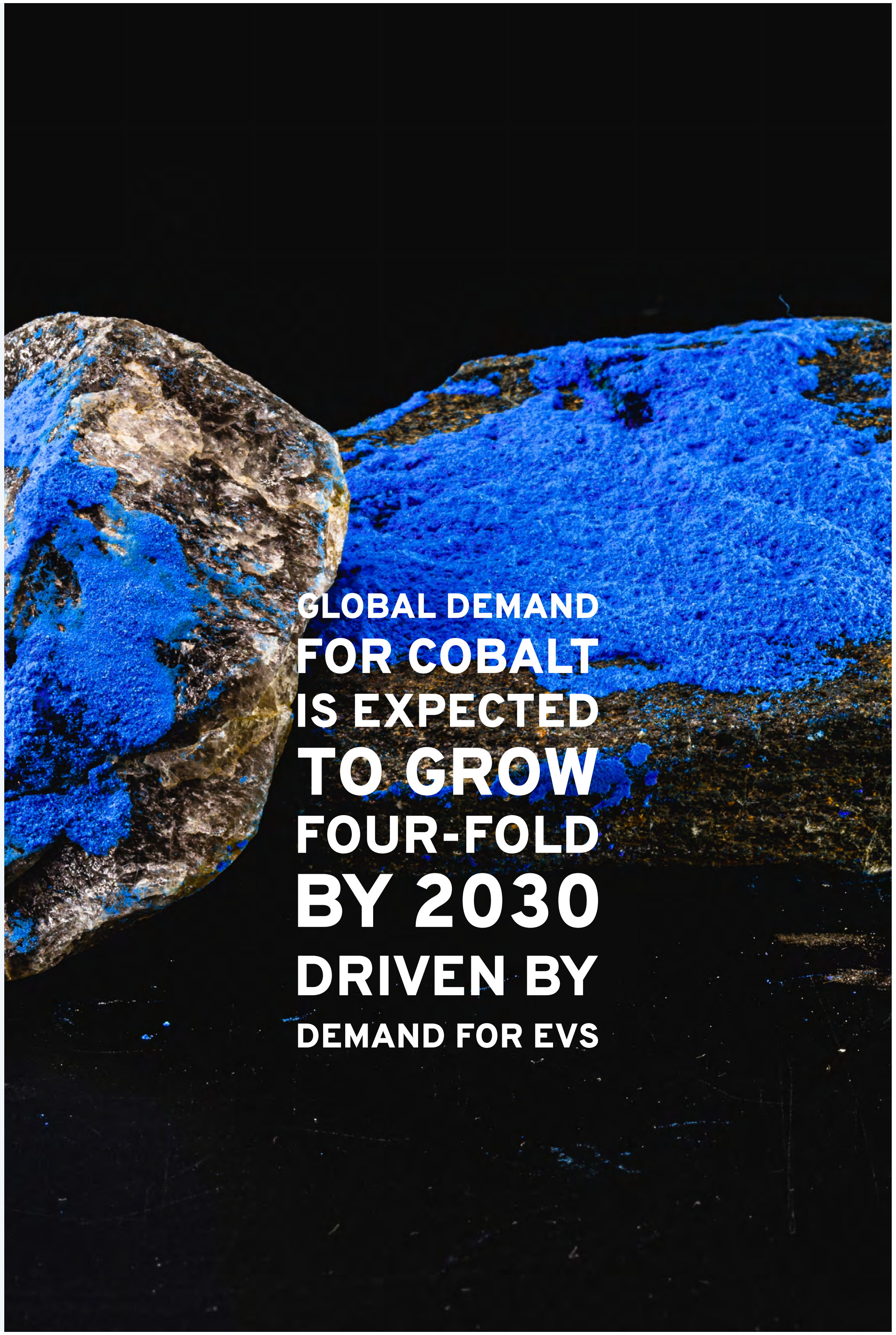
China produced the most refined Cobalt, most of which was imported from the DRC, and is the world's leading consumer of Cobalt – 87% of which was used by China's Lithium-ion battery industry in 2023.

Gallium

Gallium does not occur as a free element in nature, but rather as a Gallium compound found in trace amounts in Zinc ores and Bauxite. Elemental Gallium will melt in the human hand, and then solidify again once removed as it has a low melting point (29°C).

Gallium is essential for use in semiconductors, light-emitting diodes (LEDs), and pharmaceuticals. When mixed with arsenic it produces Gallium Arsenide, which is used in smartphones and other electronic devices. Gallium wafers used in semiconductor circuits are more efficient than silicon wafers, providing more power and less heat.

Alloys such as Copper-Indium-Gallium-Selenium are used to produce thin-film solar cells, which are mature second-generation solar cells.



Gallium-based compounds are also essential for producing high-performance Neodymium-Iron-Boron magnets for electric motors in EVs and wind turbines. Gallium-based semiconductors are a crucial material for integrated circuits. The mineral's unique properties enable high-speed processing, improved power efficiency, and miniaturization of consumer electronics.

In 2022, China accounted for more than 98% of global production of Gallium – Russia was the second largest producer at a meagre 0.81%[4]. With future demand for clean technologies and consumer electronic products rapidly growing demand for Gallium is expected to increase significantly. The U.S., the EU, the UK, and Australia all designate Gallium as a critical material.

Germanium

Germanium is a silvery-white, brittle, semi-metal, which can act as both a conductor and an insulator. When doped with Arsenic, Gallium and other elements, it is used in solid-state electronics, semiconductors, fiber optic systems, rectifiers, and transistors.

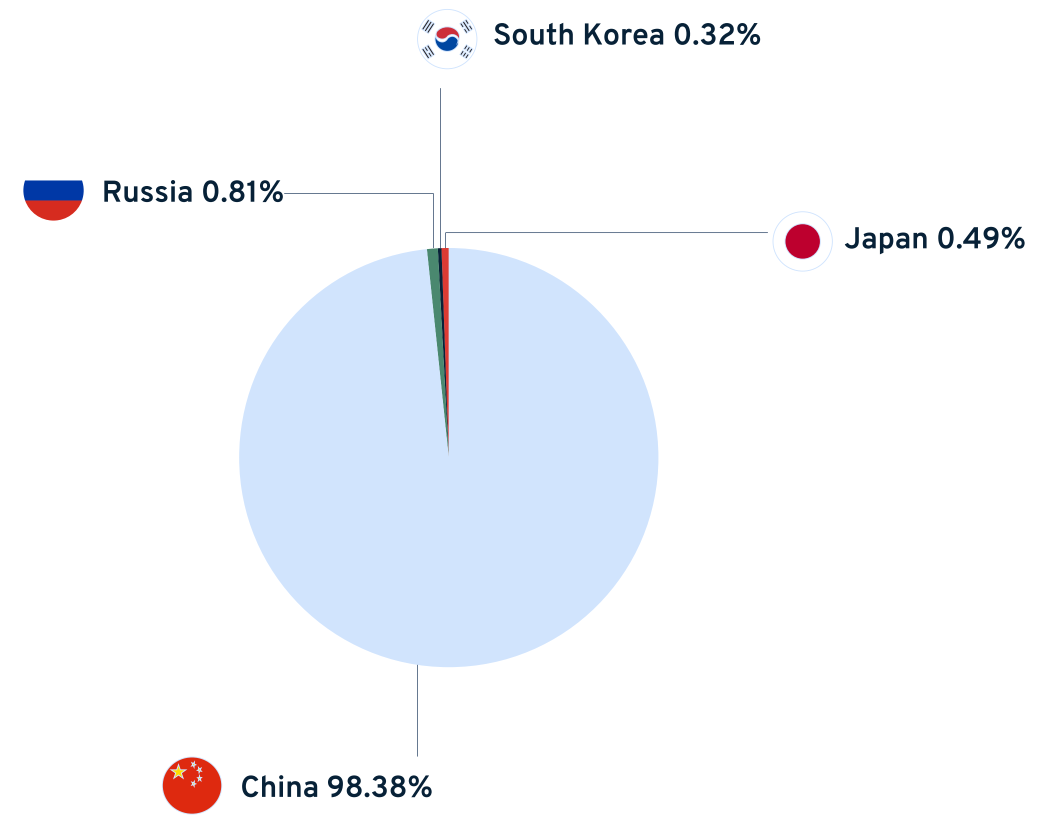
Its high diffraction index also makes it suitable for use in wide-angle camera lenses and microscopes. It is also used as an alloying agent in fluorescent lamps. When converted to Germanium Oxide it can be used in infrared optical applications.

Germanium ores are scarce but not completely rare and found in small quantities as Germanite and Argyrodite. Germanium minerals are also present in Zinc ores and can be recovered from the by-products of the combustion of certain coals.

In 2022, China accounted for more than 93.5% of global production of Germanium[5]. The U.S. and Japan each accounted for 1.44% of global production in the same year.

Distribution of gallium production by country, 2022

Source: US Geological Survey, BMLRT



Indium

Indium is a soft, silvery metal that is mainly used to make Indium Tin Oxide (ITO), which is an essential component for touch screens, flatscreen TVs, and photovoltaic panels. It conducts electricity, bonds strongly to glass and is transparent. Indium nitride, phosphide and antimonide are semiconductors used in transistors and microchips.

Indium is one of the least abundant minerals on Earth, and is usually found with Zinc minerals (90% of all Indium is a byproduct of Zinc mining), as well as in Iron, Lead and Copper ores. It is commercially produced as a by-product of Zinc refining, which itself is a critical and rare mineral.

The main producers of Indium are China (40%), South Korea (31%), Canada (9%) and Japan (9%). China controls between 43% and 66% of the world's Indium reserves. There is no Indium production in the U.S.

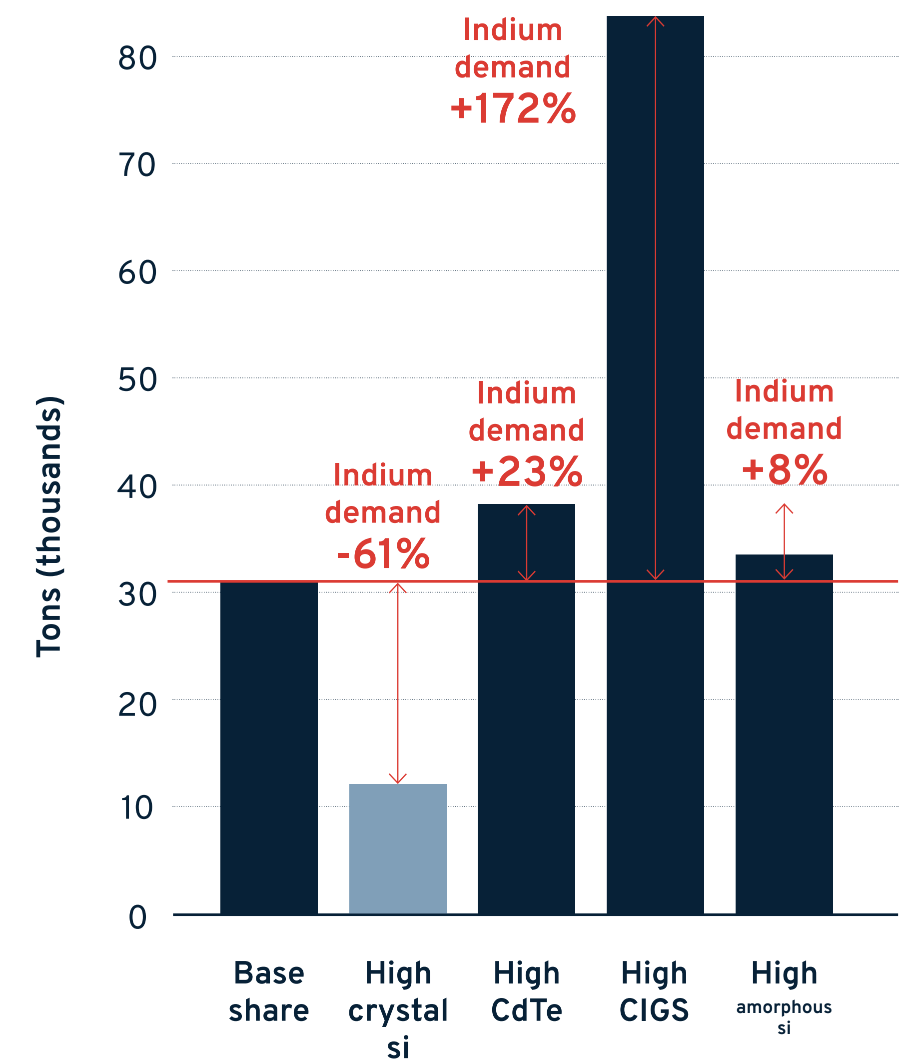
Lithium

Lithium is the lightest metal in nature, but also one of the most reactive. It would float on water if it wasn't so reactive with it. It has become the de facto element for powering multiple applications, and will become increasingly important in power storage, electronics, automative, defense, and aerospace applications.

Lithium-ion batteries have been around since the 1990s and now power everything from smartphones to pacemakers. Lithium's high energy density and low weight makes it ideally suited for use in electronic devices. It is also used in Lithium-Iron-Phosphate batteries, which offer greater stability and a longer lifespan making them ideal for use in EVs and large-scale energy storage systems.

The growth of indium demand for solar panels

Source: World Bank



Note: 2 degree scenario. amorphous Si=amorphous silicon, CdTe=cadmium telluride, CIGS=copper indium gallium selenide, Crystal Si= crystalline silicon

Around 70% of the world's Lithium resources are found in brine deposits – specifically the salt flats of Chile, Argentina, and Bolivia.

Lithium pegmatites, (which are found in a rare kind of graphitic rock) are also found in Australia, Canada, China and Zimbabwe, while Lithium deposits found in clay and Borate minerals in sedimentary basins can be found in locations such as Nevada in the U.S. – known as the 'Lithium Hub', near to which the Tesla Gigafactory facility is being built.

However, Lithium extraction from rock ores is relatively complex and energy-intensive and so large reserves do not necessarily mean significant production of Lithium.

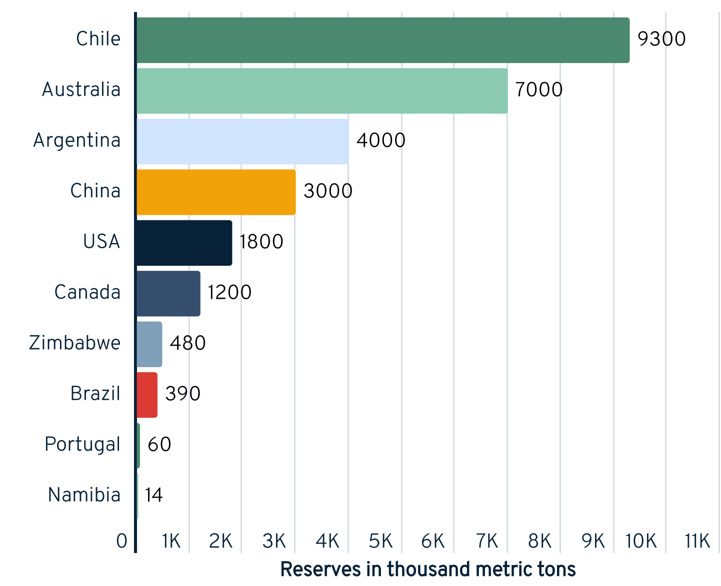
As a result of demand for EVs and cleaner energy technologies, demand for Lithium is expected to more than quadruple between 2022 and 2030 from 720,000 metric tons to 3.1 million tons over the forecast period[6].

Neon

Neon is essential for the ultraviolet lasers that are used in chip fabrication. It transfers energy more efficiently to the laser, and improves performance and accuracy. The semiconductor industry is therefore reliant upon Neon. However, it is difficult to create high-purity Neon and the process has a large carbon footprint.

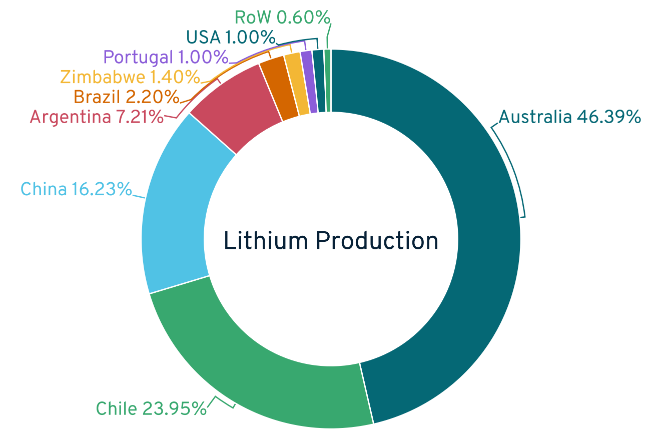
Global distribution of Lithium reserves

Source: US Geological Survey



Top 8 Lithium producers in 2021

Source: Visual Capitalist



Up until the Ukraine-Russia war, two companies in the Ukraine, Ingas and Cryoin, supplied 45%-55% of the world's semiconductor-grade Neon, however both have halted operations since, meaning that Neon is at high risk of supply chain disruption.

Palladium

Palladium is used for plating (which is used to lay down the initial wiring on semiductors) Small quantities (16% of total consumption) are mined domestically in Montana, U.S., but the majority of the metal is imported from Russia (34%), South Africa (30%), Italy (8%), and Germany (8%).

Rare Earth Elements

The Rare Earth Elements (REEs) are known as the lanthanides, and contrary to their name are relatively abundant in the earth's crust – the name refers to the difficulty in separating the individual elements rather than their scarcity.

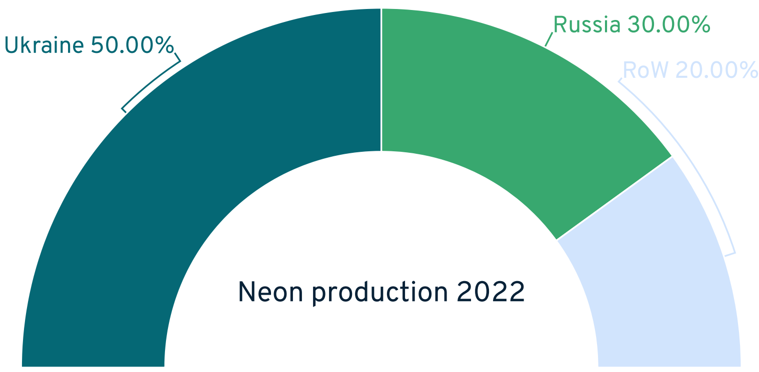
They are silvery metals that are often soft, malleable, and ductile with high melting and boiling points. They also exhibit high magnetism and fluorescence properties.

As a result, they are used for multiple purposes, including smartphone and TV screens, fiber optic cables for undersea communications, the magnetic motors that drive wind turbines, lasers, EV batteries, nuclear reactors, magnetic resonance imaging, guided missiles, and fuel cells for jet engines. They may even be used to develop new components for quantum computers.

Their importance means that they are highly sought after.

Global Neon production in 2022

Source: World Population Review



The lanthanides comprise 15 elements:

- Lanthanum – mixed with alloys and then used in batteries and hydrogen vehicles
- Cerium – used in light bulbs, TVs, and ovens
- Praseodymium – used in aircraft engines, fiber optic cables, and magnets
- Neodymium – used in magnets, and lasers
- Promethium – used in pacemakers, and guided missiles
- Samarium – used in microwave devices, and magnets
- Europium – used in light bulbs, nuclear reactors, and lasers
- Gadolinium – used in magnets, nuclear reactors, and magnetic resonance imaging
- Terbium – used in light bulbs, memory devices, and x-rays
- Dysprosium – mixed with other alloys and used wind turbines, electric vehicles, and nuclear reactors
- Holmium – used in magnets, and nuclear reactors
- Erbium – used in lasers, and fiber optic cables
- Thulium – used in lasers
- Ytterbium – used in displays, x-ray machines, and fiber optic cables
- Lutetium – used as a catalyst in refineries

In addition, Yttrium and Scandium are often classed in the same group – although they are not technically REEs. But they are often found together in the same ore deposits as the lanthanide elements and demonstrate similar properties. Yttrium is used in radars and, when mixed with other alloys, in smartphones and other devices. Scandium is used in fuel cells and to make alloys used in jet airplanes.

Silicon production by country

Source: World Population Review

	Silicon production 2023 (1000 tons)	Silicon production 2022 (1000 tons)	Silicon production 2021 (1000 tons)
China	6600	6670	6400
Russia	620	626	644
Brazil	390	391	389
Norway	340	339	361
Iceland	130	128	111
Kazakhstan	125	101	122
France	11o	121	127
Malaysia	80	91	85
Bhutan	80	75	85
India	60	59	59
Germany	60	62	63
Spain	56	52	60

China has 38% of global reserves of REEs, followed by Vietnam with 19%, Brazil with 18%, and Russia with 10%.

In comparison, the U.S. has just 1% of global reserves of REEs. The U.S. imported around $90 million of REEs in 2023, 72% of which came from China – although that is a 7% decrease on 2022 imports[7].

China also leads the way in the production of REEs.

Silicon

Silicon is the bedrock of the modern semiconductor industry. It can conduct electricity under certain conditions, and these properties can be tuned by mixing it with other materials. But it also has unique electrical properties that allow it to switch between conducting and insulating states, making it ideal for integrated circuits, memory applications, and computer chips.

It has a stable structure and is the second most abundant element on Earth, after oxygen.

It's made from sand, which is mostly silicon dioxide. It is also cheap to extract and purify into single crystal ingots, which are then used to produce silicon wafers.

It has good switching speeds, low resistance, and negligible reverse leakage current flow, and is stable at high temperatures. Silicon is also the major component in solar cells (photovoltaic cells), which means that it is vital for the transition to cleaner energy technologies.

Other key Silicon-producing countries include Spain, India, Poland, Australia, Ukraines, and Canada. Spain, India, Poland, Australia, Ukraine, and Canada. China is by far the world's leading Silicon producer due to its robust quartz preserves and well-run infrastructure. Those two factors combined allow China to produce vast quantities of Silicon and sell it globally at competitive prices.

Synthetic alternatives to critical minerals

Given the concentration of many advanced minerals in single countries, there is a high risk of supply chain disruption, and price hiking. That's why many Western countries, where supplies are in short supply, are launching programmes to discover and develop synthetic alternatives.

For example, in October 2024, the U.S. Department of Commerce's National Institute of Standards and Technology (NIST) issued a Notice of Intent (NOI) launched a $100 million-funded open competition to create new sustainable semiconductor materials and processes using AI. The U.S. is heavily reliant on imports, particularly from Southeast Asia (including China), for the critical minerals it uses to develop devices, EV batteries, and clean technologies.

The NIST competition, under Washington's CHIPS for America initiative, encourages informed academic and industry research to experiment with AI to develop novel, sustainable semiconductor materials and processes that can be designed and adopted within five years. Washington hopes that generative AI can help to quickly discover new sustainable materials as alternatives to rare and critical elements, while protecting the environment.

Likewise, the EU and Japan recently agreed to cooperate in the discovery and development of synthetic materials for future applications (see Japan and the European Union agree closer cooperation to develop advanced materials as they look to de-risk from Chinese supply chains).

According to the U.S. Geological Survey, China mines over 60% of the world's natural Graphite and produces over 50% of the world's synthetic graphite. It also dominates processing, with Chinese organizations producing 99% of spherical Graphite and 93% of all graphite anode materials. In 2024, Beijing placed an export ban on graphite, which prompted Washington to announce that U.S. producers needed to start building a domestic supply chain for producing synthetic Graphite.

Applications for Critical Minerals

Batteries

According to the IEA's annual Global EV Outlook report, more than 10 million electric cars were sold globally in 2022, with sales forecast to grow by another 35% in 2023 to reach 14 million[8]. It highlights that the move away from internal combustion engines and our reliance on fossil fuels in transportation is well underway, with EV-based automobiles accounting to nearly one-fifth of all new sales in 2023.

Since 2022, electric cars' share of the overall car market has risen from around 4% in 2020 to 14% in 2022 and was predicted to increase to 18% in 2023. While cars lead the way, electric buses and trucks are expected to follow. According to the IEA, there are currently three major markets for EVs – China, Europe, and the U.S. China accounted for 60% of global electric car sales in 2022, meaning that more than half of all electric cars on the road worldwide are in China. China's dominance in EV battery manufacturing reflects its dominance in mining and extraction of the minerals used in EV batteries.

Europe and the U.S., the second and third largest markets, both saw strong growth with sales increasing 15% and 55%, respectively, in 2022. Policy programmes, such as the Fit for 55 package in the European Union and the Inflation Reduction Act in the U.S., are expected to further increase market share for electric vehicles through this decade and beyond. By 2030, the average share of electric cars in total sales across China, the EU and the United States is forecast to rise to around 60%. The U.S. is actively developing domestic battery supply chains to meet some of its demand.

Other regions are also seeing significant growth. For example, electric car sales more than tripled in India and Indonesia in 2023, and more than doubled in Thailand. The share of electric car total sales rose to 3% in Thailand, and 1.5% in India and Indonesia. In India, a government $3.2 billion incentive programme, which has attracted investments worth $8.3 billion, is expected to increase battery manufacturing and EV rollout significantly in future years.

China dominates the EV manufacturing industry, accounting for a 35% share of global electric car exports in 2022. However, Western nations are trying to counter this. The EU's Net Zero Industry Act aims for nearly 90% of annual battery demand to be met by domestic battery manufacturers, while the US Inflation Reduction Act is aimed at strengthening domestic supply chains for EVs, batteries and minerals.

The main advanced minerals used in EV battery production include:

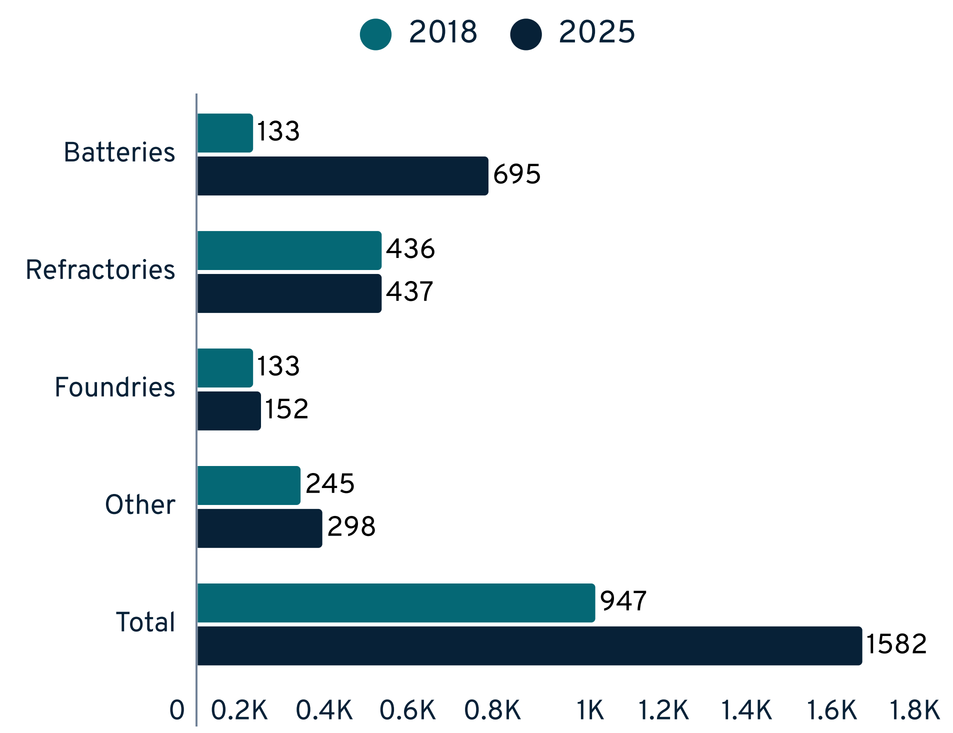
- Lithium
- Cobalt
- Manganese
- Nickel
- Iron
- Graphite

Lithium, Nickel, Cobalt, Manganese and Graphite are crucial to battery performance, longevity and energy density. Lithium-ion based batteries dominate the market, accounting for around 60% of the EV battery market in 2022[9]. EVs require 6-times more critical minerals to produce compared to a conventional car. EVs will also drive a 20-times increase in demand for Graphite, Cobalt, and Nickel. The IEA also predicts a 13-times increase in demand for Lithium between 2020 and 2040 due to the growth of the EV market.

Lithium batteries have a high energy density (they can store a lot of power in a small space), high heat resistance, and high energy efficiency. Lithium iron phosphate (LFP) batteries are gaining popularity because they're less expensive to produce and don't require the use of cobalt or nickel.

Global graphite demand 2018 vs 2025 forecast

Source: Roskill; DERA



They primarily contain Lithium, Iron, Graphite, and Aluminium, with Graphite considered an essential mineral (China currently produces around 90% of LFP batteries and the components for them.

The IEA also predicts an estimated $239.4 billion market value for EV batteries by 2030, growing at a CAGR of 9.6% from 2020 – 39.2% of which it forecasts will come from the Asia Pacific region[10].

The production of EVs is estimated to use 7-8 times more critical minerals than a conventional car, meaning that global demand is set to soar over the next few decades.

Clean Energy Technologies

Global deals, such as the Paris Agreement which aims to limit the global temperature rise this century to well below 2°C, mean that demand for critical minerals from the clean energy sector is set to grow significantly over the next few decades. That's on top of the transition to EVs and clean fuel vehicles.

While emissions from clean energy technologies account for just 6% of those caused by fossil fuel usage, the critical mineral requirement for clean energy technologies is high[11] . Low-carbon technologies, such as solar photovoltaic (PV) cells, wind turbines (and the magnetic motors that drive them), and geothermal, are more mineral intensive relative to fossil fuel technologies.

The World Bank estimates that the production of Graphite, Lithium, and Cobalt will need to increase by 450% by 2050 (from 2018 levels) to meet this demand for the energy transition. It means that any disruption to global supply chain could have significant ramifications for the scale and speed of this transition.

THE IEA FORECASTS $239.4 BILLION MARKET VALUE FOR EV BATTERIES BY 2030

Some of the critical minerals used in clean energy technologies include (but are not limited to):

- Lithium, nickel, cobalt, manganese and graphite – which are crucial to battery performance.
- Rare Earth Elements – which are essential for the permanent magnets used in wind turbines and EV motors.
- Aluminium and Copper – which are vital for the electricity networks and infrastructure that moves energy around.

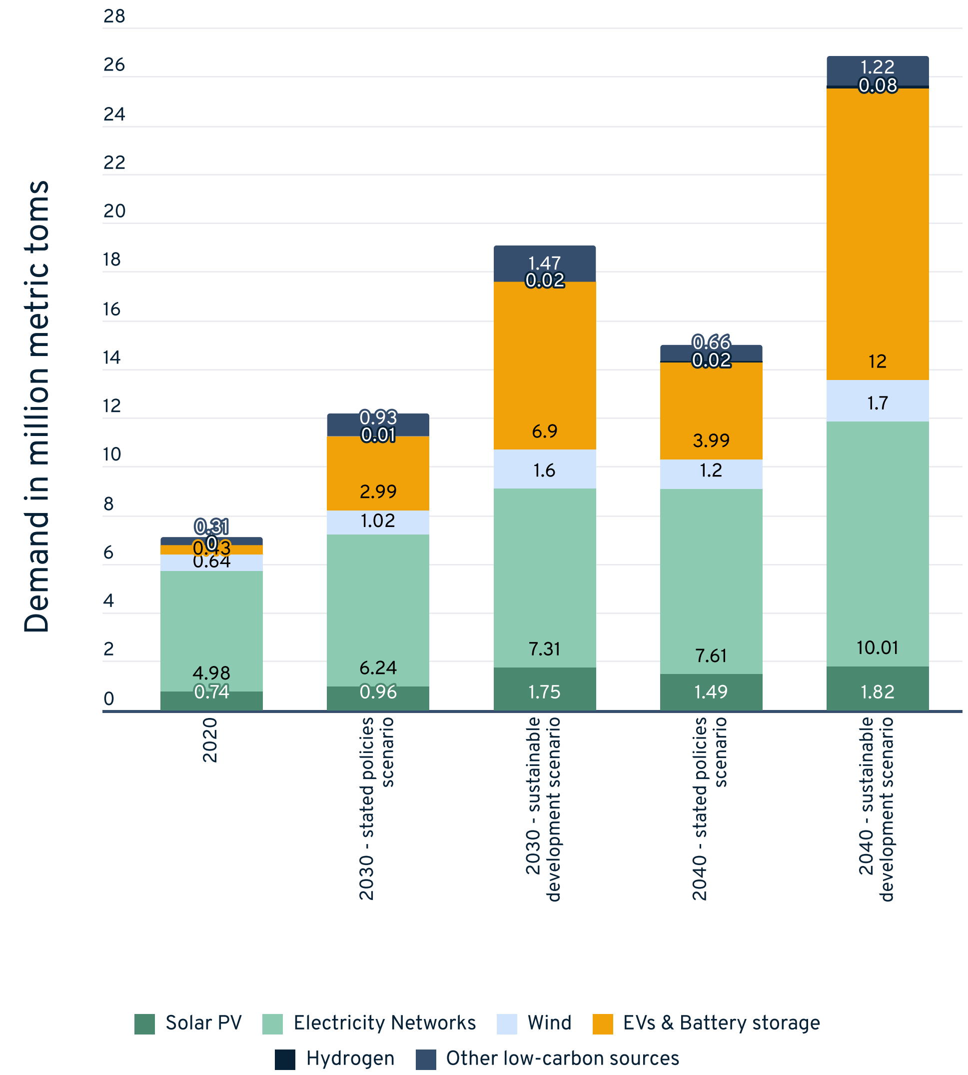
REEs are also essential for the permanent magnets that are vital for driving wind turbines. Electricity networks, meanwhile, need significant amounts of Copper and Aluminium. According to the IEA, this will lead to a six-fold increase in demand for critical minerals – in particular Copper, Lithium, Nickel, and Cobalt – by 2050 with their market value reaching $400 billion, which is greater than all the coal extracted in 2020[12].

According to the IEA an onshore wind plant, for example, requires nine times more mineral resources than a gas-fired plant. It also adds that, since 2010, the average amount of minerals needed for a new unit of power generation capacity has increased by 50% as the share of renewables has risen.

To achieve the aims of the Paris Agreement and Sustainable Devlopment Goals, UNEP and the UN have been working with countries to build and share critical mineral supply chains and will develop the UN Framework on Just Transitions for Critical Energy Transition Minerals, which is expected by the end of 2024. During COP 28, the UN Secretary-General also set up the Panel on Critical Energy Transition Minerals, highlighting their significance in the global energy transition.

Mineral demand for clean energy technologies worldwide in 2010 and 2020, with forecasts for 2030 and 2040, by technology and scenario

Source: IEA



The IEA estimates that to meet the Paris Agreement goals total demand for Copper and REEs rises by 40% over the next two decades, 60%-70% for Nickel and Cobalt, and nearly 90% for Lithium.

It means that the market value for these critical minerals, as well as Graphite is forecast to double from around $325 billion today to $770 billion by 2040 in the Net-Zero Scenario.

However, on the flip side, recycling of Copper, Lithium, Nickel, and Cobalt from spent batteries could reduce primary supply requirements by around 10%, with those countries that have widely deployed clean energy technologies benefiting even further through economies of scale[13].

IN ORDER TO MEET PARIS AGREEMENT GOALS DEMAND FOR COPPER AND REES WILL RISE BY 40% NICKEL AND COBALT DEMAND WILL RISE BY 60% AND LITHIUM DEMAND WILL RISE BY 90% OVER THE NEXT TWO DECADES

Semiconductors

Massive growth expected

Semiconductors have been at the vanguard of technological advancement for decades. Now, advanced semiconductors, and even quantum chips, are being developed as tools for gaining and retaining global competitive advantage, security, and exploration. Leading-node logic chips (those under 14 nanometers), also known as ‘advanced chips’, require over 300 hundred materials that enable their design, production, printing, etching, fabricating, and the components that they consist of.

The semiconductor industry is expected to grow from $580.35 billion in 2024 to $882.09 billion by 2029, a CAGR of 8.73% over the period[14]. Shipment volumes are expected to grow from 1.27 trillion units in 2024 to 2.07 trillion units by 2029 (a CAGR of 10.32%). The main driver is the ownership of smartphones, as the population increases, however advanced semiconductors for uses in applications such as AI, Machine Learning, and quantum computing are expected to drive the market further.

The Semiconductor Industry Association (SEMI), a global association for the industry, states: “In many instances, there are no known alternatives to these materials that satisfy our functional needs, and therefore a secure and continuous supply of critical materials is of critical importance to our industry.”

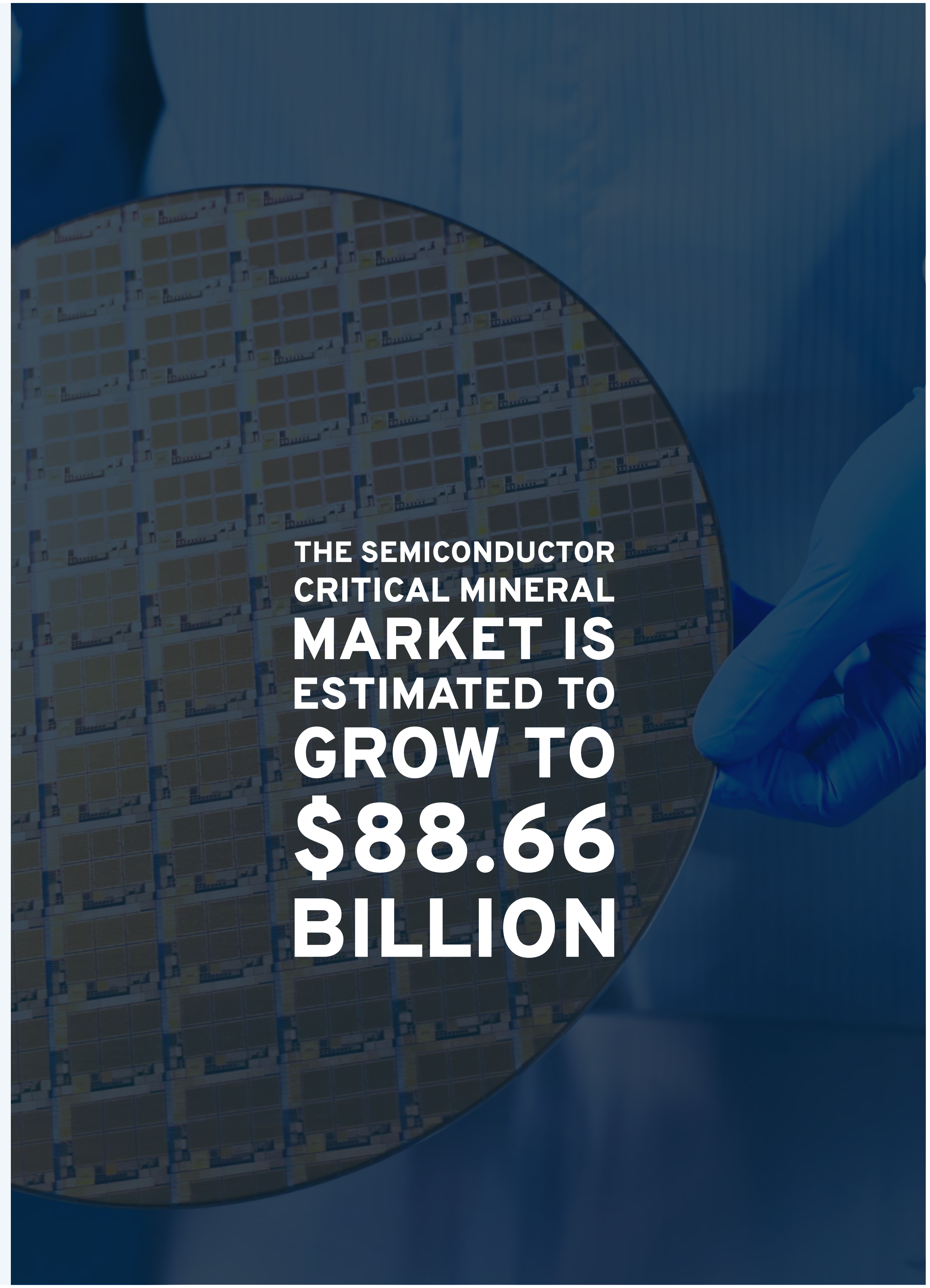
It estimates that the fabrication materials market is worth just over $40 billion currently, but notes that this is expected to rise significantly due to on-going digitization of emerging economies, the rise of remote working that requires smartphones, laptops, and other devices, 5G deployments, as well for defense, military, and aerospace applications. Some analysts predict the market for semiconductors to reach $1 trillion by 2030[15].

Due to the difficulty in creating advanced semiconductors, it requires a global supply chain, with many countries specializing in specific aspects of the design and production. For example, SMTC in the Netherlands accounts for almost all global fabrication machines that are required to produce them, while Taiwan produces an estimated 80% of the world's advanced chips.

This creates the potential for significant supply chain disruption. It also means that their production – and the supply of critical mineral they require – has become a global geopolitical battleground.

Silicon is the primary semiconductor raw material for wafer fabrication and is vital in the chip production process. It is the second most abundant element (28%) in the Earth's crust. However, doping Silicon with other critical minerals gives it different properties. Some of the most used doping minerals include Arsenic (0.00018% rarity), Bismuth (0.0000008%). Boron (0.001%), Gallium (0.0019%), Germanium, and Indium (0.000025%). It is the doping minerals that present the highest supply chain disruption factors. Fluorspar, Hydrogen fluoride (HF), is also essential for the etching process of semiconductors.

As a result, the semiconductor critical mineral market is estimated to reach $70.30 billion in 2023 and is expected to grow to $88.66 billion within the next five years, according to Mordor Intelligence – a CAGR of 4.75%.



While estimates vary, JP Morgan estimates that China could have up to 94% of the world's Gallium resources and 83% of Germanium supplies (see blog 'Pamir opinion: U.S.-China competition in building critical elements supply chains intensifies').

On 3 July 2023, China set restrictions, starting on 1 August 2023, on exports of Gallium and Germanium. The U.S. is also 100% reliant on China for its Arsenic, making it a significant supply chain risk.

Germanium is another significant critical mineral in the production of semiconductors. Germanium wafers can be used as a substitute for Silicon wafers, and offer greater thermal resistance, which means they are more suitable for smaller and faster advanced chips – it enables more power than Silicon from a smaller size.

It is used in minimal amounts, but can change the characteristics of Silicon-based chips. Although China is the leading supplier, Canada has sufficient supplies, or at least production capabilities.

CHINA IS THE LEADING PRODUCER OF AT LEAST 16 OF THE 50 LISTED CRITICAL MINERALS

Conclusion

The supply of advanced minerals embraces a global supply chain, which is often highly specialized (in terms of production) or concentrated in specific regions. This creates risk to the global technological economy and supply of goods, such as devices, batteries, and clean energy technologies. In each region, any drop in production, geopolitical tensions, or war could have a significant impact on the supply chain and therefore global production of devices, components, and technologies.

Countries that do not have natural resources, the U.S. being one of them, are reliant on their supply. China has already restricted the export of Gallium and Germanium, which are essential for the production of semiconductors. Likewise, the Ukraine-Russia war has strained the supply chain of Neon, which is used in the lasers that etch semiconductor wafers. Meanwhile, The Democratic Republic of Congo is a politically unstable nation that supplies the majority of the world's Cobalt, which is vital for the production of Lithium-ion batteries.

These represent just a few examples of the fragile nature of the global critical minerals supply chain. Many countries, including the U.S., are trying to build domestic supply chains for chips, batteries, clean energy technologies, and so on – via the CHIPS and Science Act 2022, for example – but without the domestic resources of critical minerals required to manufacture components, they still remain vulnerable.

The U.N.'s initiatives to create stable and fair supply chains for everyone are to be credited, but they are still vulnerable to unpredictable circumstances. Likewise, cooperation between regions, such as the EU and Japan (for synthetic graphite), to collaborate on developing synthetic alternatives are a positive move, but could take years for any substantive development to be created.

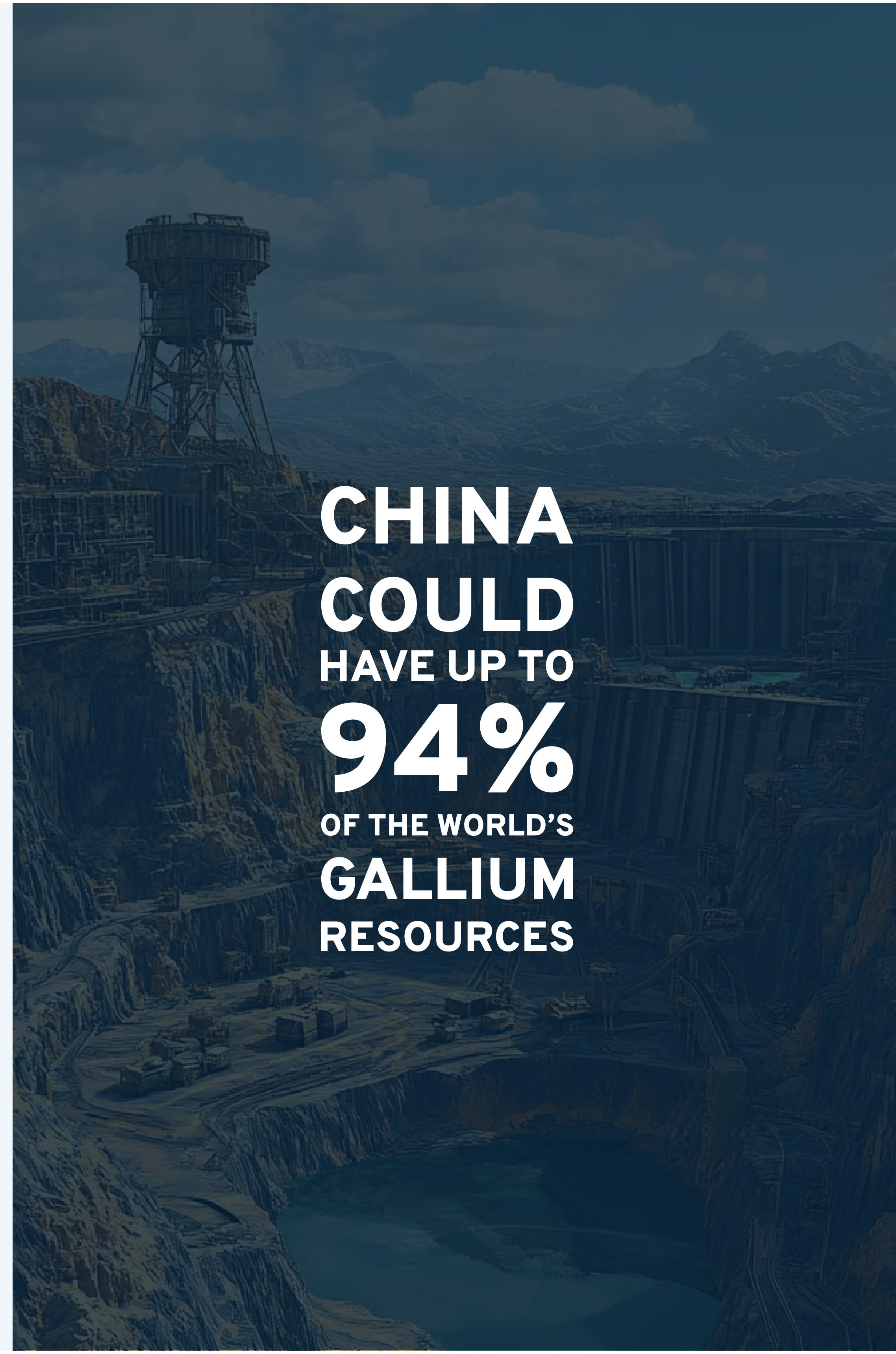
Like many countries in the developed Western world, natural resources are in short supply. The U.S. in particular is highly reliant on imports of critical materials. Conversely, China remains the leading producer of at least 16 of the 50 U.S.-listed critical minerals.

Other countries, including Australia, the Democratic Republic of Congo (DRC), and South Africa, also supply additional critical minerals to the world.

Recycling of these minerals can help the situation, although it is estimated that this would supply only around 10% of the required advanced minerals in future. The U.S. is highly aware of its reliance on foreign imports of these minerals – in 2021, for example, the Biden administration issued Executive Order 14017, which directs federal agencies to identify potential threats to the supply chain of strategic minerals, noting REEs as essential, and ways to to mitigate and address potential threats. The 2020 Energy Act, meanwhile, requires updates to the list of strategic minerals every three years, including recycling trends.

Taiwan and the Netherlands are also essential cogs in the global supply chain of semiconductors. Netherlands-based ASML Holding produces almost 100% of chip fabrication machines and in June 2023, after significant pressure from Washington, the company applied new export controls that require Chinese companies to apply for a licence to ship deep ultraviolet lithography systems. Taiwan, meanwhile, supplies almost all of the world's advanced semiconductors, and the U.S. has made clear signs, including bilateral trade agreements, that it would like to align further with Taiwan – the U.S. is already Taiwan's most important arms supplier, with a new order of around $2 billion of missile systems announced in October 2024[16].

Arsenic, Palladium, Gallium, Germanium, Cobalt, and REEs, among others are critical for the production of essential technologies. However, the global supply chain remains vulnerable to disruption with many of these strategic minerals highly concentrated in specific regions. A pragmatic, political, diplomatic approach to minimizing risk seems the only viable option currently. In time, alternatives may be found, but for the foreseeable future, there remains significant vulnerability to the supply of many of these critical minerals.



References

1. https://pubs.usgs.gov/periodicals/mcs2024/mcs2024-arsenic.pdf
2. https://www3.weforum.org/docs/WEF_Making_Mining_Safe_2020.pdf
3. https://pubs.usgs.gov/periodicals/mcs2024/mcs2024-cobalt.pdf
4. https://bit.ly/3EFKOWp
5. https://bit.ly/430gUnF
6. https://bit.ly/4jJFzEg
7. https://pubs.usgs.gov/periodicals/mcs2024/mcs2024-rare-earths.pdf
8. https://www.iea.org/reports/global-ev-outlook-2023
9. https://www.theecoexperts.co.uk/electric-vehicles/battery-minerals
10. https://www.iisd.org/system/files/2023-09/critical-minerals-primer-en.pdf
11. https://pubdocs.worldbank.org/en/961711588875536384/minerals-for-climate-action-the-mineral-intensity-of-the-clean-energy-transition.pdf
12. https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/executive-summary
13. Ibid.
14. https://www.mordorintelligence.com/industry-reports/semiconductor-industry-landscape/market-size
15. https://www.wsj.com/tech/ai/sam-altman-seeks-trillions-of-dollars-to-reshape-business-of-chips-and-ai-89ab3db0
16. https://www.reuters.com/world/taiwan-trumps-protection-money-may-mean-new-early-big-ticket-arms-deals-2024-11-07/

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