Global Critical Minerals Outlook 2026

INTERNATIONAL ENERGY AGENCY

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Abstract

Critical minerals have rapidly moved to the heart of global discussions on energy and economic security. Their indispensable role across several energy technologies as well as other industries of strategic importance such as high-tech manufacturing, AI and digital systems, and aerospace and defence, have underlined the need to enhance the resilience and diversity of their supply chains.

The 2026 edition of the IEA's annual Global Critical Minerals Outlook includes a detailed assessment of the latest market, investment and technology trends, along with their implications for critical mineral security. The report provides a snapshot of recent industry developments and offers medium- and long-term projections for the supply and demand of key energy minerals, taking into account the latest policy and technology developments. This year's report will also include several areas of special focus: strategic minor minerals with applications beyond energy, nuclear supply chains and the role of Latin America in global mineral supply chains.

As countries increasingly call on the IEA to deepen its work on critical mineral security and supply chain diversification – as reflected in the declaration by IEA Ministers and G7 leaders – the 2026 *Outlook* will include a new chapter examining the policy implications of building resilient and diversified supply chains, including emergency preparedness, policy and market frameworks, and technology, equipment and workforce issues.

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Executive summary

Executive summary

Critical minerals have moved to the forefront of energy, economic and national security agendas in recent years. This reflects growing concerns about supply chain concentration and the expanding use of trade restrictions. Although the adequacy of supply remains a major concern, notably for copper, governments are now placing greater attention on resilience, diversification and the security of supply in an increasingly complex geopolitical environment.

Critical mineral prices rebounded in 2025 and early 2026 after declining in recent years. Driven by tight supply conditions, prices for base metals such as aluminium, copper and tin rose by one-third between January 2025 and April 2026, with copper prices reaching record highs. Battery material prices also recovered following a downturn in 2023 and 2024. Lithium prices more than doubled amid strong demand from energy storage applications and constrained supply, while cobalt prices rose by around 130%, largely due to export restrictions imposed by the Democratic Republic of the Congo (DRC). Prices for strategic minor minerals – those with relatively small market sizes but critical roles across the energy, high-tech, aerospace and defence sectors – had already started rising in 2024 and continued to rally through 2025 and early 2026 amid new export controls and robust demand growth. Prices for these minerals more than doubled, with prices for tungsten surging sixfold. Export controls have also led to a sharp price divergence between Chinese markets and those in other regions. In Europe, prices for gallium and heavy rare earths (dysprosium and terbium) are currently around five times higher than Chinese domestic prices, and germanium prices are almost three times higher – highlighting the challenges of securing supply outside the dominant supplier.

Supply concentration in refining continued to edge higher for most minerals in 2025, with rare earths the notable exception. Over the past two years, the top refining countries – Indonesia for nickel and China for other key energy minerals – accounted for over three-quarters of total growth in refined supply. In several markets, including for manganese, nickel and graphite, virtually all supply growth came from the dominant supplier. Rare earth refining was an exception, with new projects in the United States and production increases in Malaysia leading to a modest decline in concentration, highlighting the role of targeted policy and investment support in enabling diversification. Excluding rare earths, the average share of the top refining country rose to 72% in 2025, up from 70% in 2023.

Gaps between projected demand and anticipated supply over the next decade have narrowed for copper and lithium, but new risks have emerged for cobalt due to policy shifts in major producers. Based on the project pipeline, supply deficits for copper and lithium are set to persist through 2035, although the outlook has somewhat improved. For copper, the projected supply deficit in 2035 has narrowed from around 30% in last year's *Outlook* to 25% as new projects advance, particularly in the DRC and Zambia. By contrast, a projected supply gap has emerged for cobalt due to the DRC's new export quota. This development underscores how policy changes by major producers can rapidly reshape the global supply outlook in markets with high levels of geographic concentration.

New export controls have turned supply concentration risks into reality. The number of mineral tariff codes subject to Chinese export controls has tripled since 2023. Other countries also introduced new restrictions, including the cobalt export quota by the DRC and trade restrictions by Zimbabwe for lithium and Mozambique for graphite. The recent proliferation of export controls has transformed concerns around high supply concentration from a theoretical vulnerability into an immediate economic security challenge.

2025 marked the year when the economic risks of highly concentrated supply chains materialised at scale. In April 2025, the Chinese government introduced major export controls on seven heavy rare earth elements, with significant impacts across downstream industries, forcing some automakers to reduce utilisation rates or temporarily halt operations. In October 2025, they were further expanded, extending proposed restrictions to internationally-made products containing rare earths sourced from China or produced using Chinese technologies. Although the expanded measures were suspended for one year until November 2026, the vulnerabilities remain. Their full implementation could put an estimated USD 6.5 trillion per year of downstream production outside China at risk across the automotive, high-tech, defence and energy sectors. In October 2025, China also announced export controls on key battery supply chain chokepoints, including cathode materials, cathode precursors and graphite anode materials, as well as on battery manufacturing equipment and technologies. If battery-grade graphite trade were fully disrupted, over USD 300 billion per year of downstream production outside China would be at risk. These developments underscore how small volumes of critical minerals underpin vast economic value and highlight the fragility of highly concentrated supply chains.

Strategic stockpiles can provide an important short-term buffer against supply disruptions. The largest-ever oil stock release by IEA Member countries in March 2026 amid the Middle East conflict helped mitigate market disruptions. While critical mineral markets differ from oil markets, strategic stockpiles can still provide an important emergency buffer, helping safeguard industrial activities during supply shocks. For the 11 high-risk materials assessed by the IEA, the net annual cost of stockpiling for countries outside the dominant supplier is estimated at less than USD 900 million, modest relative to the potentially major economic impacts of disruptions.

The conflict in the Middle East has provided another stark reminder of the vulnerabilities affecting mineral supply chains. While the key impacts of the conflict centred on oil and gas markets, there has also been considerable impact on mineral and metal markets from the closure of the Strait of Hormuz, notably for aluminium, sulphur and helium. The Middle East accounts for around 8% of global aluminium production, and production curtailments at several regional smelters added strain to an already tight market. The region also supplies around one-quarter of global sulphur and half of global seaborne sulphur trade passes through the Strait of Hormuz. Sulphur is a key feedstock for sulphuric acid, which is essential for fertiliser production and the processing of a range of critical minerals such as copper, lithium, cobalt, nickel and rare earths. Disrupted sulphur supplies prompted China to curb sulphuric acid exports in May 2026, creating ripple effects across both mineral and fertiliser value chains. The resulting surge in acid prices increased production costs for several critical minerals with acid costs overtaking energy costs to become the largest cost component in some cases.

Critical mineral investment declined by 9% in 2025, ending several years of growth. Amid rising geopolitical tensions and price volatility, investors became more cautious despite strong underlying demand. Battery metals saw the sharpest pullback, with capital spending falling by more than 20% – the largest decline in over a decade – and lithium companies cutting investment by around 40%. By contrast, spending by copper-focused companies increased by 8%, reflecting confidence in copper's long-term prospects.

Exploration spending also declined by more than 10%, with modest growth in spending on uranium and steady spending on copper offset by around 45% declines in lithium and nickel. Most regions recorded lower exploration spending, although Asia Pacific bucked the trend with a 20% increase. Merges and acquisitions rebounded in 2025, with strong demand for high-quality copper assets driving a 20% increase in overall deal value compared with 2024. Venture capital investment also recovered, increasingly targeting artificial intelligence (AI) technologies that could improve the efficiency of mineral exploration and resource extraction.

Public finance is increasingly being deployed to accelerate critical mineral investment. Governments are taking a more active role in reducing project risks and mobilising private capital. Public finance commitments in advanced economies reached around USD 65 billion in 2025, over four times higher than in 2023. However, a considerable gap remains between commitments and actual disbursements, which will ultimately determine their impact on supply diversification.

Analysis of project pipelines reveals a structural imbalance in efforts to promote supply chain diversification, with refining and downstream capacity lagging behind mining. Many projects are being developed outside the dominant supplier, but investment remains concentrated in upstream projects compared with refining and manufacturing capacity. In rare earth supply chains, existing and announced refining capacity in geographically diversified regions is equivalent to around two-thirds of expected mined supply by 2035, while planned magnet production represents only one-third. A similar pattern is evident in battery materials, where planned cathode production capacity is only about one-third of projected lithium mining capacity. These imbalances underscore the need for a more balanced approach to development across value chains.

There is a strong case for greater policy attention to strategic minor minerals. As semiconductors, robotics and AI drive the next wave of innovation, securing supplies of minerals such as gallium, germanium, indium and antimony is becoming increasingly important. Similarly, the aerospace and defence sectors depend on minerals including cobalt, titanium, tungsten and yttrium to meet stringent performance requirements. Based on the IEA's risk assessment framework, gallium, magnet rare earths, yttrium, graphite, tungsten, tellurium, cobalt and germanium rank among the materials most exposed to supply vulnerabilities, due to their high supply concentration, limited substitution potential and critical importance across multiple end-use applications. Many of them are already subject to some form of export restrictions.

Despite extremely high supply concentration today, strategic minor minerals offer promising opportunities to strengthen supply security at a reasonable cost, if accompanied by strong policy support. The markets for these minerals are small, but supply disruptions can carry disproportionate economic consequences. However, diversifying these supply chains typically does not require investment on the scale needed for bulk commodities, and bringing a limited number of high-quality projects online can substantially improve resilience. For example, diversifying magnet rare earth supply chains would require around USD 60 billion of investment over the next decade – modest relative to the huge potential economic cost of supply disruptions.

Greater attention is also needed on the strategic role of base metal smelters. Many strategic minor minerals are recovered as by-products of copper, zinc and lead processing, making base metal smelters essential to the security of these materials. Modern copper and zinc smelters are more than producers of refined base metals – they are strategic processing hubs that enable the recovery of numerous critical by-product minerals, support downstream manufacturing and provide recycling capacity for scrap metal. As such, they warrant greater policy attention as critical midstream infrastructure to ensure supply chain resilience.

The base metal smelting sector is showing increasing signs of stress. Despite rising base metal prices, smelter fees have fallen to historic lows. Benchmark copper smelter fees were settled at USD 0 per tonne in 2026, the lowest level ever agreed in annual negotiations, while spot charges have remained negative since 2024; zinc and lead smelter fees have also turned negative. As this revenue stream has effectively disappeared, smelters have become increasingly reliant on by-product sales, which are inherently more volatile. Tight concentrate supplies, combined with rapid smelter capacity expansion in China, have driven this trend. Since 2005, China has accounted for over 90% of growth in global copper smelting, increasing its share of global capacity from around 15% to

50% by 2025. Smelter utilisation rates have also diverged sharply since 2020, falling below 70% outside China by 2025 while remaining around 85% in China. If these conditions persist, many custom smelters outside China could face growing economic pressure, further increasing supply concentration in strategic midstream capacity.

New projects in geographically diverse regions often face higher costs than incumbent suppliers, complicating investment decisions. Capital costs for refining projects are 20% to over 150% higher outside the dominant supplier, due to higher equipment and construction costs. Operating costs are, on average, around 50% higher, driven by feedstock and energy prices. These cost disadvantages are compounded by technical and skills constraints, infrastructure gaps, and lengthy permitting processes, making it more difficult for market forces alone to bring forward new projects.

Diversification requires well-designed policy tools to reduce investment risks. Measures such as grants, equity participation, concessional loans and loan guarantees can lower upfront financing barriers for capital expenditures. Contracts for difference, price cap-and-floor, offtake backstops and strategic reserves can support operating expenditures and boost project viability by reducing price and volume risks. Price-based mechanisms are particularly well suited to strategically important supply chains with a limited number of viable projects, provided they are carefully designed to balance investment incentives with fiscal exposure, such as through competitive tenders and performance-based eligibility.

Policy tools should be tailored to the characteristics of each mineral market and supply chain segment. Large, liquid markets such as copper are generally best supported through measures that reduce upfront investment risks, complemented by support for enabling infrastructure. By contrast, small, opaque and highly concentrated markets such as rare earths may require targeted measures to mitigate price and volume risks. Across the value chain, mining is typically capital-intensive, making upfront capital support more relevant. Refining projects are more sensitive to cost and margin pressures and may require operational risk-mitigation tools to improve competitiveness.

Countries can combine supply-side support with demand-side measures to strengthen the commercial viability of diversified supply chains. While supply-side policies can help bring new projects online, they may not by themselves create sufficient incentives for manufacturers to source from these suppliers. Demand-side measures can provide predictable demand, improving the bankability of projects and incentive to invest in them. Available tools include diversified sourcing requirements, potentially complemented by fiscal incentives such as tax credits, to encourage procurement from non-dominant suppliers; demand aggregation and facilitated offtake arrangements to build a stable and sizeable customer base; and trade-based measures to narrow price gaps between incumbent and diversified supply. Their effectiveness depends on careful design to balance investment incentives, market efficiency and trade considerations.

Critical minerals generally account for a small share of final product prices, although their cost contribution varies significantly across value chains, with important implications for policy design. While higher mineral prices can substantially increase the cost of intermediate products such as battery cells and permanent magnets, the impact on final products is often limited. For example, critical minerals account for around one-quarter of battery cell costs but only about 3% of the price of an average electric vehicle (EV), while rare earths represent around 40% of permanent magnet costs but less than 1% of a vehicle's value. By contrast, materials such as copper represent a larger share of equipment costs, accounting for around 10-15% of transformer and power cable prices. These differences suggest that, in some supply chains, downstream users may be able to absorb higher material costs more readily, providing scope for diversified sourcing without materially affecting end-product prices. For example, a tripling of rare earth prices would increase the cost of a car by just 0.1%, while a tripling of battery material prices would increase the final price of EVs and storage systems by around 5%.

The additional cost of supply diversification can be viewed as a mineral security premium – a form of economic insurance against major supply risks. Diversified supply often comes at a higher cost, raising the question of how these additional costs should be addressed. These costs could be justified as the price of enhanced economic resilience – a security premium that provides insurance against the risks associated with concentration. As critical minerals generally represent a small share of final product costs, much of the additional cost of diversification could be absorbed with limited impact on consumers, although some intermediate sectors may face greater cost pressures and require targeted support. A shared approach involving governments, industry and consumers could help finance this premium and unlock the investment needed to build more diversified and resilient supply chains.

Successful diversification requires addressing critical gaps in technology, equipment and skilled workforce across the value chain. Diversification is not simply a question of developing new projects; it requires building a broader ecosystem of capabilities. From lithium chemicals and graphite to rare earths and gallium, processing and refining stages rely on complex technologies, specialised equipment and highly skilled expertise that remain concentrated in a small number of countries. Outside the dominant supplier, equipment providers are limited, lead times can be lengthy, and accumulation of technical know-how often takes time and resources. For example, outside China, only a handful of suppliers provide key battery-grade-graphite processing equipment, while ultra-high-purity gallium refining and compound semiconductor manufacturing rely on only one or two specialised equipment suppliers. In rare earth magnet production, grain boundary diffusion – a key technology to enhance magnet performance – is highly patented, with only one equipment supplier outside China and equipment costs that are reportedly more than ten times higher, alongside longer lead times. Recent export controls targeting not only critical minerals but also processing technologies and equipment underscore the importance of closing these capability gaps. Addressing these challenges will require a holistic approach combining innovation, workforce development, policy support and international co-operation to build the technological foundations for diversified and resilient supply chains.

Recycling could play an increasingly important role in easing supply strains, with secondary supply potentially doubling its contribution by 2040. Under today's policy settings, average recycling rates across key energy minerals could rise from around 10% today to close to 20% by 2040. Cobalt and copper already have relatively established recycling streams, with rates expected to increase further to 2040, while rare earth magnet recycling could benefit from growing end-of-life volumes from early generations of EVs and wind turbines. Lithium and nickel recycling remain at an early stage but are expected to expand rapidly. Battery recycling capacity has expanded significantly, but remains highly concentrated, with China accounting for over three-quarters of global pre-treatment capacity and 90% of material recovery capacity. Outside China, Korea is the leading player in material recovery. Realising the full potential of secondary supply will require continued investment in collection and recycling infrastructure and sustained demand for recycled materials.

The renewed expansion of nuclear power is driving a need for significant investment across the uranium and nuclear fuel cycle. Uranium markets have strengthened sharply since 2020, reflecting expectations of substantial growth in demand for nuclear fuel and the need to expand supply. As global uranium requirements rise, new mine projects will need to be successfully developed and brought online. However, the most immediate constraints are emerging further downstream, particularly in uranium conversion, where global capacity is already tight and additional investment will be needed to avoid bottlenecks. Enrichment capacity will also need to expand over the medium term, driven by both nuclear capacity growth and rising demand for higher-assay fuels, such as high-assay low-enriched uranium (HALEU), in some next-generation reactors. Fuel fabrication capacity is generally adequate for conventional fuels, although reactor-specific requirements could create challenges for some technologies. Supply security risks are heightened by concentration across the fuel cycle, with the top three countries accounting for almost three-quarters of uranium mining and around 70% of conversion and enrichment capacity.

Latin America and the Caribbean is well positioned to play a larger role in diversified global critical mineral supply chains. The region is a major producer of base metals, accounting for over 20% of global tin and zinc production and around 40% of global copper mine output. It is also a key producer of strategic minor minerals such as molybdenum, niobium and rhenium. The region is strengthening its position in energy minerals, producing around one-quarter of global lithium supply, with output expected to grow by nearly 50% by the end of the decade. It also holds substantial reserves of silver, graphite, rare earths and other strategic minerals.

However, the region refines only around one-fifth of its mined output of key energy minerals, with the exception of lithium where integrated chemical processing has developed. If lithium, nickel, cobalt, graphite and rare earths were refined locally and two-thirds of copper production were processed within the region, the economic value generated could increase by nearly 50% from today, reaching around USD 220 billion by 2035. Realising this opportunity requires addressing high financing costs, infrastructure gaps in power and water, technology and skills constraints, and strengthening engagement with local stakeholders.

The IEA Critical Minerals Security Programme will continue to serve as a key international platform for advancing global efforts on mineral security. Recent market developments have elevated mineral supply security, placing it at the forefront of energy and economic policymaking. As the Agency's flagship framework, the Programme supports countries in strengthening emergency preparedness and accelerating supply diversification. Building on mandates from IEA Ministers in February 2026 and G7 Leaders in June 2026, the IEA will continue to expand Programme activities to help deliver more resilient and diversified supply chain.

Introduction

Introduction

Critical minerals have rapidly risen to the top of the economic and national security agenda, extending well beyond their role in energy security. Over the past year, critical minerals have become an increasingly prominent feature of geopolitical and industrial policy debates, reflecting growing concerns about supply chain concentration, strategic dependencies and the expanding use of trade and export restrictions. While earlier discussions focused primarily on whether supply could keep pace with rapidly rising demand from energy technologies, the emphasis has increasingly shifted towards the vulnerabilities created by concentrated supply chains, particularly in processing and refining. Although supply adequacy remains a major concern for some materials, notably copper, governments are now placing greater attention on resilience, diversification and security of supply in an increasingly complex geopolitical environment.

Although the risks associated with high supply concentration have long been recognised, the proliferation of export controls by dominant suppliers in recent years has transformed these concerns from a theoretical vulnerability into an immediate economic and industrial security challenge. In particular, the rare earth and magnet export controls introduced by the People's Republic of China (hereafter, "China") in April and October 2025 marked a major turning point. Many downstream manufacturers struggled to maintain operations as they faced difficulties securing the magnets required for key technologies and industrial equipment. Although the stricter export controls announced in October 2025 were subsequently suspended for one year, the episode demonstrated the scale of the risks associated with concentrated supply chains and highlighted the fragility of critical mineral markets.

The conflict in the Middle East in 2026 provided another stark reminder of the vulnerabilities arising from geopolitical tensions and dependence on a limited number of suppliers and trade routes. While the immediate focus centred on risks to oil and gas markets, significant impacts were also felt across mineral and metal supply chains. Disruptions first affected commodities in which the region plays a major role, including aluminium, sulphur and helium, but quickly propagated through interconnected downstream value chains. Sulphuric acid, for example, is a critical input into copper, cobalt and nickel production, while helium is indispensable for semiconductor manufacturing and a range of medical technologies.

These developments have firmly placed mineral supply security at the centre of energy and economic policy making, reinforcing the urgency of diversifying supply chains. Governments are increasingly responding through a growing number of policy initiatives, strategic partnerships and bilateral or plurilateral co-operation frameworks. However, while there is broad consensus on the need for diversification, the question of how to achieve it remains far more complex. New projects in geographically diverse regions often face higher costs than incumbent suppliers, as well as a range of challenges, including technical and skills constraints, infrastructure gaps, lengthy permitting processes and more stringent environmental requirements.

Against this backdrop, this year's *Global Critical Minerals Outlook* aims to provide a comprehensive assessment of evolving market dynamics and the implications of recent geopolitical developments for the future of critical mineral supply chains. The report analyses the latest market, technology and policy trends; examines future demand, supply and investment prospects for key minerals; and assesses potential risks across different stages of the value chain.

In addition to the regular analysis of demand, supply, prices and investment trends, this year's edition places particular emphasis on the actions needed to build resilient and diversified supply chains. It explores short-term emergency preparedness measures, policy and market frameworks to support investment in diversified supply chains, and approaches to overcoming technology and industrial ecosystem bottlenecks.

The analysis also builds on activities under the IEA Critical Minerals Security Programme, the Agency's flagship framework designed to help countries enhance emergency preparedness and accelerate supply diversification. In February 2026, IEA Ministers adopted the Declaration Supporting the IEA's Work on Critical Minerals Security. In June 2026, G7 leaders recognised the Programme's central role as a key platform for international co-operation on mineral security.

Scope of the analysis, scenarios and chapter structure

Critical minerals play a vital role in a wide range of energy technologies, but recent market and geopolitical developments have underscored their strategic importance far beyond the energy sector. Minerals and metals are increasingly recognised as foundational inputs for a broad range of strategic industries, including energy, semiconductors, advanced manufacturing, aerospace, defence and other high-tech sectors. As a result, policy attention has expanded beyond energy-related materials to a wider suite of strategic minerals that underpin economic competitiveness and national security.

The report continues to place greater focus on "key energy minerals", notably such as copper, lithium, nickel, cobalt, graphite and rare earth elements, for which we provide detailed demand and supply projections based on bottom-up modelling. However, reflecting recent developments, its scope has expanded to cover a broader range of critical minerals that play an important role across strategic industries. It examines key market trends for important materials such as aluminium, manganese, phosphate, platinum-group metals, silicon, silver, tin and uranium, as well as strategic minor minerals such as gallium, germanium, antimony and tungsten. While these minor minerals represent relatively small markets in terms of volume, they carry significant economic and strategic importance.

Our assessment of mineral demand in the energy sector includes demand for low-emissions power generation (solar photovoltaic, wind, hydro, nuclear and other renewables), electric vehicle (EV) batteries and battery storage, grid networks (transmission, distribution and transformers), and hydrogen technologies (fuel cells and electrolysers) based on detailed assessments of technology deployment, sub-technology shares, mineral intensity and material efficiency measures. Demand outside the energy sector is projected using historical consumption by end-use application, relevant activity drivers and material intensity trends.

Mineral supply projections are based on a detailed review of all announced projects across the globe. We present two supply scenarios: a base case and a high-production case. The base case includes production from existing assets and those under construction, along with projects that have a high chance of moving ahead because they have obtained all necessary permits, secured financing and/or established offtake contracts. The high production case additionally considers projects at a reasonably advanced stage of development that are seeking financing and/or permits. Neither case considers projects that are in the very early stages of development, nor does it include theoretical projects for which resources might be adequate, but which have not been proposed. For these reasons, our supply projections focus on the period to 2040.

Our forward-looking analysis is based on the main IEA scenarios included in the World Energy Outlook 2025, updated for the latest data on EVs from the Global EV Outlook 2026.

- The **Current Policies Scenario (CPS)** considers a snapshot of policies and regulations that are already in place and offers a cautious perspective on the speed at which new energy technologies are deployed and integrated into the energy system.
- The **Stated Policies Scenario (STEPS)** is an exploratory scenario that provides a sense of the prevailing direction of travel for the energy system, based on today's policy settings. Barriers to the introduction of new technologies are lower than in the CPS, but the STEPS does not assume that aspirational targets are met.
- The **High Demand Scenario (HDS)** assumes a higher level of energy technology development, in line with the levels projected in the Announced Pledges Scenario of the World Energy Outlook 2024. This scenario is included in the report to illustrate the upper range of potential future demand.

All projection results are made available in the IEA Critical Minerals Data Explorer, an interactive online tool that allows users to easily access the IEA's projection data.

Chapter 1 (Market review) offers a snapshot of industry developments in 2025 and early 2026. It reviews major demand, production, investment and price trends for key minerals. The chapter also discusses the latest policy developments and insights based on systematic tracking of the industry's sustainability performance.

Chapter 2 (Outlook for key minerals) provides an outlook for demand and supply of key minerals and related market and policy issues. The chapter provides detailed projections for key energy minerals, including copper, lithium, nickel, cobalt, graphite and rare earth elements. It also reviews key trends for other important materials and includes two special focus areas: (i) minerals critical to high-tech, defence and aerospace industries and (ii) mineral supply chain issues related to nuclear energy.

Chapter 3 (Pathways to resilient and diversified supply chains) provides practical insights into some of the most pressing questions about the development of resilient and diversified mineral supply chains. The chapter is structured around three key themes: how countries can strengthen preparedness against potential supply disruptions; how effective policy and market frameworks can be designed to support investment in diversified assets; and how technology and broader ecosystem bottlenecks can be addressed.

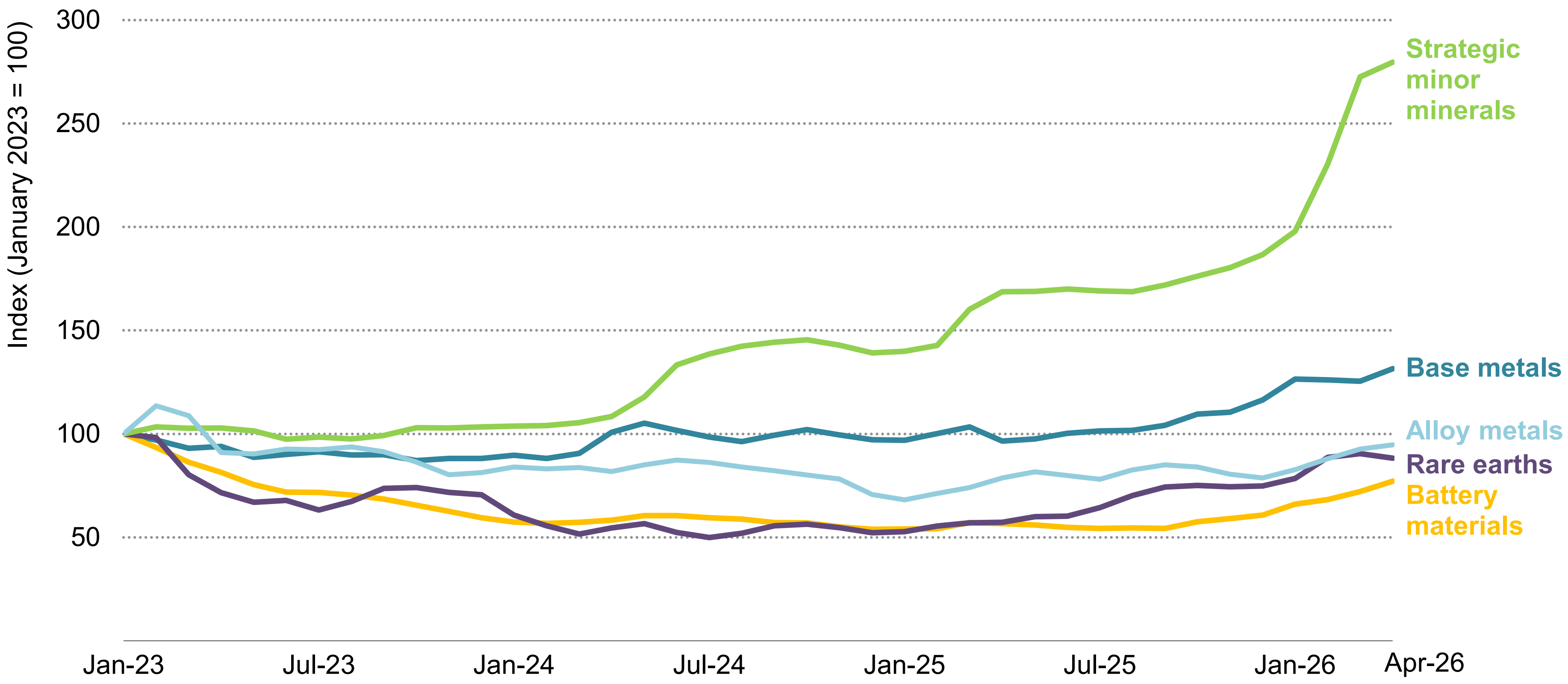
Chapter 4 (Special focus on Latin America and the Caribbean) highlights one of the world's most important mineral-producing regions, examining its current state of play, potential for value addition, and the key challenges and opportunities associated with developing mineral resources in a sustainable and responsible manner.

1. Market review

Mineral market trends

Critical mineral prices rebounded in 2025, while strategic minor minerals continued to rally on export controls and robust demand growth

Price developments for selected critical minerals by category

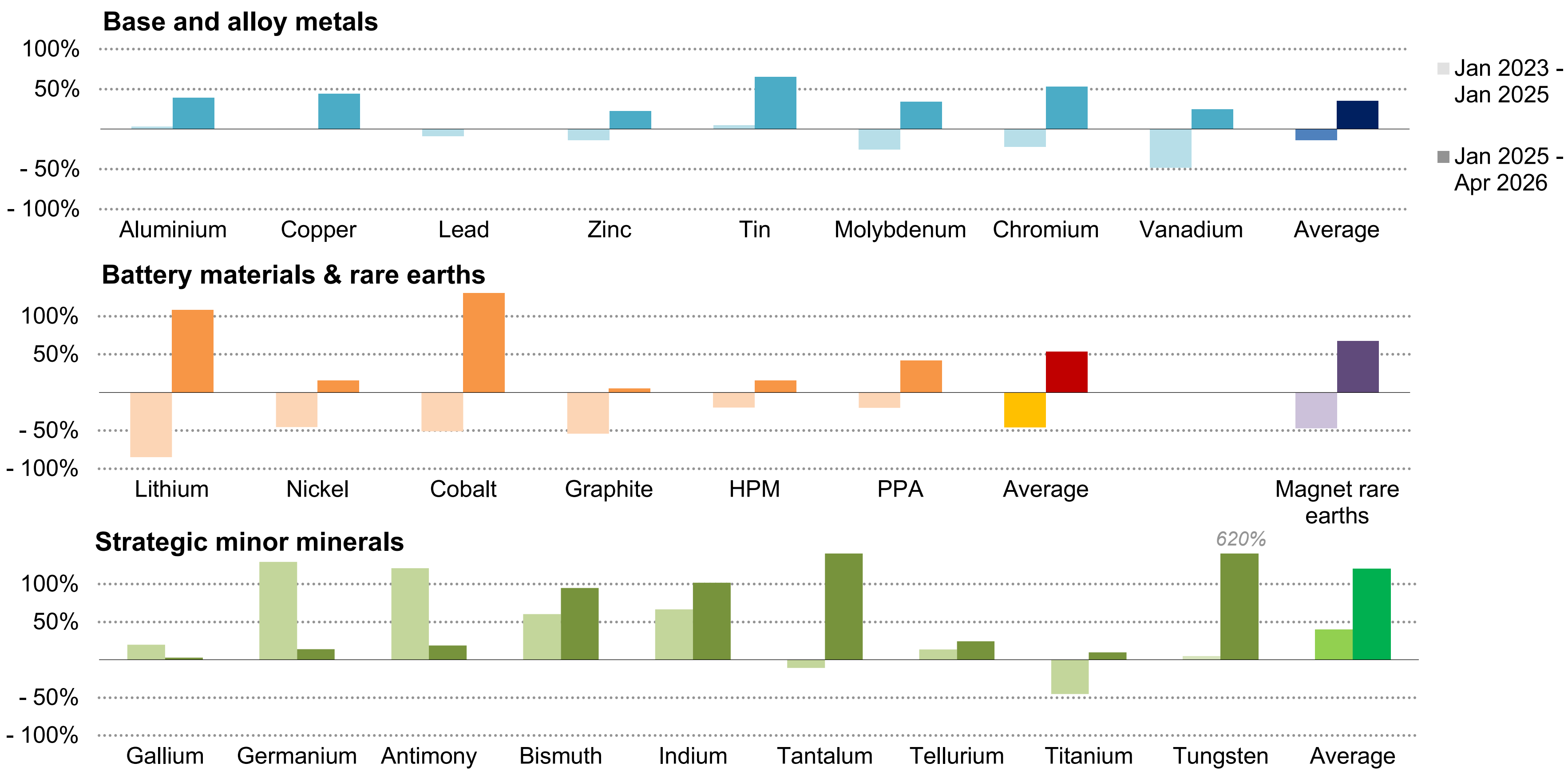


Note: Base metals include aluminium, copper, lead, tin and zinc; alloy metals include chromium, molybdenum and vanadium; battery metals include lithium, nickel, cobalt, graphite, high-purity manganese and purified phosphoric acid; rare earths include four magnet-related elements – neodymium, praseodymium, dysprosium and terbium; strategic minor minerals include antimony, bismuth, gallium, germanium, indium, tantalum, tellurium, titanium and tungsten.

Sources: IEA analysis based on data from S&P Capital IQ, Bloomberg and KOMIS.

Battery materials and rare earth prices are recovering from recent downturns

Change in prices for selected critical minerals

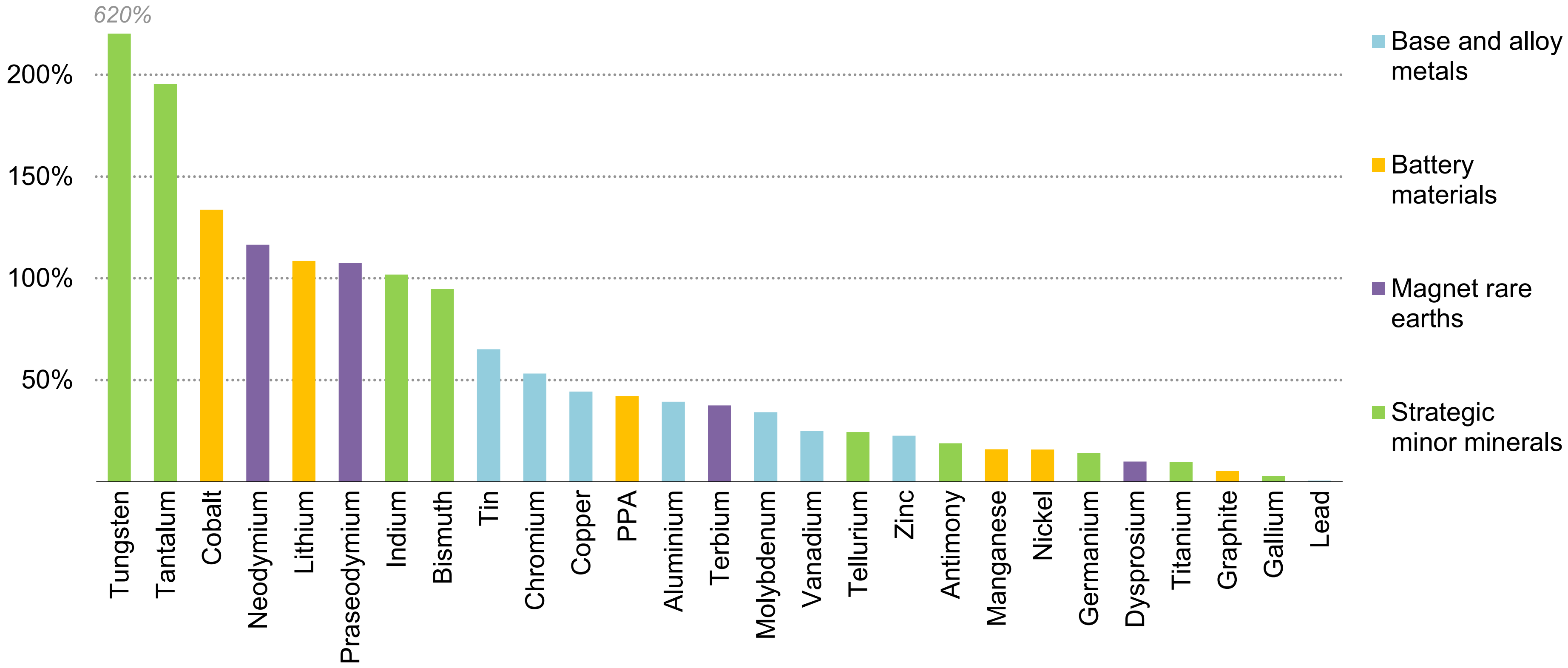


Notes: HPM = high-purity manganese sulphate; PPA = purified phosphoric acid. Assessment based on London Metal Exchange cash prices for aluminium, copper, zinc, tin, nickel and cobalt; China domestic or export prices for molybdenum, graphite, phosphoric acid, manganese sulphate, gallium, germanium, antimony, bismuth, indium, magnet rare earths, tantalum, tellurium, titanium and tungsten; global average prices for lithium carbonate.

Sources: IEA analysis based on S&P Capital IQ, Bloomberg and KOMIS.

Tungsten, tantalum, cobalt, lithium and rare earth elements have recorded the largest price increases since 2025

Change in selected critical mineral prices, January 2025-April 2026

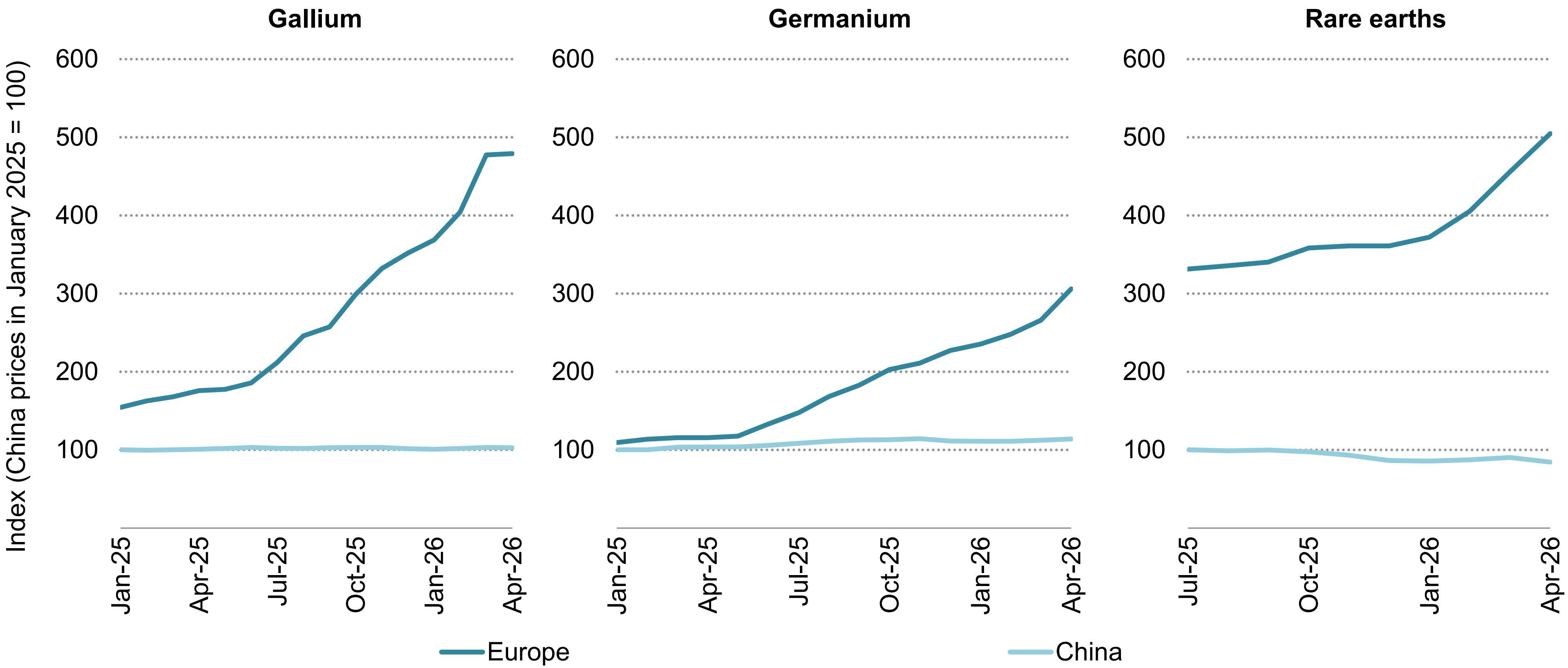


Notes: PPA = purified phosphoric acid. Manganese refers to manganese sulphate. Assessment based on London Metal Exchange cash prices for aluminium, copper, zinc, tin, nickel and cobalt; China domestic or export prices for molybdenum, graphite, phosphoric acid, manganese sulphate, gallium, germanium, antimony, bismuth, indium, magnet rare earths, tantalum, tellurium, titanium and tungsten; global average prices for lithium carbonate.

Sources: IEA analysis based on S&P Capital IQ, Bloomberg and KOMIS.

Price divergence between Chinese and ex-China products has widened for several minerals under export controls

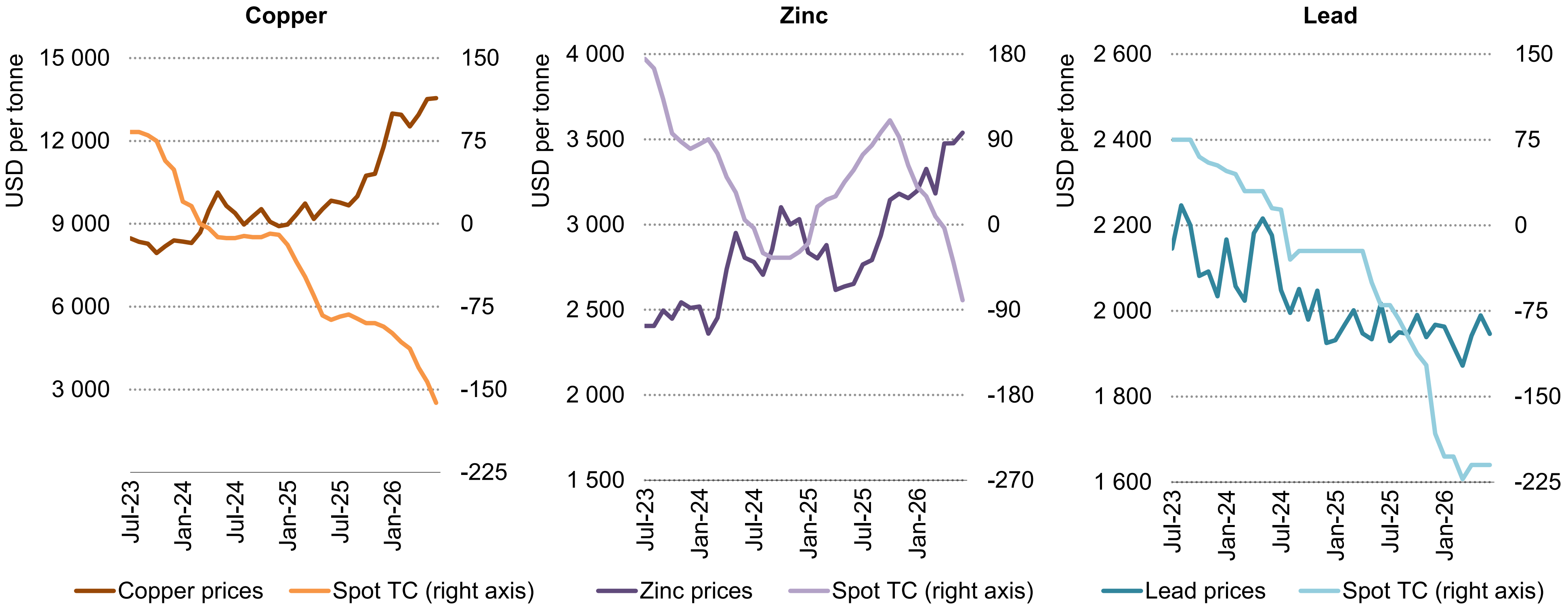
Recent price development for selected minerals in China and Europe



Note: European prices - gallium 99.99%, germanium 99.999%; Rotterdam prices from Fastmarkets; average dysprosium and terbium oxide prices from Benchmark Mineral Intelligence.
Sources: IEA analysis based on Bloomberg, Fastmarkets and Benchmark Mineral Intelligence.

Despite rising base metal prices, treatment charges for smelters have fallen into negative territory in recent years

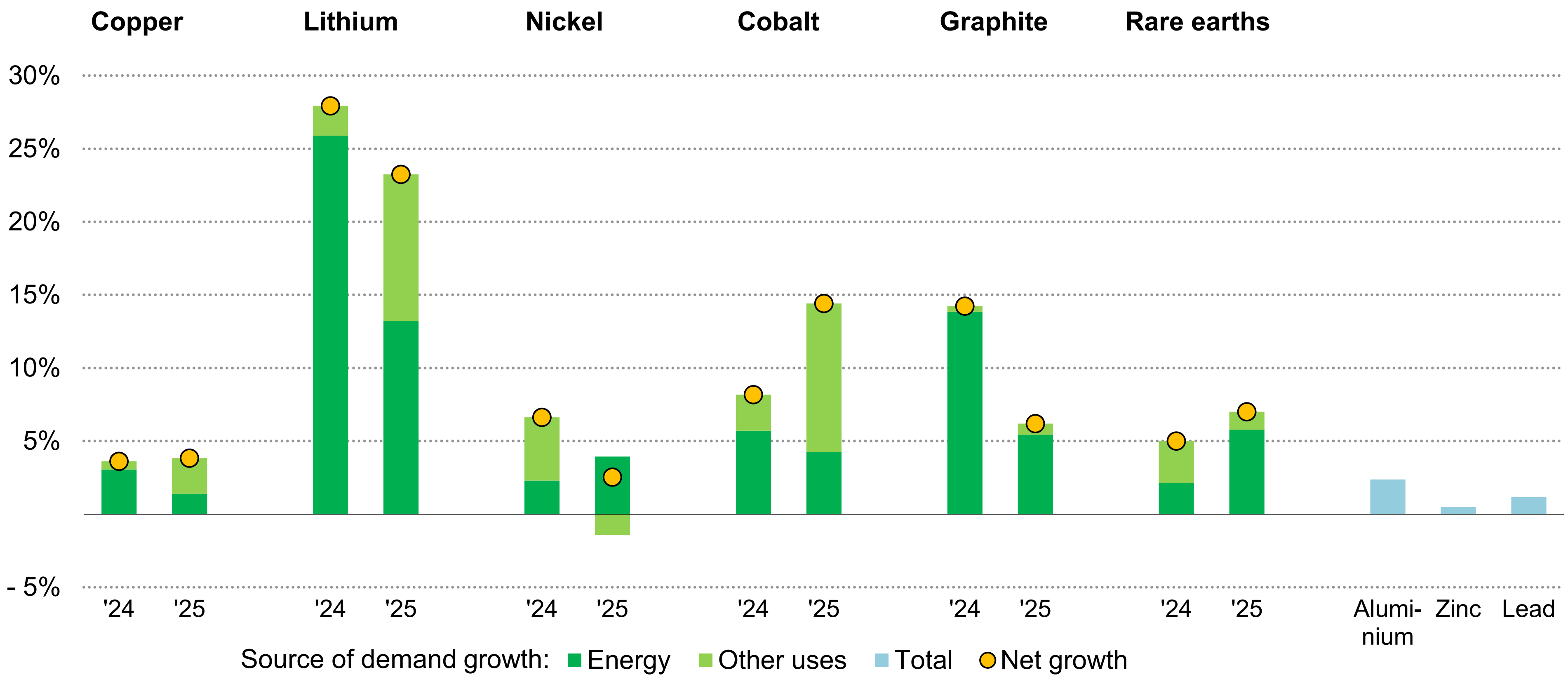
Base metal prices and treatment charges



Note: TC = treatment charges.
Sources: IEA analysis based on S&P Capital IQ, Wood Mackenzie and Fastmarkets.

Demand for key energy minerals grew much faster than demand for other materials, driven predominantly by energy sector applications

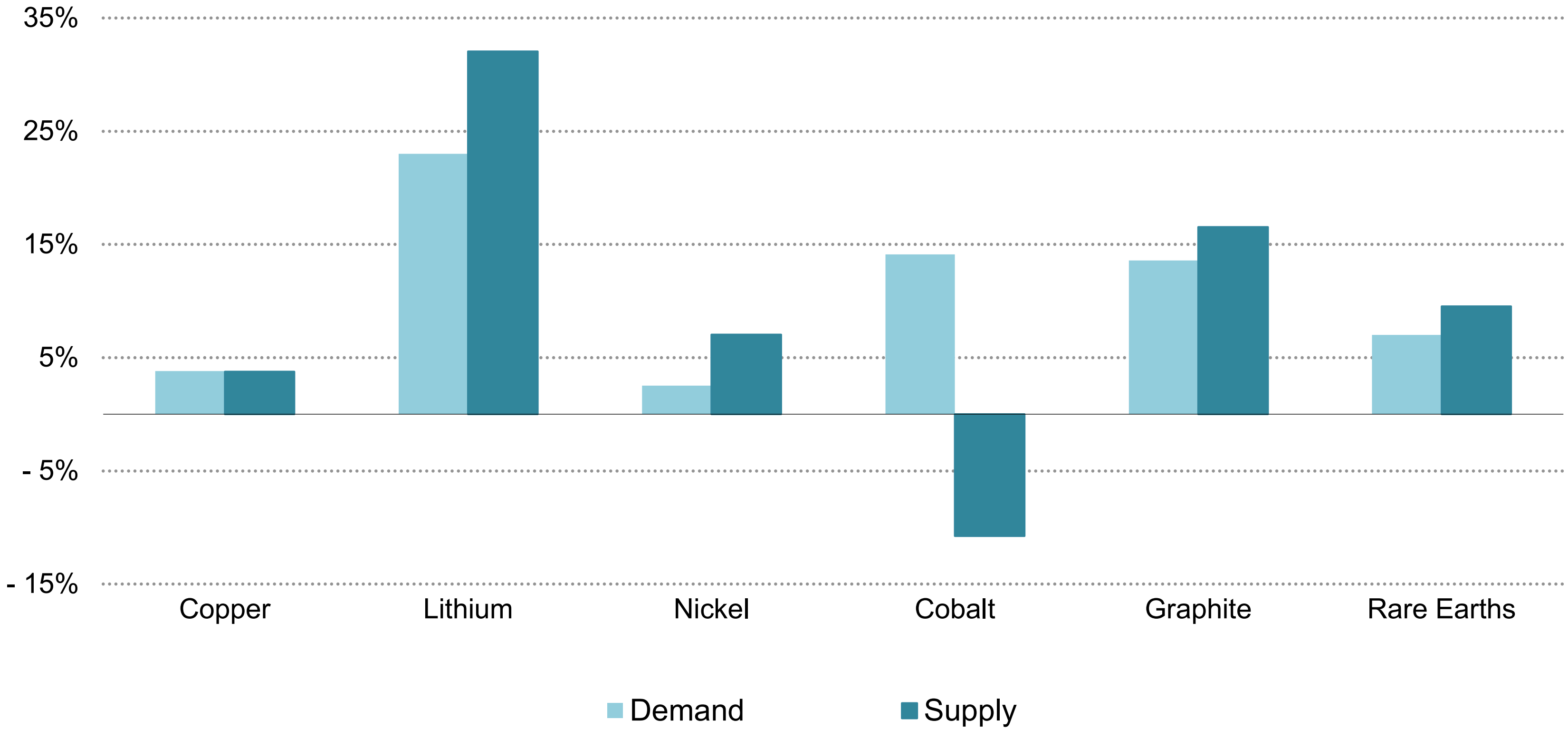
Annual change in demand for key energy minerals



Notes: Key energy minerals include copper, battery metals and rare earth elements. Rare earths refer to magnet rare earths only.

Despite strong demand growth, robust supply expansion kept most key energy mineral markets in surplus in 2025

Demand and refined supply growth for key energy minerals, 2024-2025



Note: Rare earths refer to magnet rare earths only.

Critical mineral markets turned upward in 2025, driven by tightening supply conditions, export controls and resilient demand growth

Prices for critical minerals rebounded in 2025 following downturns in recent years. Base metals such as aluminium, copper, zinc and tin rose strongly, driven by tight supply conditions, particularly in copper and aluminium markets. Copper prices reached record highs in early 2026, exceeding USD 14 000 per tonne in May. Aluminium prices increased by over 10% in 2025 and rose a further 20% from February 2026 following the Middle East conflict, reflecting the region's role as a key supplier and the importance of shipping routes through the Strait of Hormuz (see Geopolitical implications section). Tin prices also increased sharply, by around 40% in 2025, driven by supply disruptions in Myanmar, tight concentrate availability for smelters, and resilient demand from the electronics and semiconductor sectors. Prices for bulk alloy metals such as chromium, molybdenum and vanadium also edged up, albeit to a lesser extent than base metals.

Battery metals and rare earth prices remained subdued in 2023-2024 as supply growth outpaced demand, reflecting capacity expansions following the 2021-2022 price cycle. However, prices began to recover in 2025. Lithium prices almost doubled between January 2025 and April 2026, supported by strong growth in battery demand, particularly from energy storage applications, alongside constrained supply conditions caused by Zimbabwe's export restrictions and tighter permitting in China's Jiangxi region. Cobalt prices increased by around 120% in 2025, largely driven by export restrictions imposed by the Democratic Republic of the Congo (DRC). Policy changes in Indonesia created uncertainty around future nickel supply, contributing to a 20% increase in nickel prices since the end of 2025. The conflict in the Middle East and associated disruptions to sulphur and sulphuric acid supply added further upward pressure on prices, particularly for purified phosphoric acid, which increased by around 50% following the crisis. However, not all battery metals followed this trend: graphite prices remained subdued due to persistent oversupply conditions.

Rare earth markets also experienced strong price increases following the introduction of export controls by China in 2025. In recent months, yttrium prices have seen particularly sharp gains, driven by strong demand from high-tech, aerospace and defence applications, compounded by tighter export conditions.

For strategic minor minerals – those with relatively small market sizes but critical roles across energy, high-tech, aerospace and defence – prices had already been rising since 2024 due to robust demand and a series of export controls imposed by China, the dominant supplier for many of these materials. As export restrictions broadened and tightened further, prices surged in 2025, with particularly strong increases in indium and tungsten. Indium prices were supported by growing demand from semiconductor, display and photovoltaic applications, while tungsten prices rose on the back of strong demand from the electronics, aerospace and defence sectors. The expansion of export controls further tightened market conditions, contributing to sharp price increases. Given the highly concentrated nature of supply and the relatively small size of these markets, small shifts in supply patterns or purchasing behaviour had an outsized impact on prices. Between January 2025 and April 2026, tungsten, tantalum, cobalt, lithium and rare earth elements have recorded the largest price increases, with tungsten prices surging six-fold.

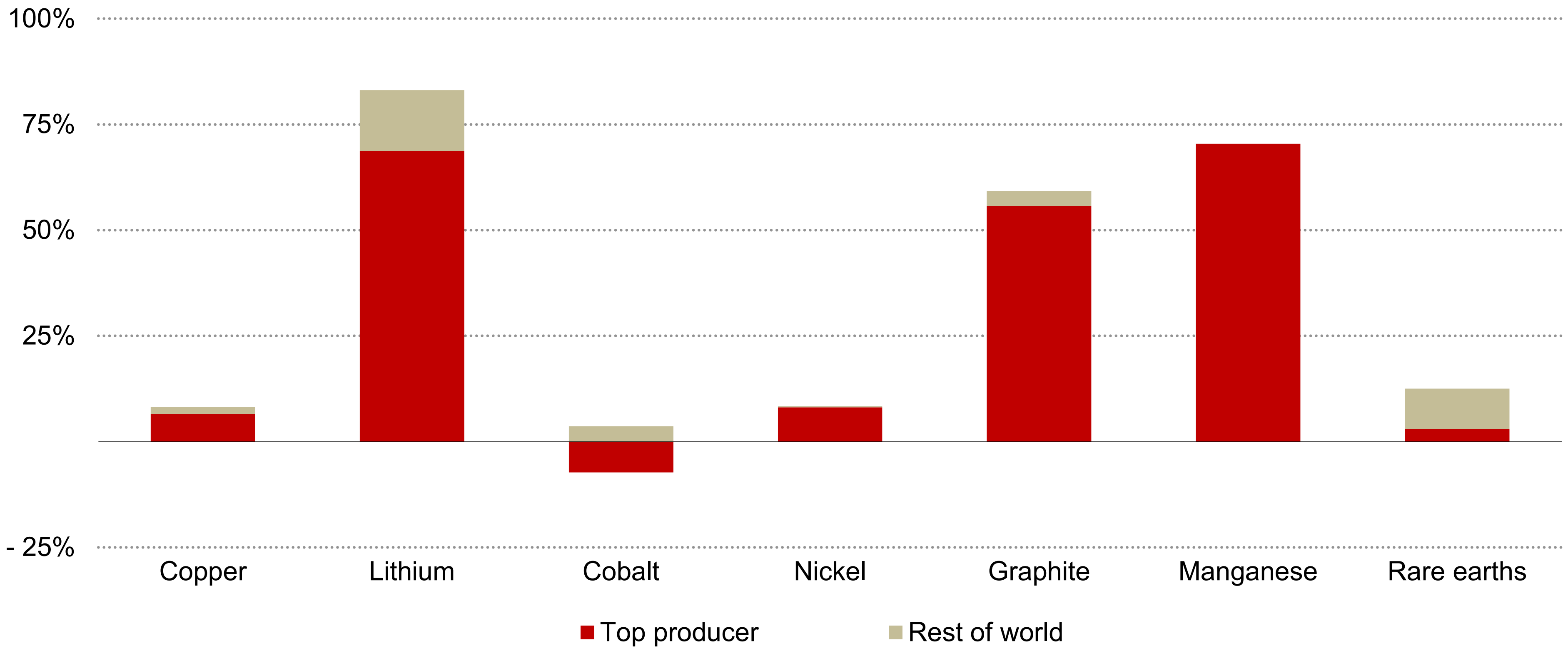
A widening divergence between Chinese domestic and ex-China prices has emerged for several critical minerals. European prices are currently around five times higher than Chinese domestic prices for gallium and heavy rare earths, and around three times higher for germanium. While ex-China price assessments are based on relatively limited market liquidity and fewer transactions, the widening premium highlights the growing challenges of securing supply outside the dominant supplier.

Despite rising base metal prices, smelter fees, known as treatment and refining charges (TC/RCs), have moved in the opposite direction, falling to historic lows. Annual copper benchmark TC/RCs settled at USD 0 per tonne in 2026, the lowest level ever agreed in annual negotiations, while spot charges have remained negative since 2024; zinc and lead smelter fees have also turned negative. Tight concentrate supplies, combined with rapid smelter capacity expansion in China, have driven this trend, placing increasing pressure on the economic viability of base metal smelters, particularly outside the dominant supplier.

For key energy minerals such as copper, lithium, nickel, cobalt, graphite and rare earth elements, demand continued to grow strongly in 2025, driven primarily by their increasing use in energy technologies, including batteries for electric vehicles (EVs) and energy storage, electricity infrastructure such as grids, wind turbines and solar PV, and permanent magnets for high-performance applications. Demand for these minerals has grown at close to 10% per year on average in recent years, significantly outpacing demand growth for base metals such as aluminium, lead and zinc, which averaged around 1% annually. Lithium demand has been particularly strong, increasing by around 25% per year on average over the past two years. Across key energy minerals, the energy sector drove, on average, around 75% of demand growth in 2025, up from 70% in 2024. Cobalt is an exception, where end uses such as portable electronics, aerospace and defence have been accounting for an increasing share of demand in recent years.

The leading producer has led refined supply growth across almost all key energy minerals

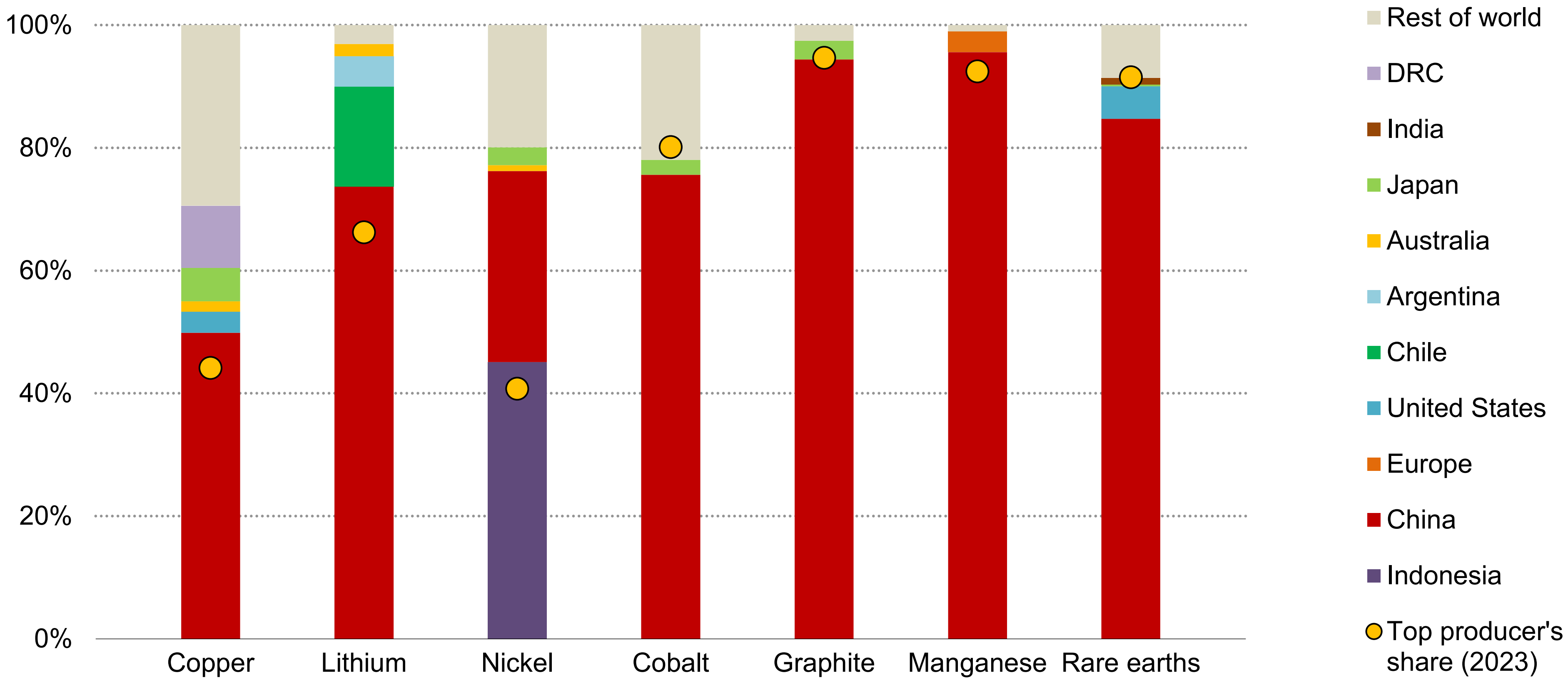
Change in refined output of key energy minerals, 2023-2025



Notes: Manganese refers to manganese sulphate. The top producer is Indonesia for nickel and China for all others.

As a result, concentration in refined material production edged higher again in 2025 across most minerals, with rare earths being the exception

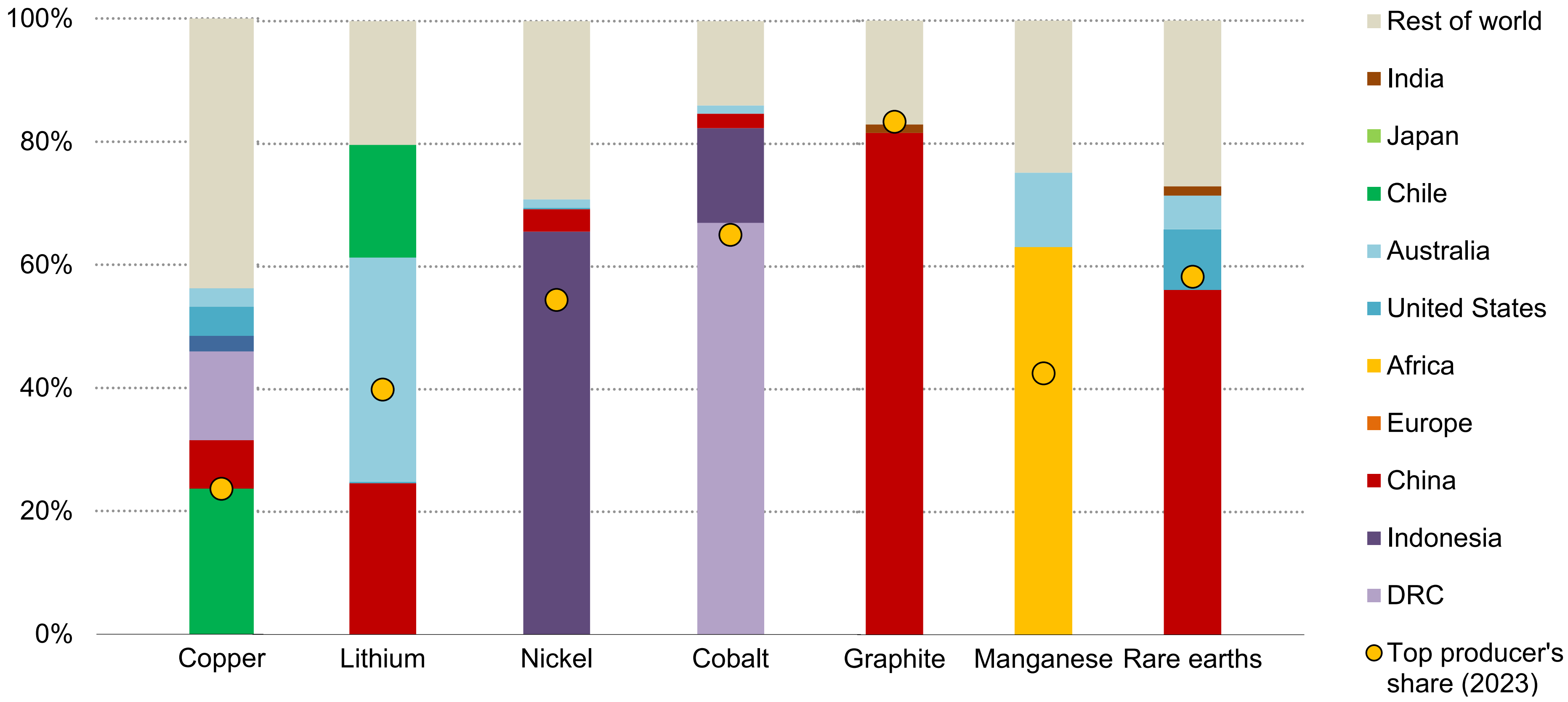
Share of refined material production by country in 2025 compared with the top producer's share in 2023



Notes: DRC = Democratic Republic of the Congo. Graphite refers to battery-grade graphite, and rare earths to magnet rare earths.

Mining concentration shows a mixed picture across minerals, with lithium, graphite and rare earths seeing modest improvement

Share of mined output by country in 2025 compared with the top producer's share in 2023



Notes: DRC = Democratic Republic of the Congo. Graphite refers to mined natural graphite, and rare earths to magnet rare earths.

Refining concentration has again reached record levels, while mining has seen mixed progress

Mined and refined output growth has become increasingly concentrated in recent years, driven by capacity expansions in a small number of leading producers. For refined materials, this growth was largely driven by the top producers – Indonesia for nickel and China for most other key energy minerals – which together accounted for over three-quarters of total supply growth between 2023 and 2025. In several markets, including manganese, nickel and graphite, almost all supply growth originated from the leading supplier. Rare earth refining was a notable exception, with new projects in Malaysia and the United States leading to a modest decline in supply concentration between 2023 and 2025, highlighting the role of targeted policy and investment support in enabling diversification.

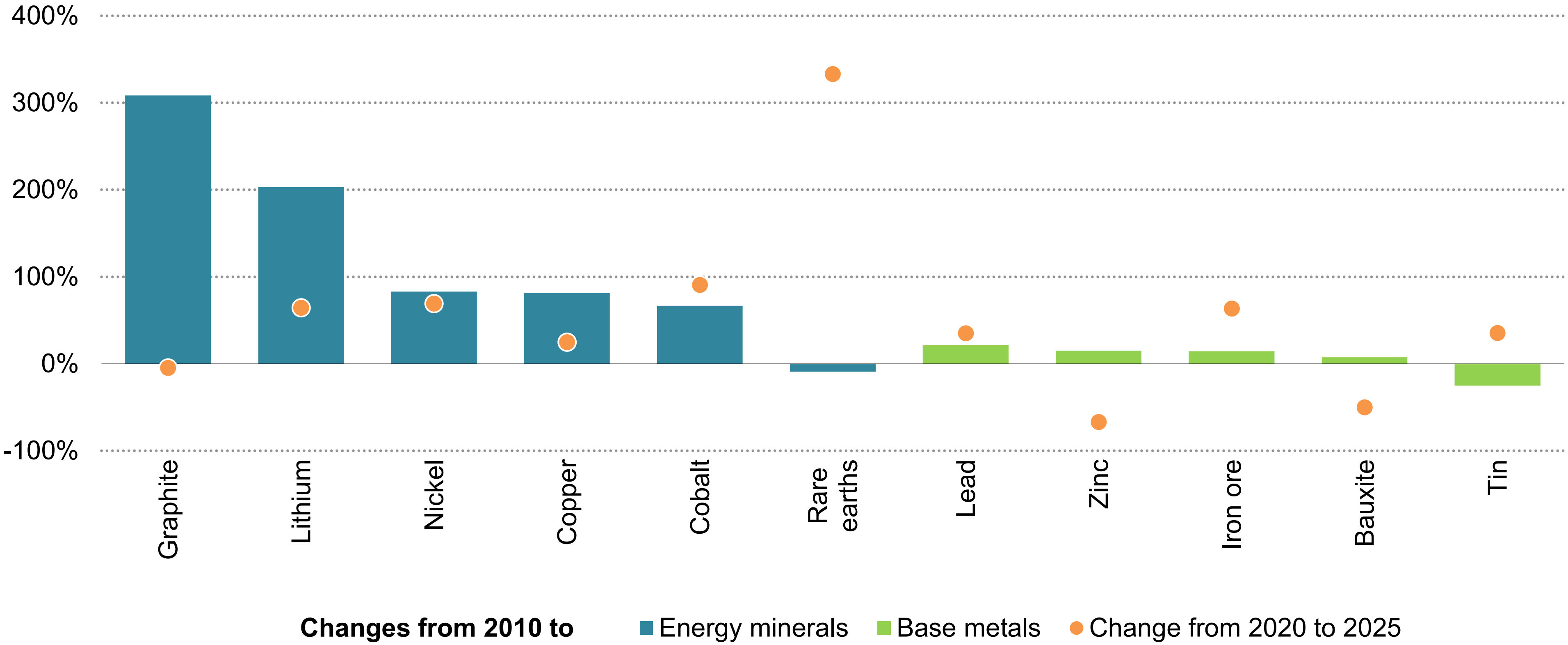
As a result, refining concentration across energy minerals reached new record levels. The average share of the top refined supplier stood at around 72% in 2025, up from 70% in 2020. Lithium recorded the largest increase, reflecting continued investment in refining capacity in China and its dominant position in chemical conversion, particularly for battery-grade lithium chemicals. Nickel also saw a marked increase, driven by rapidly expanding integrated industrial parks in Indonesia such as Morowali, Weda Bay and Pomalaa. For graphite, China accounted for virtually all growth in battery-grade supply in recent years, particularly through the expansion of synthetic graphite anode production.

By contrast, changes in concentration were more mixed for mining, with the top producer's share declining for lithium, graphite and rare earths between 2023 and 2025. For rare earths, this reflects new projects in regions such as the United States (MP Materials) and Australia-Malaysia (Lynas) coming online, while lithium and graphite saw diversified projects come online in Latin America and Africa. Copper concentration remained broadly stable. Nickel, however, saw increased mining concentration: Indonesia expanded its share of nickel output through growth in hubs such as Weda Bay, while higher-cost projects elsewhere were curtailed or put under care and maintenance amid weaker prices. For cobalt, the Democratic Republic of the Congo (DRC) remained dominant despite policy changes in the country that affect production, while Indonesia continued to gain market share.

China not only dominates mined and refined output by geography, but also by ownership, with Chinese firms holding major positions in upstream mining in countries such as the DRC and Indonesia and dominating midstream processing globally. Recent investments, particularly in rare earths, have supported some diversification of ownership (see Investment trends and Latest policy developments sections).

Energy mineral reserves increased notably, particularly between 2020 and 2025, reflecting rising interest in exploration and development activities

Changes in selected commodity reserves, 2010-2025



Notes: Graphite refers to natural graphite. Reserves are defined by the United States Geological Survey as the portion of an identified resource that can be economically and legally extracted at the time of determination.
Source: IEA analysis based on data from the United States Geological Survey.

Reserves for energy minerals have increased notably in recent years, driven by increased exploration activity

From 2010 to 2025, energy minerals, including copper, lithium, nickel, cobalt, natural graphite and rare earth elements, recorded stronger reserve growth than base metals, reflecting increased exploration activity. Across key energy minerals, estimated reserves increased on average by 120% between 2010 and 2025, compared with a much more modest 7% increase for base metals.

This growth was not uniform across commodities. Natural graphite recorded the largest increase in reserves among energy minerals. China, the largest producer, steadily expanded its reserve base over the period. Brazil also recorded strong growth, while Mozambique saw a sharp increase following the discovery of significant new deposits.

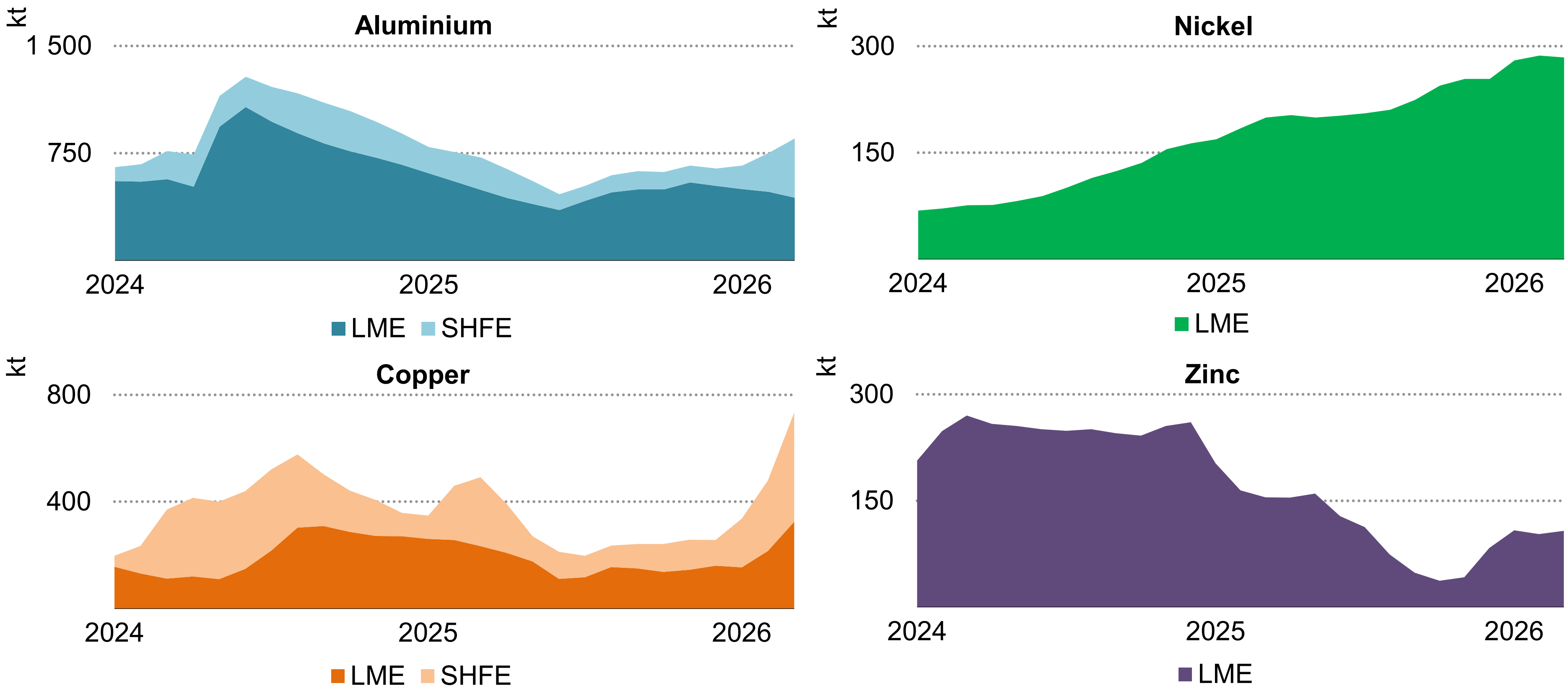
Lithium also recorded strong reserve growth, led by Chile, Australia and Argentina. Nickel reserves increased significantly, particularly in Indonesia, which increased its share of global reserves from around 5% in 2010 to more than 40% by 2025. Australia, which accounted for around 40% of global reserves in 2010, maintained broadly stable absolute volumes, although its global share declined to around 20% by 2025.

Cobalt reserves increased notably during the 2020s, driven by intensified exploration in copper-rich areas of the DRC. Traditional producers such as Australia and Cuba saw relatively limited changes in reserve volumes, while Indonesia emerged as a new contributor to global cobalt reserves over the period.

Rare earths were the only major energy mineral group to record a decline in reported reserves. China increased its reported reserves over the period, while the United States saw decreases following the restart of previously idle mines after 2012. Countries such as the Russian Federation (hereafter, “Russia”) and Viet Nam also recorded decreases in reserve estimates.

Aluminium inventory trends diverged across regions, with stocks declining at the LME and rising at the SHFE, while copper inventories have moved higher in recent months

Inventory levels of selected metals at major exchanges



Notes: LME = London Metal Exchange; SHFE = Shanghai Futures Exchange. Inventory levels indicate the monthly average of daily inventory volumes on major metal exchanges: aluminium (LME, SHFE); copper (LME, SHFE); nickel (LME); and zinc (LME).

Source: IEA analysis based on data from Bloomberg.

Inventory levels remained highly volatile amid rapidly changing market conditions

Monitoring inventory levels is important from a supply security perspective. A sharp decline in inventories may indicate potential supply tightening, whereas a rapid build-up in inventories may signal weakening demand or oversupply. Over the past two years, inventory trends for aluminium, copper, nickel and zinc have reflected differing regional market conditions and supply-demand balances.

Aluminium inventories at the London Metal Exchange (LME) and Shanghai Futures Exchange (SHFE) have followed contrasting paths. LME inventories generally declined, reflecting tighter availability in international markets amid relatively robust demand and supply constraints, including production challenges in Europe linked to high energy costs. By contrast, SHFE inventories began to rise from mid-2025 as domestic production in China increased and downstream consumption softened. The divergence between LME and SHFE inventories became particularly pronounced from late 2025, highlighting growing regional imbalances in market fundamentals.

Copper inventories on both the LME and SHFE were highly volatile. LME stocks declined through late 2024 and much of 2025 as supply tightened and demand expectations improved. Anticipation of US import tariffs under Section 232 measures also encouraged the movement of copper inventories into COMEX warehouses in the United States. However, from late 2025, inventories across both the LME and SHFE began to increase, driven largely by short-term demand weakness.

Nickel inventories on the LME followed a markedly different trajectory, rising steadily throughout the period. This reflected persistent oversupply in global markets, driven by rapid production growth in Indonesia and the inclusion of intermediate products such as mixed hydroxide precipitate into LME-deliverable nickel products. The approval of additional nickel brands for LME delivery further expanded the pool of eligible material, contributing to inventory accumulation.

Zinc inventories on the LME generally trended downward, particularly during 2025, supported by strong demand from galvanised steel applications and some supply-side constraints. However, exchange inventories may not fully reflect overall market conditions, as a portion of metal appears to have remained outside the exchange system or concentrated in China.

Geopolitical developments and implications for supply security

Export controls: In a year characterised by rising geopolitical tensions, new export controls have been implemented on critical minerals and their processing technologies

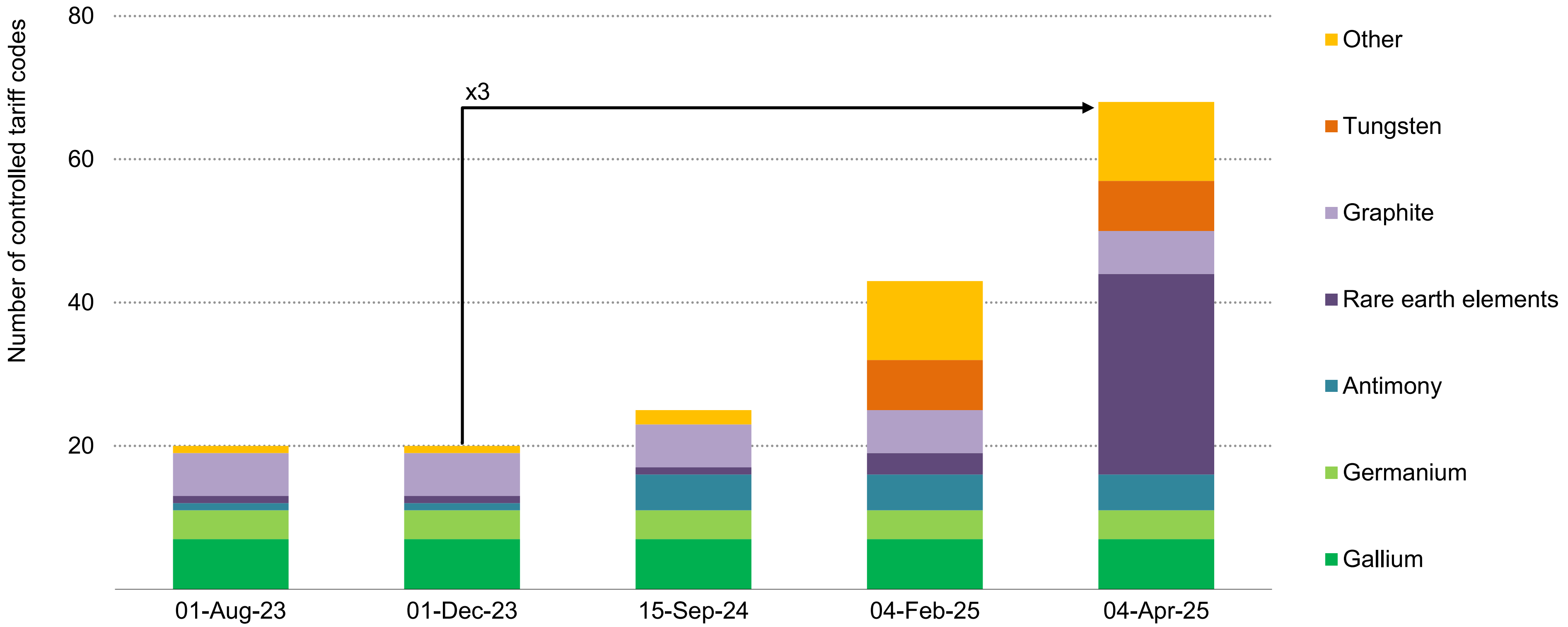
Export controls announced, proposed or updated in 2025 and 2026

		By	Market share (2025)	Latest development
Material	**Aluminium** (Bauxite)	Guinea	34% *share of mining*	Proposed new export control to be effective in Jun 2026
Material	**Antimony**	China	44% *share of refining*	Suspended its ban on export to the United States until Nov 2026
Material	**Bismuth**	China	73%	Export licensing in Feb 2025
Material	**Cobalt**	DRC	66%	Export quota system in Oct 2025
Material	**Gallium**	China	99%	Suspended its ban on export to the United States until Nov 2026
Material	**Germanium**	China	94%	Suspended its ban on export to the United States until Nov 2026
Material	**Graphite** (mined)	Mozambique	4%	Mandated local processing of mined material
Material	**Graphite** (refined)	China	94%	Proposed new restrictions, suspended until Nov 2026
Material	**Indium**	China	86%	Export licensing in Feb 2025
Material	**Lithium**	Zimbabwe	10%	Suspended exports of lithium concentrate in Feb 2026, followed by potential export ban in 2027
Material	**Manganese**	Gabon	25%	Proposed ban on raw mineral exports to start in 2029
Material	**Molybdenum**	China	41%	Export licensing in Feb 2025
Material	**Nickel**	Philippines	11%	Proposed ban on raw mineral exports to start in 2030
Material	**Rare Earths**	China	91%	Export licensing on seven rare earths in Apr 2025; further restrictions suspended until Nov 2026
Material	**Sulphuric acid**	China	34%	Halted exports from May 2026 until the end of the year
Material	**Tellurium**	China	73%	Export licensing in Feb 2025
Material	**Tungsten**	China	76%	Export licensing in Feb 2025
Technology	**Rare Earths**	China	91%	Proposed controls on related products, equipment and technologies suspended until Nov 2026
Technology	**Batteries** (LFP)	China	99% *share of cell manufacturing*	Proposed controls on batteries, battery equipment and components suspended until Nov 2026
Technology	**Lithium refining**	China	71%	Proposed technology export control in Jan 2025

Note: LFP = lithium iron phosphate.

Export controls: The number of items under export control from China has tripled since 2023

Number of tariff codes under export control from China, 2023-2025

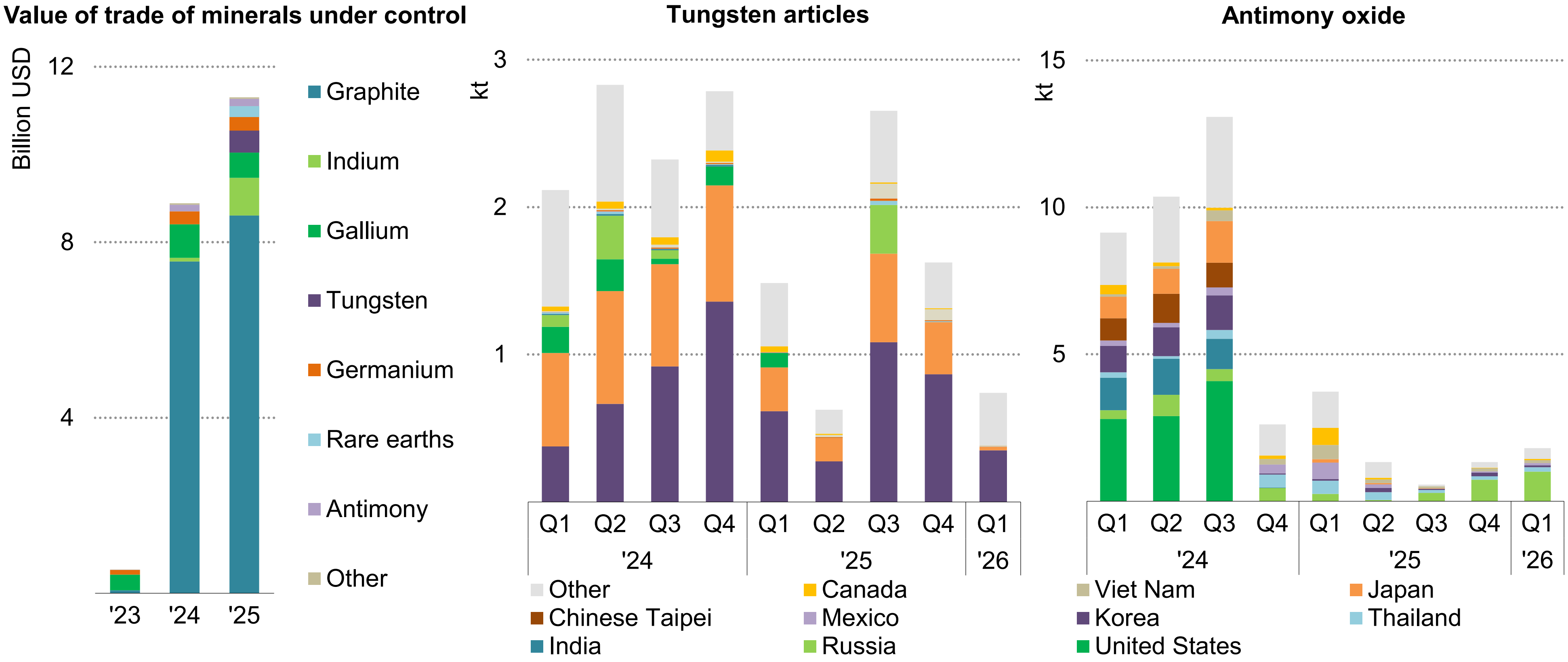


Notes: The figure shows the number of 8-digit tariff codes that have been affected by export restrictions introduced by China since 2023. Other includes bismuth, boron, cadmium, indium, molybdenum, tellurium and silver.

Source: IEA analysis based on Chinese Customs data.

Export controls: The value of exports of all items under restriction from China increased to over USD 11 billion in 2025

Value of exports from China for items under control by mineral, and exports of tungsten and antimony oxide by importing economy



Notes: Based on customs data for 8-digit tariff codes for items under export restriction from China. Tungsten articles include ammonium paratungstate (tariff code 28418010), carbides of tungsten (28499020), tungsten powders (81011000) and tungsten trioxides (28259012). Antimony oxide refers to tariff code 28258000.

Export controls: Risks from high supply chain concentration became reality in 2025, as geopolitical tensions shaped markets and export controls surged

In recent years, a series of geopolitical events, such as trade tensions, export controls and disruptions to maritime trade, have demonstrated how strongly global economies depend on secure and resilient mineral supply chains. Concerns around mineral supply security had already been an important driver of investment, but developments in 2025 drove a stronger push for policies, measures and investment aimed at strengthening resilience against future shocks.

Export controls

In 2025 and early 2026, a new wave of export controls was announced by major producers. The most significant controls were announced by China on rare earth elements and other materials such as bismuth, tellurium and tungsten, but other countries also introduced new restrictions, particularly in a number of African countries. For example, in September 2025, the DRC, the world's largest mined cobalt supplier, introduced cobalt export quotas (see Cobalt section in Chapter 2), and Zimbabwe and Mozambique introduced trade restrictions on raw materials aimed at developing local mineral processing industries for lithium and graphite, respectively.

Focusing on China, the number of tariff codes that require a licence increased threefold from December 2023 to April 2025, when the latest wave of restrictions was implemented.

For most products, trade was not fully disrupted by the controls, but they added frictions to exchanges and increased costs and prices. For some items, trade volumes significantly decreased or stopped; this was the case for some rare earth-related items, such as permanent magnets, and for other dual-use elements, such as antimony oxide and tungsten carbide and powder. In some cases, trade flows were restricted to a specific number of countries. For example, exports of antimony oxide to Japan, Chinese Taipei and the United States have been halted since September 2024.

April 2025 rare earth export controls

On 4 April 2025, the Chinese government introduced export controls on seven heavy rare earth elements. Export volumes from China dropped sharply in April and May, leaving many automakers in the United States, Europe and beyond struggling to source permanent magnets. Some were forced to reduce utilisation rates or temporarily shut down production lines. Exports of dysprosium and terbium oxides and metals were also affected by the restrictions, dropping in

May before slowly recovering in the following months, impacting the supply of feedstocks for magnet manufacturing outside China.

October 2025 export controls on rare earths

On 9 October 2025, the Ministry of Commerce of China announced further export controls on rare earth elements and related products, equipment and technologies. The new controls required foreign companies to obtain a licence from China to export “parts, components and assemblies” containing Chinese-sourced rare earth materials or produced using Chinese rare earth technologies. The announcement also included a clause implying that, from 1 December 2025 the Chinese government would require a licence to trade “internationally made” products containing Chinese-sourced materials or manufactured using Chinese technologies, even if traded outside China.

The inclusion of “internationally made” products and “parts, components and assemblies”, beyond the previous isolated controls on selected rare earth magnets and materials, marked a major escalation and considerable expansion of the scope of export controls. A wide range of strategic sectors across the world rely on products and components containing controlled Chinese rare earth elements. If the October export controls had been fully enacted, the consequences for many key strategic sectors and global economies would have been exceptional, causing major economic impacts across many sectors, given the vast range of downstream products that rely on Chinese rare earths.

In November 2025, China announced a one-year suspension of the export restrictions introduced in October 2025, providing relief to the market. However, the underlying risks and potential for future implementation remain. In January 2026, China tightened export controls on dual-use goods destined for Japan. These developments underscore the growing prominence of supply chain risks exposed by recent export controls.

October 2025 export controls on battery supply chains

Rare earth elements were not the only materials affected. On 9 October 2025, China also announced major export controls on lithium-ion battery supply chains. These controls expanded on previous targeted controls on graphite and high-performance LFP cathode material to cover a much broader range of battery materials, technologies and equipment across multiple stages of the supply chain. The controls targeted all critical chokepoints in global battery supply chains simultaneously, where China holds the highest concentration of supply, including LFP cathode materials, LFP batteries, graphite anode materials, cathode material precursors, and battery production equipment and technologies. The controls were suspended for a year until November 2026, alongside the rare earth controls.

Given the scale of the impact faced across a range of sectors by the export controls on rare earths, the potentially major consequences of the export controls on battery supply chains may have been somewhat overlooked in policy response development. However, if fully enacted, the proposed export controls would severely restrict the ability of the rest of the world to produce batteries in the near term, with major economic consequences, given the range of strategic sectors for which batteries have critical applications beyond transport and energy storage, including defence, aerospace, artificial intelligence (AI) data centres and even medical applications.

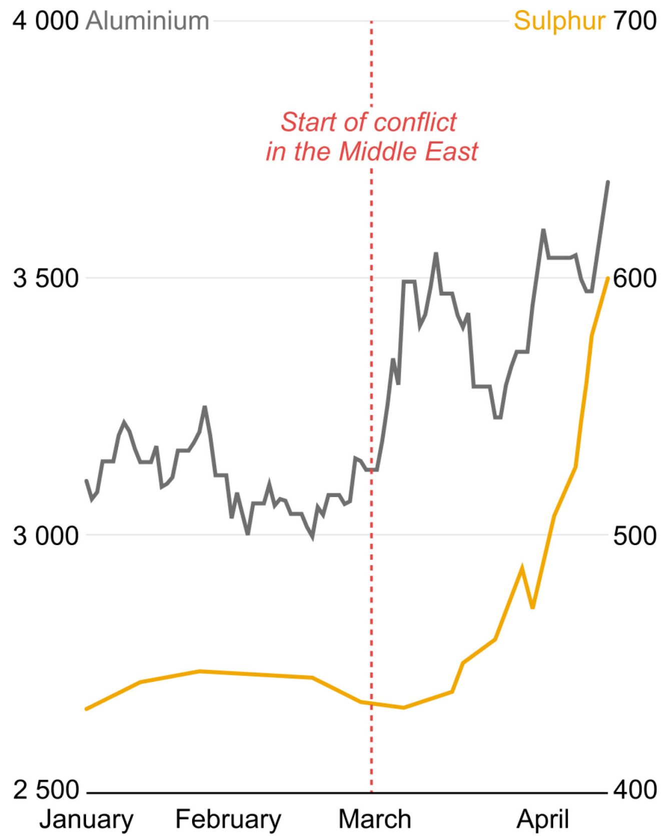
LFP batteries are a case in point, with markets expanding rapidly. They represent over half of the global electric car battery market and over 90% of the battery energy storage market. While China currently dominates this segment, efforts are underway to develop LFP battery production outside China. However, new restrictions on LFP cathode materials could impede these initiatives, reinforcing China's dominance in this technology, with major implications for grids, which increasingly depend on battery energy storage deployment. The simultaneous restrictions on battery equipment and technologies could also lead to even greater market concentration in China, as they could significantly hinder countries' efforts to produce batteries overseas. Sustained restrictions could lead to major revenue and job losses for producers of batteries and battery materials around the world, with knock-on effects for the EV producers, grid developers, data centre providers and defence contractors that depend on them.

While the focus on rare earths is imperative, this should not cloud the major strategic risks posed by the battery supply chain export controls. Strengthened emergency preparations and diversification efforts are needed across both supply chains.

Middle East conflict: The war has sent shockwaves through critical mineral value chains

	Aluminium	Sulphur	Helium
Middle East production share	*Middle East* *Rest of World*		
Most affected industries	Automotive, aerospace, energy infrastructure, defence	Fertilisers, metal (copper, nickel, and cobalt) leaching, batteries, electrical equipments, magnets	Semiconductors, electronics, fibre optics, MRI machines
Direct	Direct attacks to smelters, disruption of trade through the Strait of Hormuz	Disruption of sulphur trade affects sulphuric acid production	Direct attacks on the Ras Laffan gas processing facility producing most of the region's helium
Indirect		Fertilisers, metal (copper, nickel and cobalt) leaching, battery chemicals, and rare earths	
Most affected minerals	Al	Cu, Li, Ni, PPA, Co, REE	He

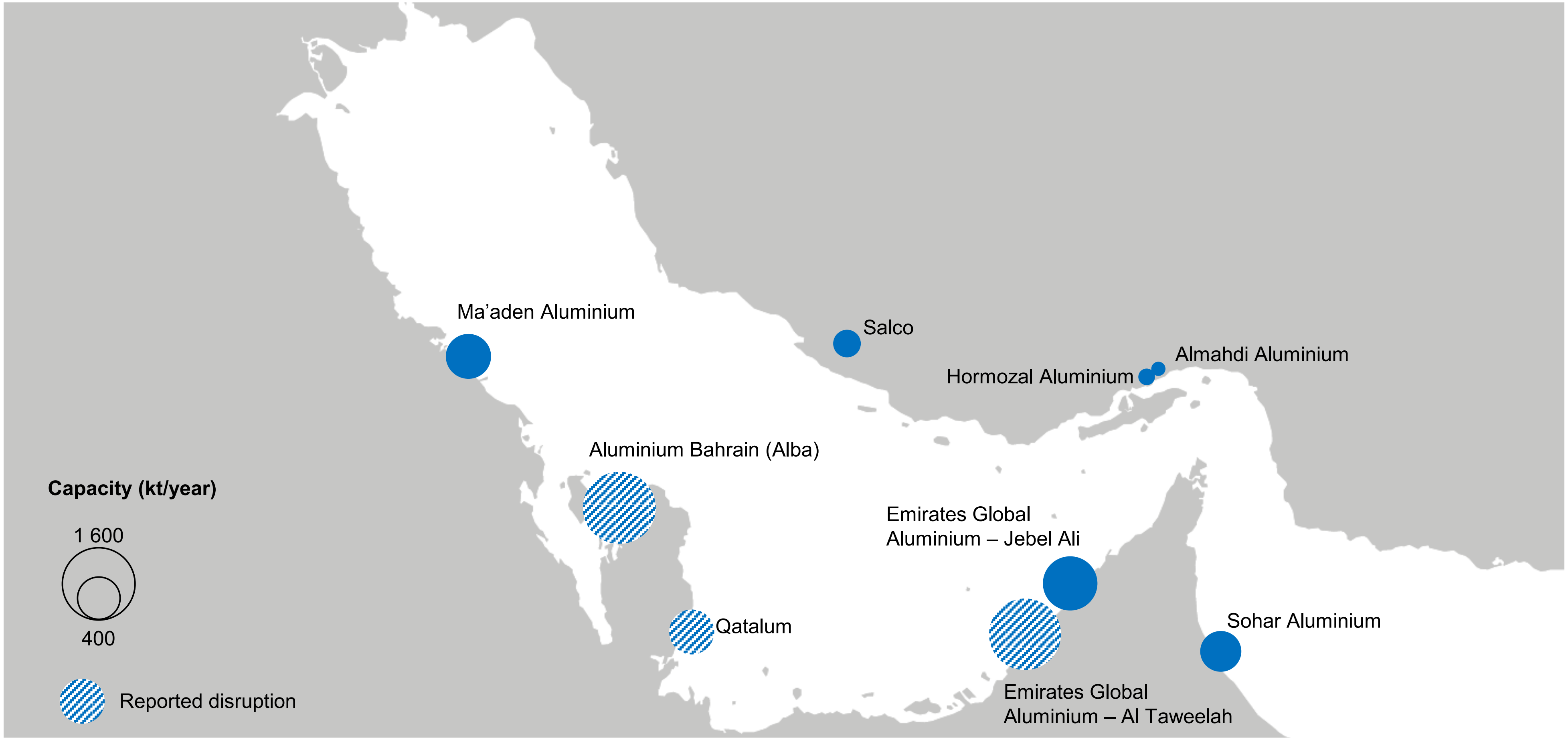
Aluminium and sulphur prices, 2026 (USD/tonne)



Notes: MRI = magnetic resonance imaging; PPA = purified phosphoric acid; REE = rare earth elements.

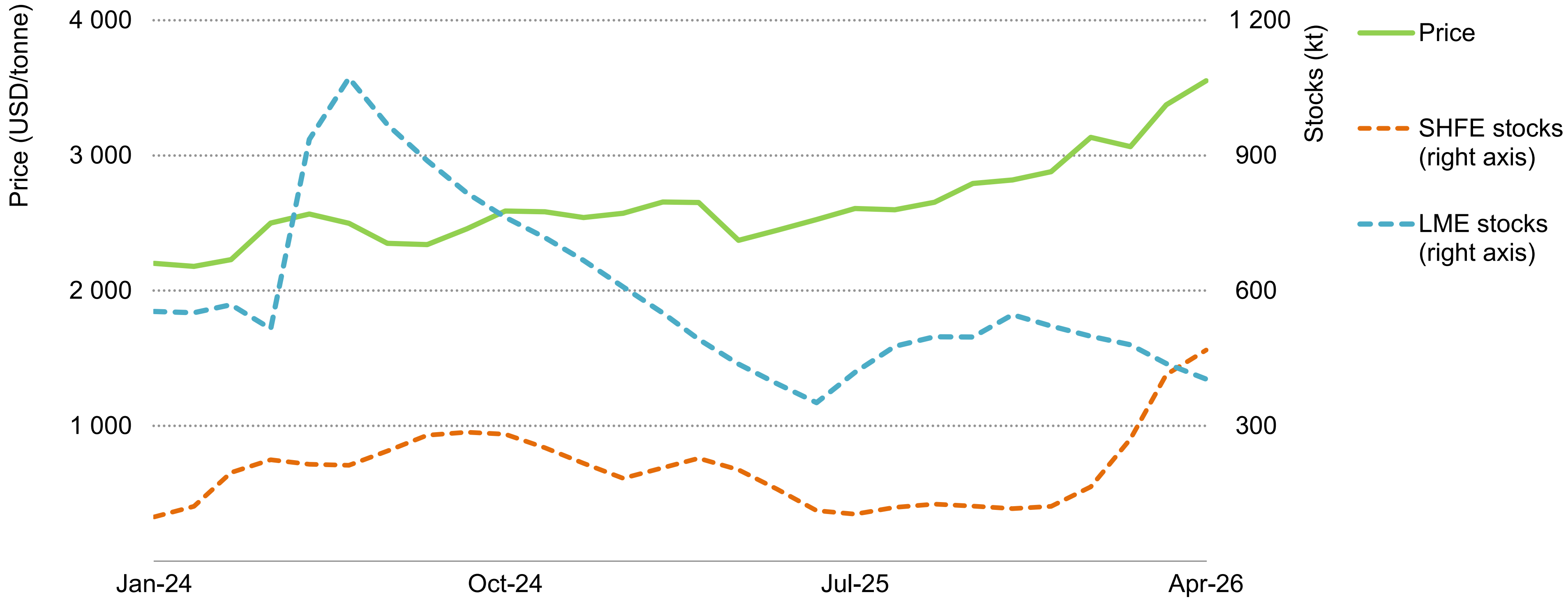
Middle East conflict: Aluminium production facilities in the Middle East, among the largest in the world, have reported major disruptions

Primary aluminium production plants in the Middle East



Middle East conflict: Further pressure on a tight aluminium market, where exchange stocks had already been declining, has contributed to higher prices

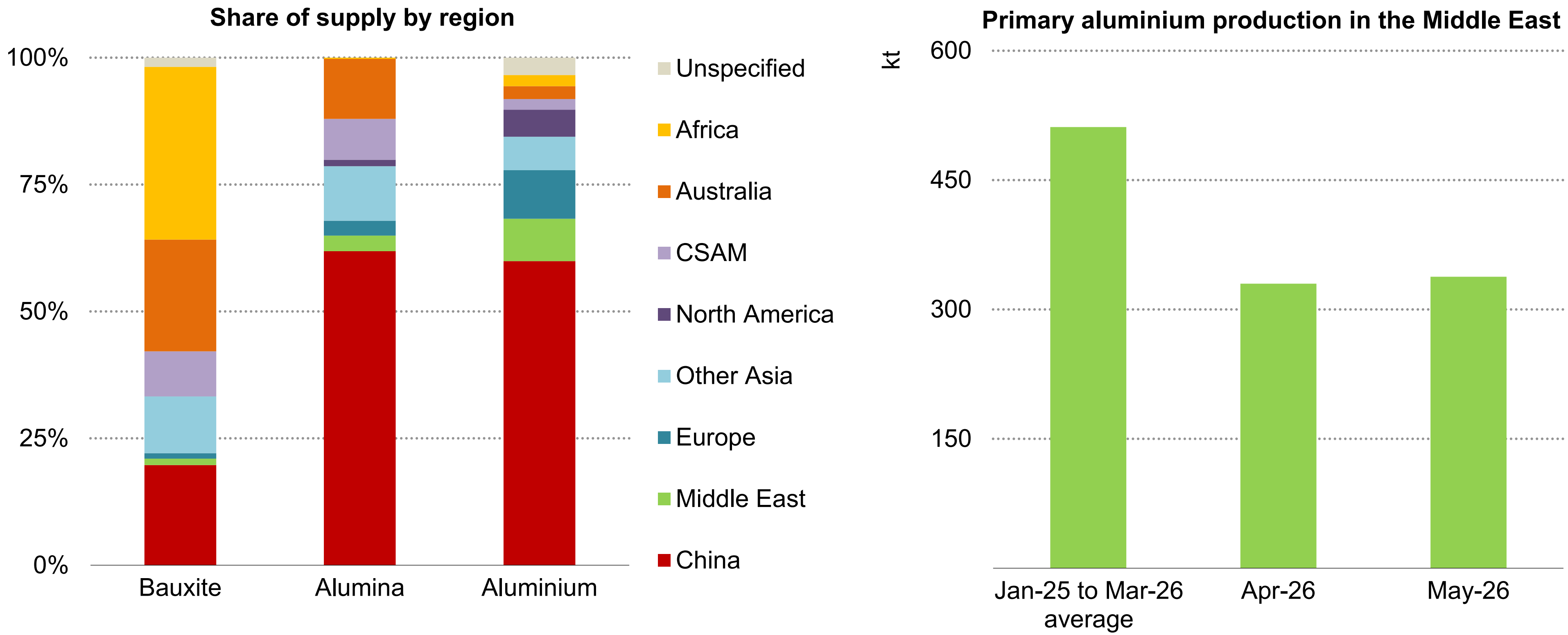
Aluminium price and stocks at major exchanges



Note: LME = London Metal Exchange; SHFE = Shanghai Futures Exchange.
Sources: IEA analysis based on data from SHFE, LME and Bloomberg.

Middle East conflict: The Middle East accounted for 8% of global primary aluminium production in 2025, one-third of which was lost during the conflict

Share of global production of primary aluminium, alumina and bauxite, and production from the Middle East



Note: CSAM = Central and South America.
Source: IEA analysis based on data from the International Aluminium Institute (2026) and United States Geological Survey (2026).

Middle East conflict: Already tight aluminium markets have been directly affected

The conflict that started in the Middle East on 28 February 2026 is having major impacts on the energy market. Trade flows through the Strait of Hormuz have been disrupted for months, causing the largest supply disruption in the history of the global oil market and significant disruptions to natural gas flows. However, the impact has also been highly visible in mineral and metal markets. While trade in key energy minerals such as copper, lithium and graphite was less directly affected, the crisis has had important implications for a range of key materials, such as aluminium and helium, as well as key feedstocks, such as sulphur and needle coke, which are used in metal processing and the production of precursor materials and synthetic graphite.

Aluminium

During the conflict, several aluminium production facilities in the Middle East were directly hit. Direct damage, together with disruptions to flows through the Strait of Hormuz, is affecting global aluminium trade. The Middle East accounts for 8% of primary aluminium production, a share that increases to one fifth when excluding China. Exports from the region before the conflict accounted for more than 10% of total aluminium supply for the European Union, Japan, Korea and Mexico, and just under 20% for the United States. Moreover, aluminium smelters in the Middle East are key producers of high-purity aluminium, particularly Emirates Global Aluminium's Al Taweelah plant. High-purity aluminium plays a crucial role in aerospace and defence applications, making the impacts of lost supply from the region a significant concern for strategic sectors.

The disruptions hit the market after demand for aluminium had increased by around 7% from 2023 to 2025. In addition to energy technologies, aluminium is an essential input across multiple strategic sectors, including transport and aerospace, construction, infrastructure and defence.

On the supply side, concerns around a supply deficit have been building, as China reached the 45 Mt production cap set in 2017 in 2025. The combination of resilient demand and constrained supply led to a drawdown of LME aluminium inventories, which decreased sharply from over 1 Mt in June 2024 to around 350 kt in June 2025. At the same time, stocks at the SHFE have been increasing since the start of 2026, reflecting softening demand in China. New trade and regulatory policies in 2025 also came into play. The United States increased tariffs to 50% on most imported aluminium products. At the same time, China removed some export tax rebates on semi-finished aluminium products on 1 December 2024, contributing to decreasing aluminium exports.

Against this backdrop, the conflict in the Middle East quickly escalated market pressures. Aluminium Bahrain (Alba), the world's largest smelter outside China, with a capacity of 1.6 Mt, was operating at 30% in April 2026 after declaring force majeure due to logistical challenges around the Strait of Hormuz and shutting down three smelting lines accounting for 19% of its capacity. Qatalum, a smelter in Qatar with a capacity of 0.65 Mt, also announced force majeure due to a lack of gas supply linked to the Ras Laffan natural gas processing facilities and was operating at 60% capacity in April 2026. In late March, Aluminium Bahrain's Alba plant and Emirates Global Aluminium's Al Taweelah plant reported damage after being hit by strikes. Following the strikes, the Al Taweelah plant had to halt operations due to damage to its power facilities. The affected capacity is likely to return only gradually, as restarting smelters after shutdown can take 6-12 months. Logistical challenges around input materials and energy supply may add further pressure. The loss of Emirates Global Aluminium is particularly concerning for aluminium supply to the aerospace sector.

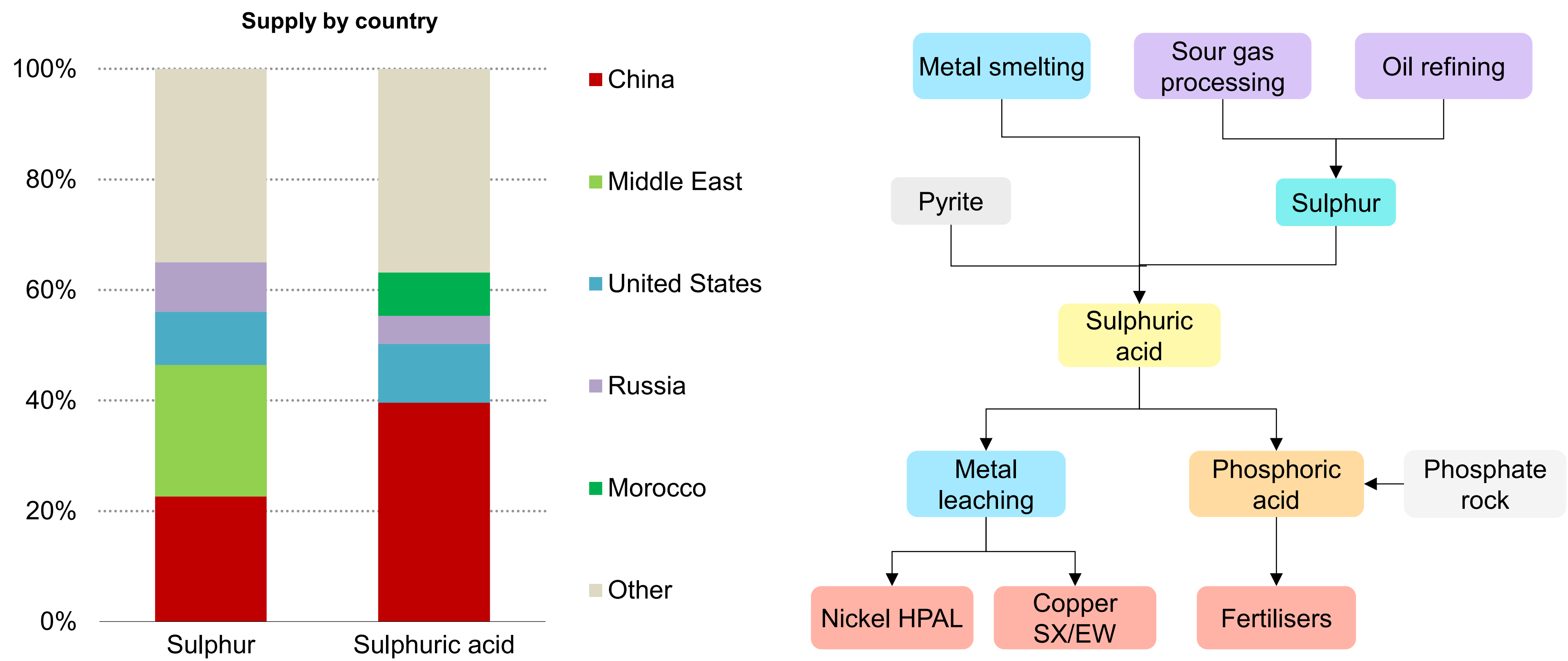
Aluminium prices reached a four-year high of almost USD 3 700 per tonne in April 2026. Regional premiums were also on the rise, with the Rotterdam premium up 60% from February to April 2026. Insurance premiums and emergency freight surcharges are adding to rising shipping costs. Aluminium users in Europe, Japan and the United States are particularly exposed to high prices, and a prolonged disruption threatens the production of finished products in sectors such as automotive, construction and packaging.

In addition to direct effects on aluminium trade, the conflict is also affecting the supply of feedstocks, such as green and calcined petroleum coke, which are needed to manufacture anodes consumed during the electrolysis of alumina to produce primary aluminium. Prices of green petroleum coke increased by around 35% between February and April 2026, a trend that is expected to be followed by calcined petroleum coke, affecting global aluminium production.

In the near term, aluminium markets are expected to remain tight, with the Middle East conflict adding further pressure. Supply growth remains constrained by China's production cap and rising energy costs. Although some easing could occur with new smelting capacity in Indonesia, aluminium prices are likely to remain elevated and volatile in the short term.

Middle East conflict: Half of global seaborne sulphur trade passes through the Strait of Hormuz, and the Gulf accounts for a quarter of global supply, affecting metals and fertilisers

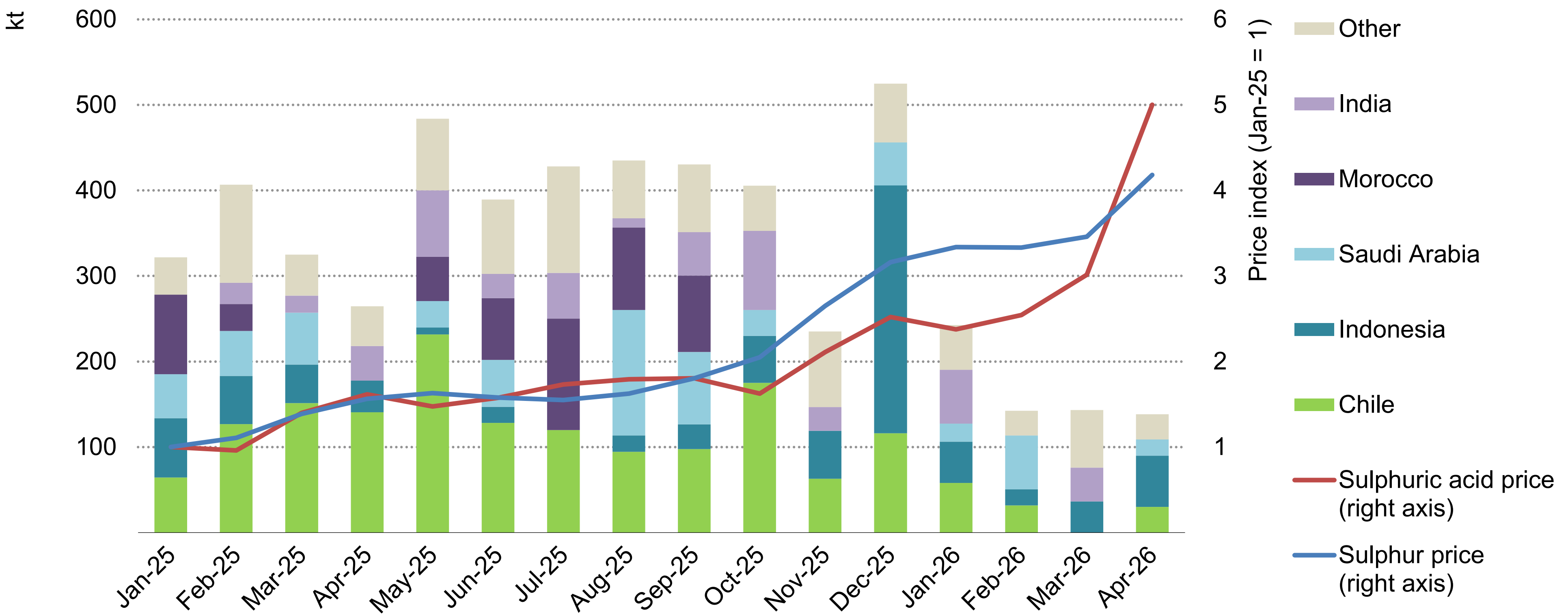
Sulphur and sulphuric acid supply, and the sulphuric acid supply chain



Notes: HPAL = high-pressure acid leaching. SX/EW = solvent extraction and electrowinning.

Middle East conflict: Disruptions to sulphur supply have prompted China to curb exports of sulphuric acid

Sulphuric acid exports from China, and sulphur and sulphuric acid prices, January 2025-April 2026



Source: IEA analysis based on Chinese Customs data.

Middle East conflict: Ripple effects from sulphur markets are increasing risks in fertiliser and metals value chains

Around half of global seaborne sulphur trade passes through the Strait of Hormuz, while the Middle East accounts for a quarter of global sulphur supply, which is produced as a by-product of oil and gas production. Disruptions to sulphur exports from the region have affected countries that rely on imported sulphur to produce sulphuric acid, which is in turn used in fertiliser production and in the leaching of key metals, such as copper, nickel and cobalt. China is particularly exposed to sulphur disruptions, as 55% of its sulphur imports in 2025 originated in the Middle East.

Sulphur markets had already been structurally tight since mid-2024, reflecting strong demand for sulphuric acid from fertiliser production and Indonesia's expanding nickel sector based on high-pressure acid leaching (HPAL) operations, alongside some supply disruptions in 2025, such as Russia's sulphur export ban and damage to its refineries. In March 2026, disruptions to maritime trade flows in the Strait of Hormuz led to sharp increases in global sulphur prices, with sulphuric acid prices also doubling from USD 144 per tonne in February 2026 to USD 283 per tonne in April 2026.

China is a net importer of sulphur and produces 40% of the world's sulphuric acid, followed by the United States, India, Russia and Morocco. China accounts for around one third of global demand, followed by North America, Africa, and Central and South America. In January 2026, as sulphuric acid prices were increasing, China announced an export cap for January-April 2026 to safeguard domestic supply, resulting in a year-on-year decrease in exports of around 50%.

As sulphur supply has tightened following the conflict in the Middle East, China halted exports of sulphuric acid from May 2026 until the end of the year, affecting almost a quarter of ex-China acid needs, with major implications for the metals and fertiliser sectors. The restrictions are expected to apply to both sulphur burner-based sulphuric acid and smelter by-product sulphuric acid, with an exemption only for electronic-grade sulphuric acid, typically used in the production of semiconductors. In 2025, China exported 4.7 Mt of sulphuric acid, with Chile and Indonesia importing half of the total.

Fertilisers

Rising sulphur prices have caused sulphuric acid prices to spike just as the northern hemisphere enters the spring planting season, when fertiliser consumption typically peaks. Sulphuric acid is a core input for phosphoric acid and thus phosphate fertiliser, but it is also used in potassium-based fertilisers and some nitrogen-based fertilisers. China halted phosphate fertiliser exports in December 2025, citing global sulphuric acid price spikes, a restriction that is expected to last until August 2026. This ban will put further pressure on the fertiliser market, with the Philippines, Kenya and Myanmar particularly vulnerable, accounting for 31%, 14% and 13%, respectively, of exposed imports from China in 2025.

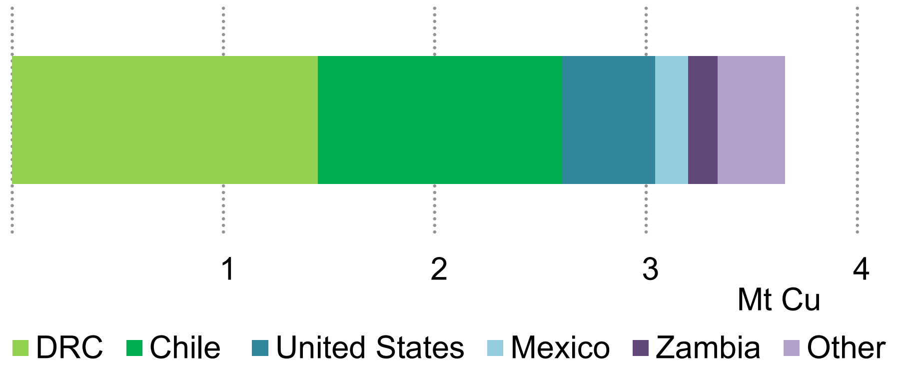
Fertiliser markets are already experiencing pressure on nitrogen-based products, as around one-quarter of ammonia and 40% of global urea exports pass through the Strait of Hormuz. By affecting the other two types of fertilisers, phosphate and potassium-based, disruptions to sulphur and sulphuric acid supply effectively put the entire fertiliser production chain at risk. Increased fertiliser costs are likely to squeeze farmer margins and have a particularly significant impact on developing countries, which could lead to reduced yields, increased food prices and higher food security risks.

Metals and battery materials production

Sulphuric acid is critical for copper, nickel and cobalt leaching operations, and disruptions to sulphur and sulphuric acid markets pose risks of increased costs, tighter supply and potentially even production cuts, with knock-on effects on downstream sectors.

Over 15% of global primary copper output is produced using sulphuric acid leaching and is therefore affected by the conflict, with the DRC and Chile the most vulnerable countries, as they have the largest sulphuric acid-based operations. For nickel, Indonesia is highly exposed, as it relies heavily on imports of sulphur from the Middle East (75% of its sulphur imports) to produce the large volumes of sulphuric acid required for nickel refining using the HPAL route. Given that the majority of cobalt is produced as a by-product of copper mining in the DRC or from nickel HPAL intermediate production in Indonesia, cobalt production is also affected.

Copper production based on sulphuric acid leaching, 2025



Note: DRC = Democratic Republic of the Congo.

Around 60% of all battery-grade lithium chemicals currently rely on sulphuric acid-based processing. Over 99% of hard rock lithium processing relies on acid roasting processing, which requires sulphuric acid. Due to the increase in acid prices, acid costs have increased from 3% of the cost of producing lithium chemicals from hard rock sources at the start of the year to over 11% as of the end of May 2026, overtaking energy inputs to become the largest cash cost component.

Sulphuric acid is also critical to rare earth concentrate processing, particularly the acid bake-and-leach route used for monazite, xenotime and lower-grade bastnaesite concentrates. Higher acid prices have caused sulphuric acid to increase to over 20% of rare earth C1 costs up from just 5% before the conflict.

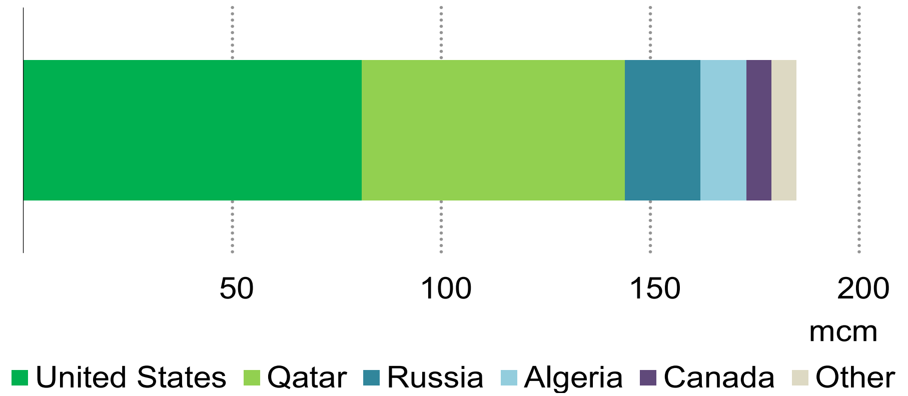
Finally, a number of critical battery precursors are affected by the conflict in the Middle East. All the battery metal sulphates, including nickel sulphate, cobalt sulphate and manganese sulphate, require sulphuric acid in their processing and, therefore, higher input costs are adding price pressure to these materials. Prices for all three have increased since the start of the conflict. Purified phosphoric acid, a critical precursor to LFP batteries, also requires sulphuric acid for its production. Phosphoric acid prices increased by almost 30% in the first quarter of 2026, reflecting the rise in sulphur and sulphuric acid prices.

Middle East conflict: Disruptions to helium and energy markets have created spillover risks for semiconductor, metals and mineral supply chains

Helium

The Middle East conflict has also affected the global supply of helium, a key material for semiconductor, fibre optics and medical supply chains, as well as semiconductor-dependent downstream industries.

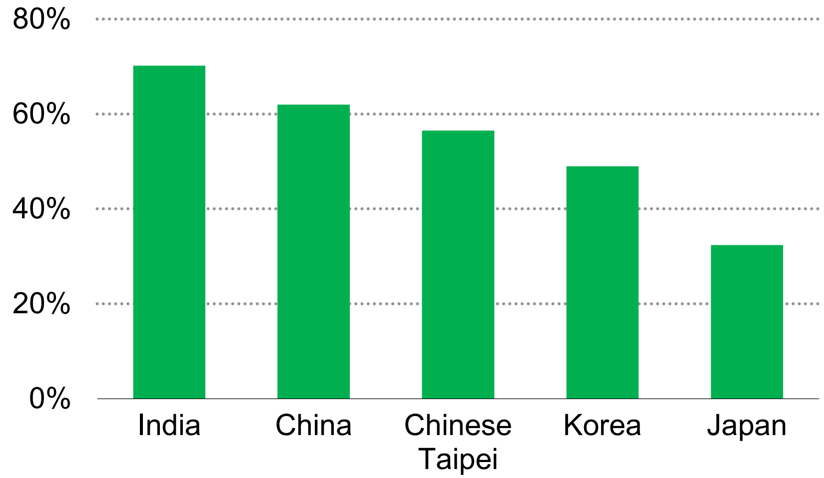
Helium production by country, 2025



Source: IEA analysis based on data from the United States Geological Survey (2026).

Qatar is the world's largest helium exporter, accounting for roughly 35% of global production. Helium production at Ras Laffan, currently halted, accounts for most of Qatar's helium supply. Helium prices spiked from around USD 15 per cubic metre in late February to almost USD 70 per cubic metre in April. This increase is not yet causing major price spikes across the downstream supply chain, as the helium price accounts for only minor shares of final product prices. However, a prolonged disruption could lead to physical supply shortages, prompting available supply to be prioritised for higher-margin applications, such as AI chips, with major implications for consumer electronics and industrial semiconductors.

Share of helium imports from Qatar in selected economies, 2025



Source: IEA analysis based on data from the World Integrated Trade Solution and International Trade Administration.

Qatar accounts for more than half of helium imports in China, India, Korea and Chinese Taipei, making these economies the most exposed to the disruptions. Alternative sources have responded differently to the crisis, with the United States increasing its exports to some of the most exposed countries, while Russia introduced export controls in April 2026.

Despite the significant disruptions, buffers and additional supply are still available to global helium markets. Major helium producers hold strategic inventories in Germany and the United States, with refining capacity available globally to process them, and both China and Russia are expected to add new production in 2026.

Other materials and feedstocks

Iran produces more than half of global strontium supply, which is key to producing permanent ceramic ferrite magnets. These are used widely in many sectors, from industrial motors to electronics and healthcare, sometimes as an alternative to rare earth magnets.

Some effects of the conflict are also being felt in steel markets. Iran accounts for 11% of global semi-finished steel trade, particularly low-cost billet and slab. Two major Iranian steel plants, Khuzestan Steel and Mobarakeh Steel, were hit by airstrikes, resulting in damage to production infrastructure. Both facilities reported having shut down operations and stated it could take up to one year to restart the units.

High crude oil prices in early 2026 had knock-on effects on the availability and pricing of needle coke, a critical feedstock for synthetic graphite production and a by-product of delayed coking units in refineries. As a result, short-term volatility in upstream oil markets translated into tighter conditions for segments of the graphite supply chain, particularly for battery-grade synthetic graphite.

Implications of energy disruptions

The outsized impact on energy markets is generating significant spillover effects in mineral supply chains. Mining operations are particularly exposed to disruptions in refined fuel markets, as diesel is a key input for heavy equipment, on-site power generation and transport, especially in remote and off-grid locations.

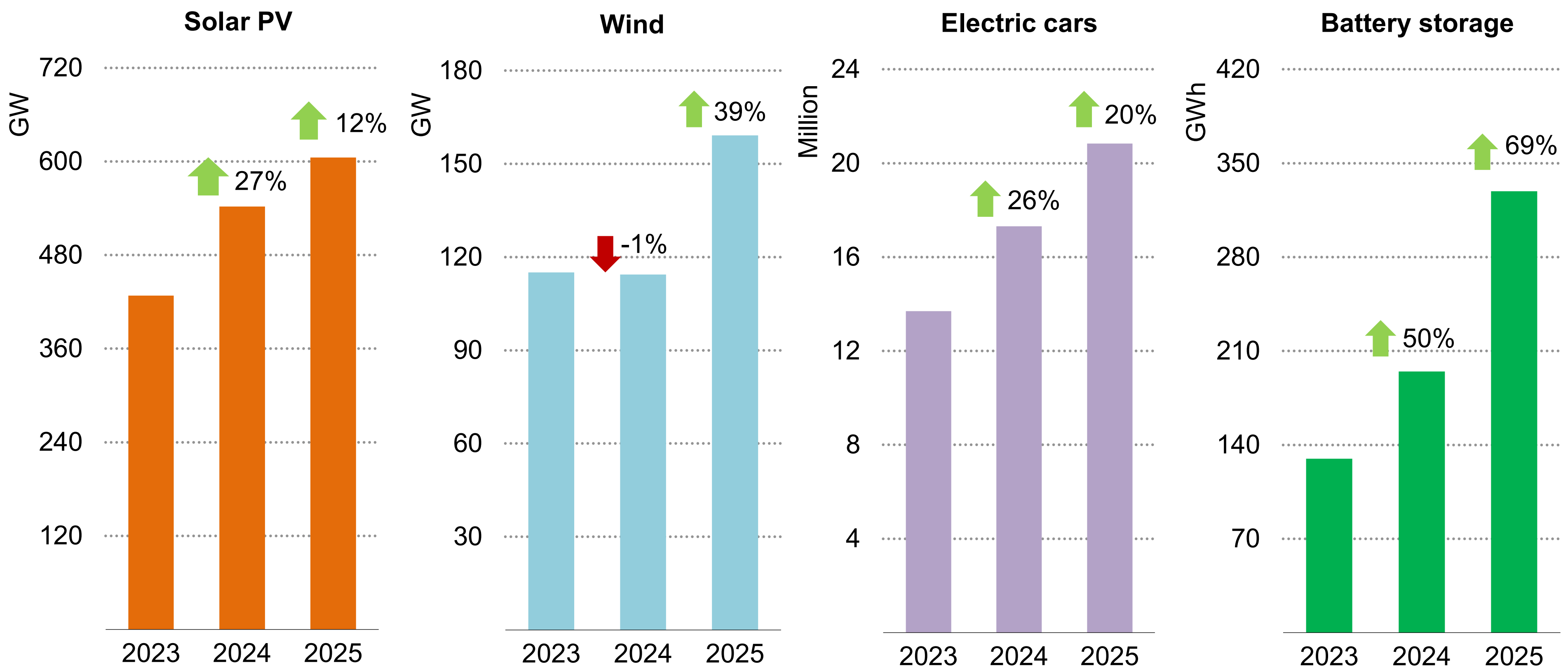
Rising diesel prices have already translated into operational challenges, especially for smaller mining producers, for which fuel logistics are more constrained. Disruptions have been reported in Australia, the DRC and Ethiopia. Large, diversified mining companies report that higher fuel costs have increased operating expenses by around 5%, though most have so far been able to maintain production by absorbing costs or drawing on long-term fuel supply contracts.

Natural gas markets have also been affected by the crisis, notably liquefied natural gas (LNG) exports from Qatar and the United Arab Emirates. Sustained constraints on LNG supply could have broader global repercussions through higher gas and electricity prices. Experience from the 2022 energy crisis highlights the vulnerability of energy-intensive metals production to such shocks, particularly in Europe, where high gas and power prices led to widespread curtailments of aluminium, zinc and other smelting capacity. While current price levels remain below the peaks observed in 2022, persistently higher energy costs may compress margins. Several smelters have announced temporary shutdowns or reduced operating rates, raising concerns about the resilience of midstream mineral processing capacity.

Downstream market trends

Deployment of renewables, electric cars and battery storage demonstrated steady growth in 2025, with solar PV breaking new records

Annual capacity additions for selected energy technologies



Note: GW = gigawatt; GWh = gigawatt-hour.

Solar PV and wind set new records across major markets, but China continues to lead global capacity additions

In 2025, global annual renewable capacity additions increased by 16%, reaching 800 GW despite facing challenges linked to supply chains, grid connection delays, financial pressures and policy shifts in some regions. It was the 23rd consecutive year in which renewables set new expansion records. Solar PV accounted for over three-quarters of new renewable capacity additions globally, followed by wind at 20%. China alone commissioned around 370 GW of solar PV and 117 GW of wind capacity, notable increases from 2024. India's annual renewable capacity additions rose by almost 60%, the fastest growth among major markets. The European Union added around 85 GW of new renewable capacity, a record high and about 10% more than in 2024. The United States installed 49 GW of renewable capacity in 2025, becoming the only major market to see a decline, at 10% compared with the previous year.

Solar PV capacity additions in 2025 rose by around 12%, surpassing 600 GW for the first time. This expansion brought cumulative global solar PV capacity to around 2 800 GW, making it the technology with the largest installed power generation capacity. Thirty countries installed over 1 GW of solar PV in 2025, almost twice as many as in 2020. China's shift from long-term fixed tariffs to competitive auctions, effective from June 2025, accelerated installations in the first half of the year, followed by a slowdown in the second half. In the European Union, solar PV led renewables growth, with almost 70 GW installed. Germany alone added 17 GW, accounting for one-quarter of the region's solar PV additions. Spain hit a record 14 GW, up 50% from 2024. India commissioned almost 50 GW of solar PV in 2025, double the previous year. Installations also continued to grow in Pakistan, with around 10 GW of additions in 2025, driven almost entirely by on- and off-grid distributed systems. South Africa installed over 3 GW of solar PV for the first time. Saudi Arabia's solar PV additions quadrupled to nearly 7 GW.

After a slowdown in 2024, annual wind capacity additions resumed growth in 2025, rising by nearly 40% globally to a record level of around 160 GW, despite ongoing supply chain challenges. Installations continued to accelerate in China as large-scale projects were completed. India's wind additions doubled in 2025 to reach over 6 GW. In the European Union, onshore wind capacity additions rose to about 13 GW. Offshore wind additions, however, fell to just 1 GW, down from 1.7 GW in 2024, with only France and Germany installing new capacity in 2025. The offshore wind industry faces multiple challenges, with several developers reducing their 2030 deployment targets. Lower expectations have been driven by the policy shift in the United States and project cancellations and delays in Europe, India and Japan due to cost and supply chain challenges.

As technology matures and scales to compete with traditional sources of power generation, the solar PV industry also continues to make strides in material efficiency

Since 2020, solar PV deployment has expanded rapidly while the intensity of key minerals has declined materially. Crystalline silicon (c-Si) technology retained a dominant market share of around 98% of global production, but manufacturers substantially reduced silicon consumption per unit of capacity through thinner wafers, lower kerf losses from improved diamond wire sawing and higher-efficiency cell architectures. Silicon intensity declined from roughly 3.2 grammes per watt (g/W) in 2020 to around 2 g/W by 2024, continuing a long-term trend of declining polysilicon consumption at an average annual rate of 10% between 2004 and 2024, despite rapidly increasing module output. At the same time, average module power ratings increased sharply, with mainstream utility-scale modules rising from around 400 W to close to 700 W over the same period as larger wafer formats and higher-efficiency tunnel oxide passivated contact (TOPCon) designs became standard.

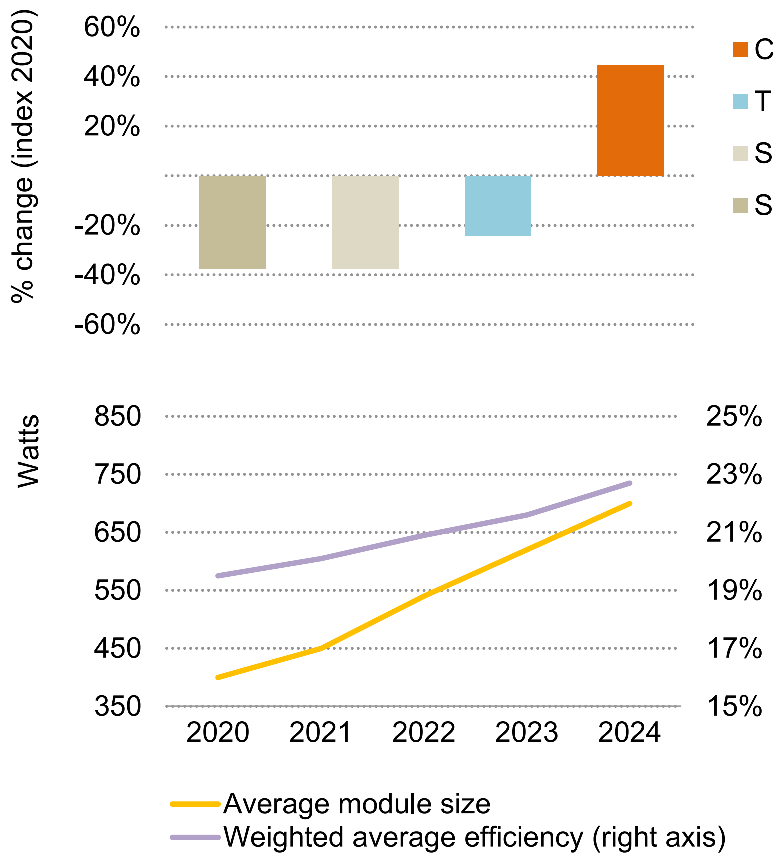
Silver intensity also declined significantly over the period, although total silver demand from the solar sector continued to rise because installation growth outpaced thrift gains. Despite making up just 0.14% of a PV module's weight, silver accounts for approximately 60% of the cell cost and 10% of the module cost. The crucial importance of silver in the PV industry is further amplified by the ongoing shift in the dominant PV technology. Within the c-Si segment, passivated emitter and rear contact (PERC) cells, which currently represent the industrial standard, are expected to be gradually replaced by more efficient c-Si sub-technologies, such as TOPCon cells and silicon heterojunction (SHJ) cells, both of which involve higher silver intensity. Nevertheless, advances in screen printing, multi-busbar architectures and finer metallisation lines reduced silver consumption in mainstream crystalline silicon cells from around 16 milligrammes per watt (mg/W) in 2020 to close to 10 mg/W in 2024. The industry is increasingly pursuing copper substitution to mitigate exposure to rising silver prices and potential supply constraints, particularly as TOPCon technologies typically require higher metallisation loadings due to contacts on both the front and rear sides of cells, compared with the earlier single-face metallisation PERC cells. Fraunhofer ISE reports that leading TOPCon and SHJ pilot designs are now approaching 5 mg/W through silver-copper pastes and copper plating technologies.

Tin intensity exhibited a more moderate downward trend over the same period. Tin is primarily used in solder ribbons and interconnection materials rather than within the solar cell itself, and reductions were driven mainly by thinner ribbons, improved module layouts and lower solder volumes associated with multi-busbar technologies. Industry estimates indicate that tin intensity declined from around 70 mg/W in 2020 to approximately 53 mg/W in 2024.

By contrast, copper intensity for solar PV increased steadily since 2020 as manufacturers increasingly substituted silver with copper for cell metallisation and expanded the use of copper-intensive electrical infrastructure associated with larger utility-scale installations. While copper has long been used in module ribbons, cabling, inverters and transformers, recent technology shifts have accelerated its role within the solar cell itself. In particular, TOPCon and SHJ architectures have prompted growing industry interest in copper electroplating and silver-copper hybrid pastes to reduce reliance on silver amid rising prices and concerns over long-term supply availability. Copper substitution is emerging as one of the principal pathways for reducing PV metallisation costs and lowering exposure to critical mineral supply risks. Although industry-wide copper intensity data for solar PV applications remain less standardised than for silicon or silver, copper use per watt increased gradually over the period as silver thrift strategies accelerated and module power ratings continued to rise.

Overall, the technology has been characterised by a structural decoupling between growth in deployment and mineral intensity per unit of power delivered. However, because annual global solar installations have consistently increased at remarkable pace, absolute demand for silicon, silver, copper, aluminium and glass has continued to rise strongly despite sustained efficiency improvements in material usage.

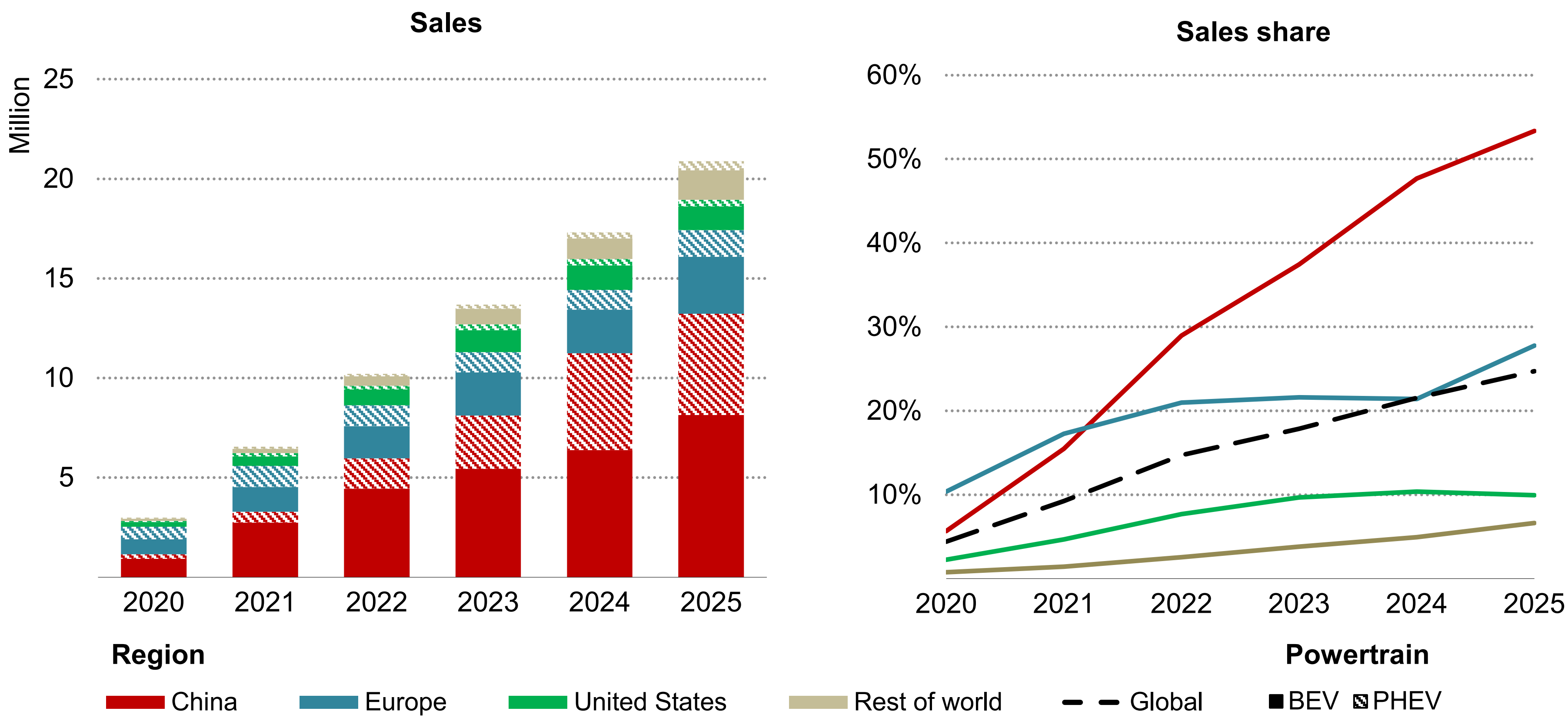
Change in material intensity per unit of power (top) and evolution of average module size and efficiency for c-Si modules (bottom), 2020-2024



Sources: IEA analysis based on data from Fraunhofer ISE and IEA-PVPS.

Global electric car sales reached 25% of global car sales, exceeding 20 million in 2025

Electric car sales by mode and region



Note: BEV = battery electric vehicle; PHEV = plug-in hybrid electric vehicle.
Source: IEA (2026), Global EV Outlook 2026.

Electric car sales resurged in Europe in 2025, reversing a stagnating trend

Global electric car sales reached new highs in 2025, exceeding 20 million, growing by 20% from 2024. One in four new cars sold globally were electric in 2025, with around 5% of the global car stock now electrified. Market developments again varied across regions, with growth slowing slightly in China due to the temporary halt of a trade-in scheme. However, the key story of 2025 was the major resurgence of electric car sales in Europe. Europe experienced strong sales growth following the step change in the European Union's carbon dioxide standards, with sales increasing 30% to more than 4 million.

China remains by far the world's largest electric car market, with more than 13 million electric cars sold in 2025, over 60% of all global electric car sales that year. Almost 55% of cars sold in China were electric in 2025, up from around half in 2024. Sales grew by almost 20% in China, a slight decline from the previous year, as the trade-in scheme introduced in 2024 was temporarily halted in several cities.

Europe was the standout story among major markets in 2025, with electric car sales increasing by more than 30%, reversing the relative stagnation seen since 2022. Europe's electric car sales share was almost 30%, and 24 out of 27 EU member states experienced an increase in their electric car sales share. This strong resurgence was the result of policy design, with the European Union's carbon dioxide standards coming into effect in 2025. In Germany, sales increased strongly, by 50%, with wider availability of affordable models reducing the average battery electric vehicle (BEV) price by 6% in 2025 and preferential tax treatment for electric car companies. In France, BEV sales increased by almost 15% while plug-in hybrid vehicle (PHEV) sales decreased by 25%. There was impressive sales growth in Italy (+65%), Poland (+125%) and Spain (+80%), supported by the reintroduction or continuation of EV purchase subsidies in 2025.

Sales grew strongly in the United Kingdom, increasing by more than 25%, with electric cars sales now comprising more than one in three new cars sold in 2025. Strong sales were supported by a subsidy for lower-priced BEVs, with over a quarter of sales eligible. One of the fastest-growing electric car markets in Europe in 2025 was Türkiye, where sales more than doubled compared to 2024. Electric cars represented over 20% of new car sales in 2025, up from just over 1% in 2022, supported by tax support and growing domestic production. As a result, Türkiye became the fourth-largest electric car market in Europe last year, after Germany, the United Kingdom and France.

In the United States, sales of electric cars were slightly lower in 2025 than in 2024, at around 1.5 million, while the sales share of electric cars remained relatively stable, at just below 10%. The stagnation was due to several policy shifts, including the ending of tax credits and removal of penalties for non-compliance with existing fuel economy standards through the passage in July 2025 of the One Big

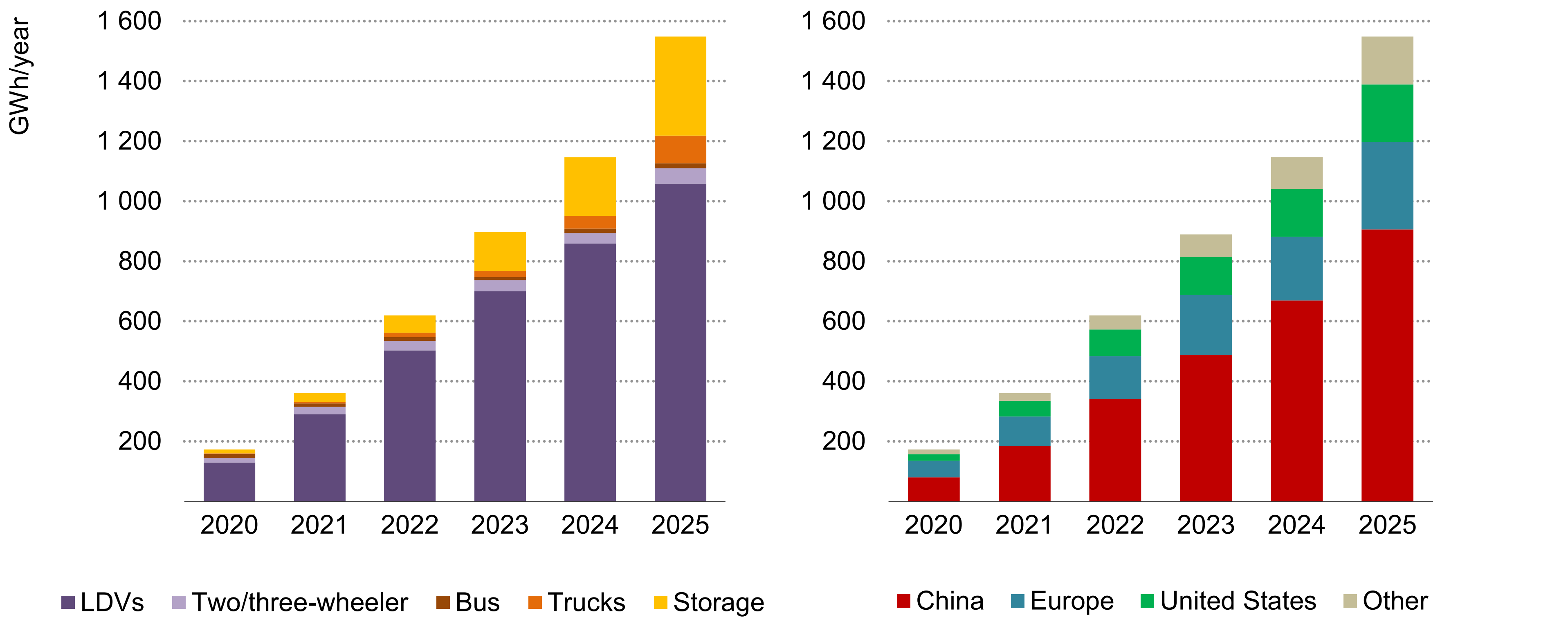
Beautiful Bill Act. The Act terminated tax credits for new and used electric car purchases after September 2025, which resulted in sales falling significantly in the last quarter of the year.

Outside these major markets, electric car sales increased steadily to reach 2 million in 2025, growing by 50%, primarily driven by increasing sales in key emerging markets. Rapid growth in these markets was driven by the increasing availability of lower-cost electric car models, primarily imported from China, which accounted for 60% of sales in these markets. Several markets doubled in size compared to 2024, with Southeast Asia experiencing the largest absolute sales growth. In Southeast Asia, annual sales more than doubled to reach a sales share of nearly 20%, led by Viet Nam, Indonesia and Thailand. In Latin America, sales grew by 75%, led by Brazil and Mexico.

In the first quarter of 2026, global sales were 8% lower than in the same period last year, mainly due to lower sales in China and the United States, following key policy changes. However, this global decline masks strong sales growth in many countries: in Europe, Q1 2026 sales were up almost 30% year-on-year, with around 250 000 more cars sold than in Q1 2025; countries in Asia Pacific outside China saw Q1 year-on-year sales growth of 80%; and Q1 sales across Latin America were up by 75%.

Global battery demand grew by over 35% in 2025, surpassing 1.5 TWh, with electric trucks the fastest growing market

EV and storage battery demand by mode and region, 2020-2025

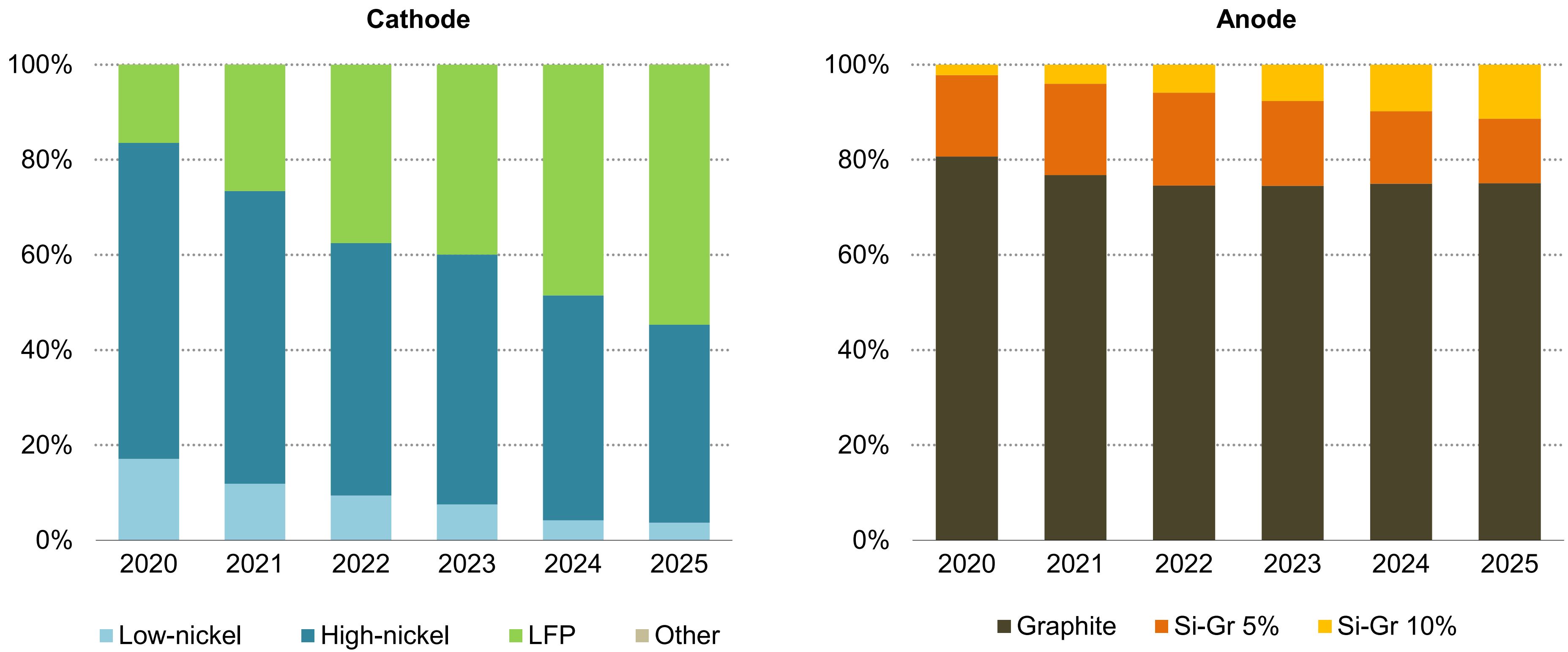


Notes: LDV = light-duty vehicle; GWh = gigawatt-hour. Battery demand reflects the batteries installed in vehicles sold in each region and not the battery demand for vehicles manufactured in each region.

Source: IEA analysis based on data from EV Volumes.

Lithium iron phosphate is now the dominant chemistry, supplying over half of the global electric car market

Electric car battery cathode and anode chemistry sales shares, 2020-2025

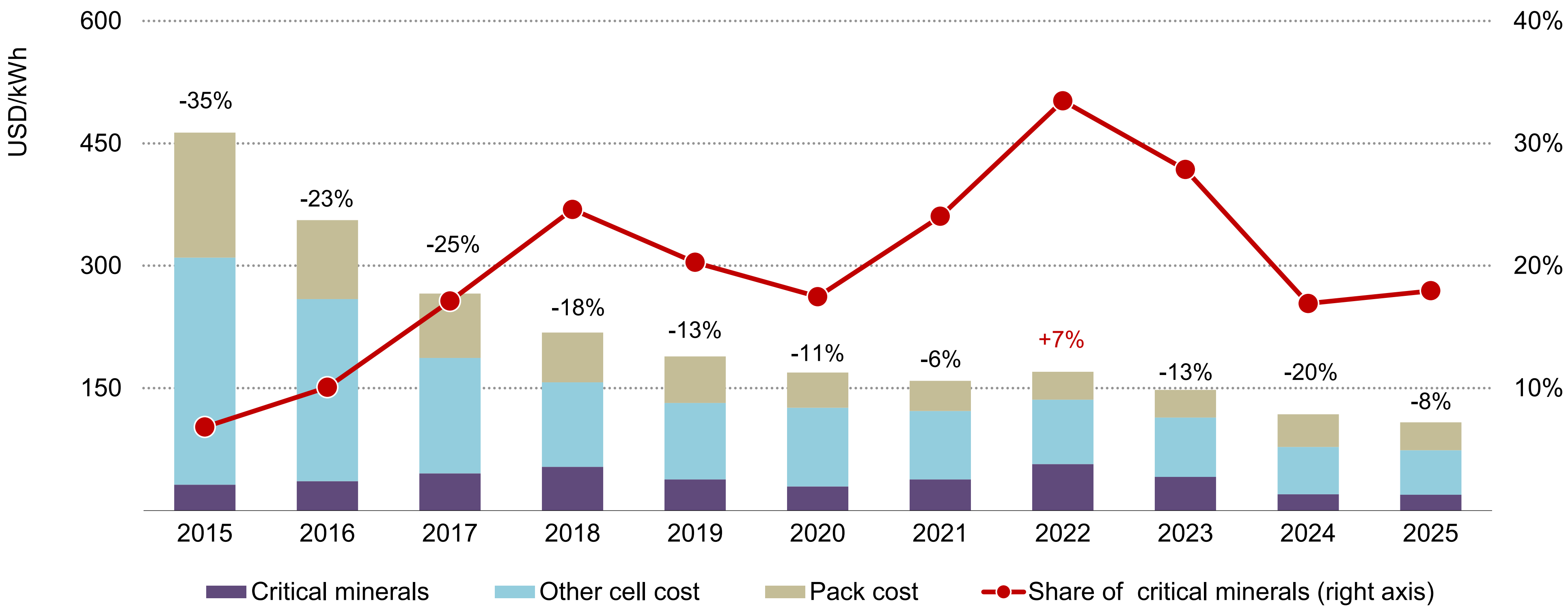


Notes: LFP = lithium iron phosphate; Si-Gr = silicon-doped graphite, with the stated percentage of silicon content. Low-nickel includes NMC333 and NMC532, where NMC refers to lithium nickel manganese cobalt oxide. High-nickel includes NMC622, NMC721, NMC811, nickel cobalt aluminium oxide and nickel manganese cobalt aluminium oxide. Sales shares are based on capacity. LFP data include some lithium manganese iron phosphate.

Sources: IEA analysis based on data from EV Volumes, BloombergNEF and the China Automotive Battery Industry Innovation Alliance.

Battery pack prices fell again in 2025, but critical minerals account for an increasing share of costs

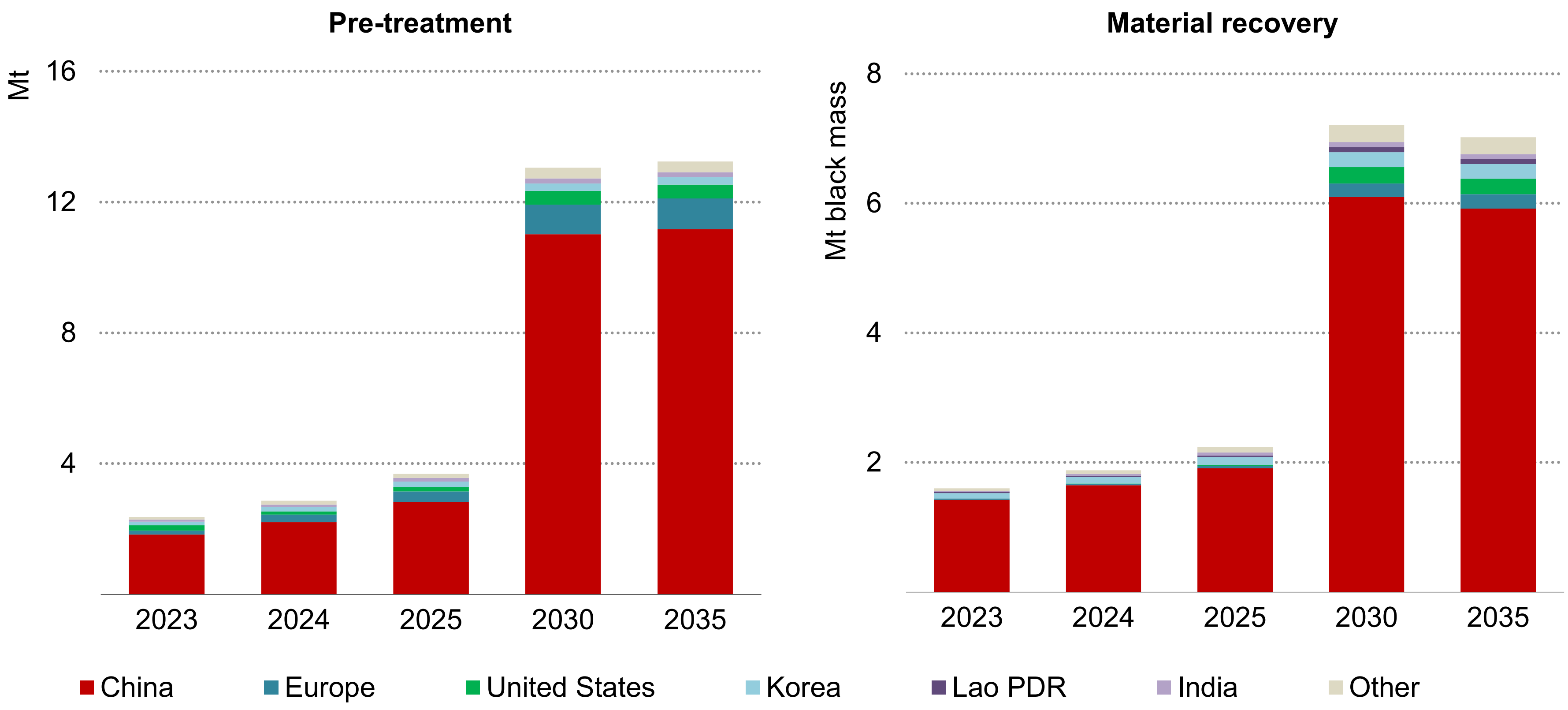
Global average lithium-ion battery pack price and share of critical mineral costs, 2015-2025



Notes: kWh = kilowatt-hour. Raw material costs include lithium, nickel, cobalt, manganese, graphite and copper. Other cell costs include electrolytes, separators and other components, as well as costs associated with labour, manufacturing and capital depreciation. The percentages on the bars show the year-on-year total global average battery pack price change. The analysis includes all cathode chemistries and global chemistry sales shares.
Source: IEA analysis based on data from BloombergNEF.

China dominates both battery recycling pre-treatment and material recovery capacity, but Korea is the current material recovery leader outside China

Pre-treatment and material recovery capacity, 2023-2035



Source: IEA analysis based on data from Benchmark Mineral Intelligence.

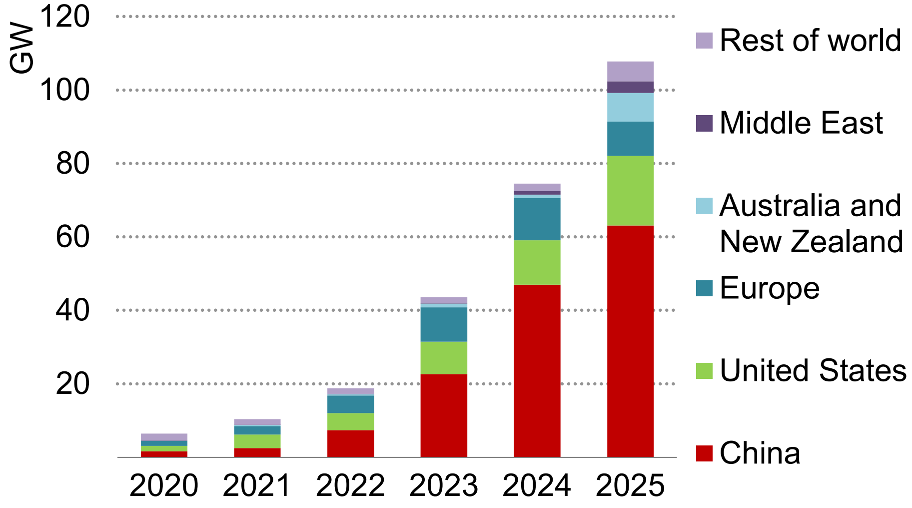
Battery markets reached new heights in 2025, but supply chain risks became a stark reality with new export controls targeting critical battery supply chain chokepoints

Global battery demand from EVs and storage surpassed 1.5 TWh in 2025, growing by over 35% year-on-year, up from 30% in 2024. Growth was primarily driven by EV deployment, with electric car battery demand alone surpassing 1 TWh. The fastest demand growth came from electric trucks, where demand more than doubled for the second year in a row, primarily driven by a sharp acceleration in sales in China. Electric trucks accounted for over 6% of total EV and storage battery demand in 2025, up from just 2% in 2023. China again dominated battery deployment, with almost 60% of global demand in 2025, at over 900 GWh, increasing its share from 2024. Europe was the second-largest battery market, with 20% of global deployment, while deployment in the United States stagnated, with its global share falling to just over 10%.

Battery storage market

Battery storage demand grew robustly in 2025, growing by over 70% to reach 330 GWh (110 GW) and over 20% of the global battery market. Battery storage is now a major driver of battery demand growth. Utility-scale battery storage accounted for the majority of capacity additions, at 80% in 2025. Deployment continued to be led by China, the United States and Europe, but there was major growth in other markets, particularly Australia and Saudi Arabia, showing a broadening of the global battery storage rollout.

Battery storage additions by region, 2020-2025



Note: Includes both utility-scale and behind-the-meter battery storage.
Source: IEA analysis based on data from Benchmark Mineral Intelligence.

Additions in China grew by one-third in 2025, with utility-scale installations accounting for around 90%, while behind-the-meter additions continued to expand steadily alongside distributed solar. The United States saw the strongest growth among major markets in 2025, growing by 75% year-on-year, with utility-scale systems comprising around 85% of demand. In Europe, total battery storage additions were slightly lower than last year falling by 20% but with a clear structural shift towards utility-scale systems, which reached 75% of additions. Australia stood out, with additions surging to nearly 8 GW, almost nine times higher than the previous year. This was driven by the increasing use of storage to support renewables integration. Behind-the-meter storage also grew strongly in Australia, supported by federal and state incentives. The Middle East saw significant growth in additions, reaching 3 GW, a threefold increase in 2025. This was driven almost entirely by Saudi Arabia, where battery storage has become a key source of system flexibility.

Battery pack price trends

In 2025, average battery pack prices fell by 8% to USD 108/kWh, driven by continued improvements in manufacturing efficiency, battery chemistries and technology developments, as well as intense global market competition. The share of critical minerals in battery prices increased in 2025 for the first time since 2022, reaching almost 20% of total pack costs, driven by major increases in lithium and cobalt prices, with lithium doubling and cobalt increasing by 130% from the start of 2025 to April 2026. Lithium prices increases were driven by strong battery demand growth, particularly from energy storage, alongside constrained supply from Australia and China and uncertainty from Zimbabwe's export restrictions. Cobalt price increases were driven by export restrictions imposed by the DRC. If these trends continue, there could be strains on battery producer profitability or increasing upward pressure on battery prices. Regional disparities in battery prices increased in 2025, with battery pack prices in China 30% lower than in North America and 35% lower than in Europe, compared with 20-25% in 2022.

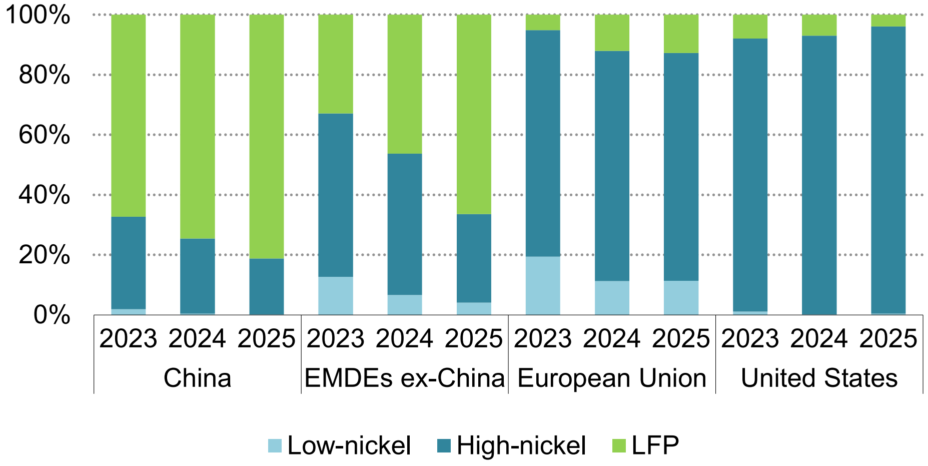
Lithium iron phosphate (LFP) battery prices hit record lows in 2025 and were a major driver of global battery price reductions that year. LFP battery packs were more than 40% cheaper on average than lithium nickel manganese cobalt oxide (NMC) alternatives per kWh in 2025. LFP batteries benefit from structurally lower material costs than nickel-based chemistries, but there are concerns that intense market competition is driving prices too low. Many LFP cathode active material producers are currently operating at a loss while still increasing manufacturing capacity, raising the risks of excess capacity and consolidation.

Battery chemistry trends

LFP is now the dominant battery chemistry, accounting for 55% of global EV batteries sold in 2025, up from nearly half in 2024. Deployment of LFP batteries remains concentrated in China, with a sales share of 80% in 2025, but LFP batteries are rapidly increasing their penetration in other emerging markets, accounting for two-thirds of EV sales in these regions in 2025, up from 45% in 2024. This remarkable growth has been driven by increasing imports of Chinese vehicles and batteries. In the European Union, the share of LFP increased slightly to almost 15%. Nearly all the batteries imported into the region were from China, with the majority (70%) imported in LFP-equipped EVs and a minority (30%) imported directly. In the United States, the share of LFP in EVs deployed almost halved in

2025 to less than 5%. This decrease was driven by increased tariffs on Chinese imports and more stringent tax credit sourcing requirements.

Share of electric vehicle battery sales by chemistry and region, 2023-2025



Notes: EMDEs = emerging markets and developing economies. Two/three-wheelers are excluded from the analysis. Low-nickel includes lithium nickel manganese cobalt oxide (NMC) 333, NMC442 and NMC532. Mid- and high-nickel includes NMC622, NMC721, NMC811, lithium nickel cobalt aluminium oxide and lithium nickel manganese cobalt aluminium oxide. Lithium iron phosphate also includes lithium iron manganese phosphate. Battery chemistry sales shares are based on the battery capacity of new electric vehicles registered.
Source: IEA (2026), Global EV Outlook 2026.

Sodium-ion batteries are on course for commercial success, and 2026 could prove to be a pivotal year for the technology's scaling efforts, with leading battery producers, such as CATL and BYD, starting to commercialise the technology at scale. The significantly improved low-temperature performance of sodium-ion batteries compared to lithium-ion batteries has driven considerable attention in China. Nevertheless, highly optimised and low-cost LFP technologies continue to offer advantages in energy density, supply chain maturity and cost. For sodium-ion batteries to compete more broadly, it is likely that there would need to be sustained higher lithium prices or technological advances. Solid-state battery research and investment continue to attract attention and financing due to promised higher energy density and safety, but these advantages have not yet been demonstrated in real-world applications. Emerging markets, such as humanoid robots, may become an early source of demand for solid-state battery manufacturers, supporting production scale-up and optimisation to help reduce high manufacturing costs.

Battery supply chains

China currently dominates the midstream and downstream battery supply chain and is particularly dominant in the LFP battery supply chain. In 2025, China processed 70-95% of global lithium, cobalt, phosphate, manganese and graphite and produced 98% of LFP cathode materials, two-thirds of nickel-based cathode material, over 90% of anode material and 80% of global battery cells. It also accounts for 95% of global cathode material precursor production capacity.

China's dominance in the production of LFP cathode materials and batteries, graphite anode materials and cathode material precursors makes these critical chokepoints in global battery supply chains. Their vulnerabilities were highlighted by the battery export controls introduced in October 2025, which are currently suspended and covered all of these materials as well as battery manufacturing equipment and technologies. Moreover, with the continued growth in LFP battery deployment and emerging chemistries such as sodium-ion and manganese-rich chemistries, the importance of battery-grade manganese sulphate and purified phosphoric acid is rapidly growing. As China also dominates the production of both materials, they are emerging as additional chokepoints for global battery supply chains.

Efforts to develop diversified LFP battery production capacity are gaining momentum. The United States is among the leaders, with over 50 GWh of battery manufacturing capacity reallocated to LFP production in 2025, notably from LG Energy Solution and Ford, targeting the rapidly expanding battery energy storage market, which accounted for one-third of battery deployment in the United States in 2025. Korean and Japanese producers are also investing in LFP production, while new capacity is being developed in Indonesia. These developments are an important first step towards diversification. However, the LFP battery supply chain remains highly concentrated in China, and there are major ecosystem barriers to realising LFP production at scale, including production expertise, equipment and technology gaps, which should not be underestimated.

Battery recycling

Global pre-treatment capacity has reached almost 4 Mt of spent batteries, while material recovery has reached over 2 Mt of black mass refining capacity, considerably exceeding available feedstock. Currently, recycling plays an important role in battery supply chains, primarily by recovering material from manufacturing scrap generated during the production of battery cells and components. China continues to dominate global battery recycling capacity, with over three-quarters of pre-treatment capacity and almost 90% of material recovery capacity. Some Chinese recyclers, such as Brunp, the battery recycling subsidiary of CATL, benefit from direct links with the top battery manufacturers, enabling preferential access to manufacturing scrap feedstock. Many other recyclers face challenges securing feedstock given the excess global recycling capacity. Outside China, Europe holds the largest share of global pre-treatment capacity, at almost 10%, but accounts for less than 2% of global material recovery capacity. Korea is the leading country outside China in material recovery, with 6% of global capacity. The United States holds less than 5% of pre-treatment capacity and less than 1% of material recovery capacity.

Black mass payables, 2024-2026

Notes: Nickel and cobalt payables, CIF South Korea (% payable against LME nickel and Fastmarkets standard-grade cobalt prices).
Source: IEA analysis based on data from Fastmarkets.

In August 2025, China started allowing imports of high-grade black mass, which had previously been banned. There has been limited short-term impact, as black mass flows were often being upgraded elsewhere for final refining in China, but this policy shift could increase direct flows to China. In March 2025, the European Union formally classified black mass as hazardous waste, banning its export to non-Organisation for Economic Co-operation and Development (OECD) countries. Black mass leakage has been prevalent due to the lack of material recovery capacity in Europe, but this policy aims to reduce further outflows and incentivise domestic recovery capacity development. At present, most black mass exported from the European Union has been directed to Korea.

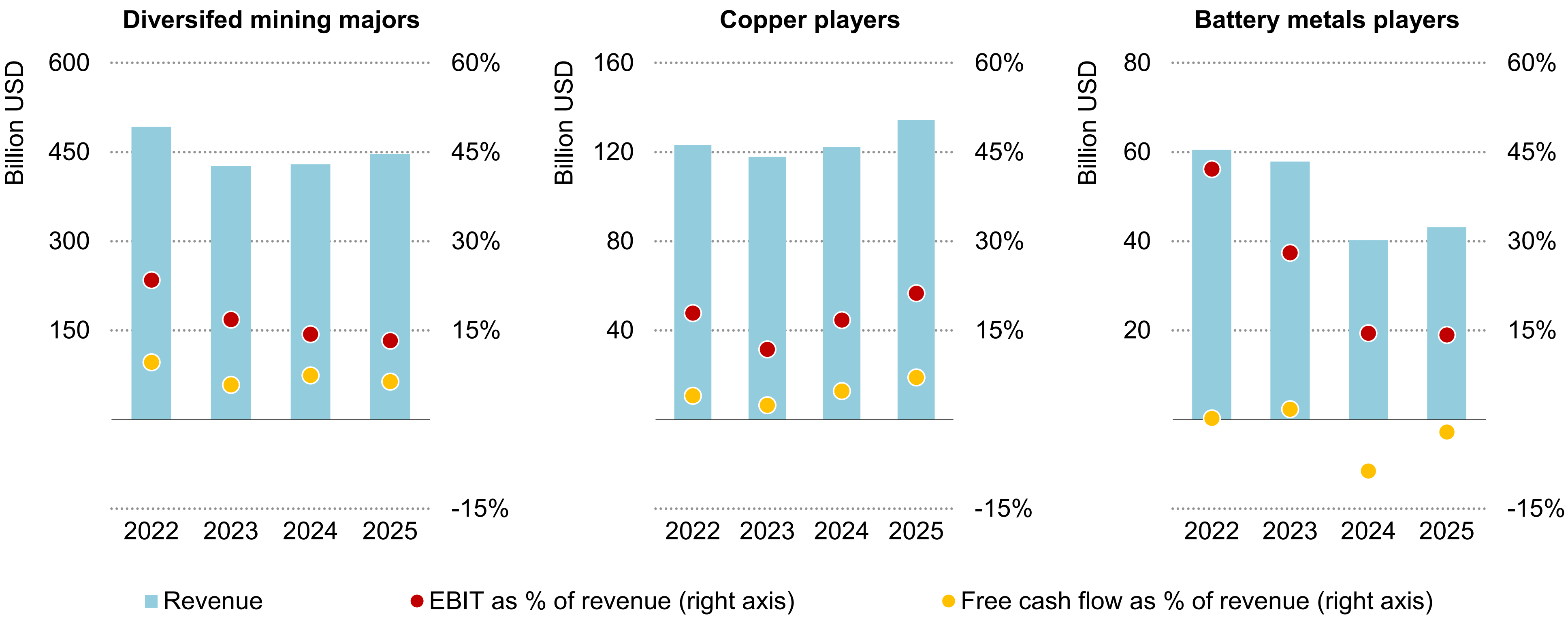
Black mass prices have surged through 2026, driven by tightening supply across battery metals. Increased demand from China due to the lifting of its black mass import ban and the reduction in import tariffs has also been fuelling price rises. Black mass payables have surged to over 100% in recent months, reflecting these compounding factors.

Global recycling capacity is set to surge in anticipation of the expected wave of end-of-life EVs in the 2030s. By 2030, pre-treatment capacity is set to increase almost fourfold while material recovery capacity is set to rise by more than threefold. However, limited global diversification is anticipated based on the current project pipeline. China dominates planned capacity expansions, increasing its share of pre-treatment capacity to 85% and maintaining a similar share of material recovery. Nevertheless, both Europe and the United States are planning to expand their material recovery capacity significantly by 2030, increasing sixfold and thirteen-fold, respectively. It remains to be seen how much of this planned material recovery capacity will materialise.

Investment trends

Financial performance improved across mineral producers in 2025, with copper companies recording the strongest gains

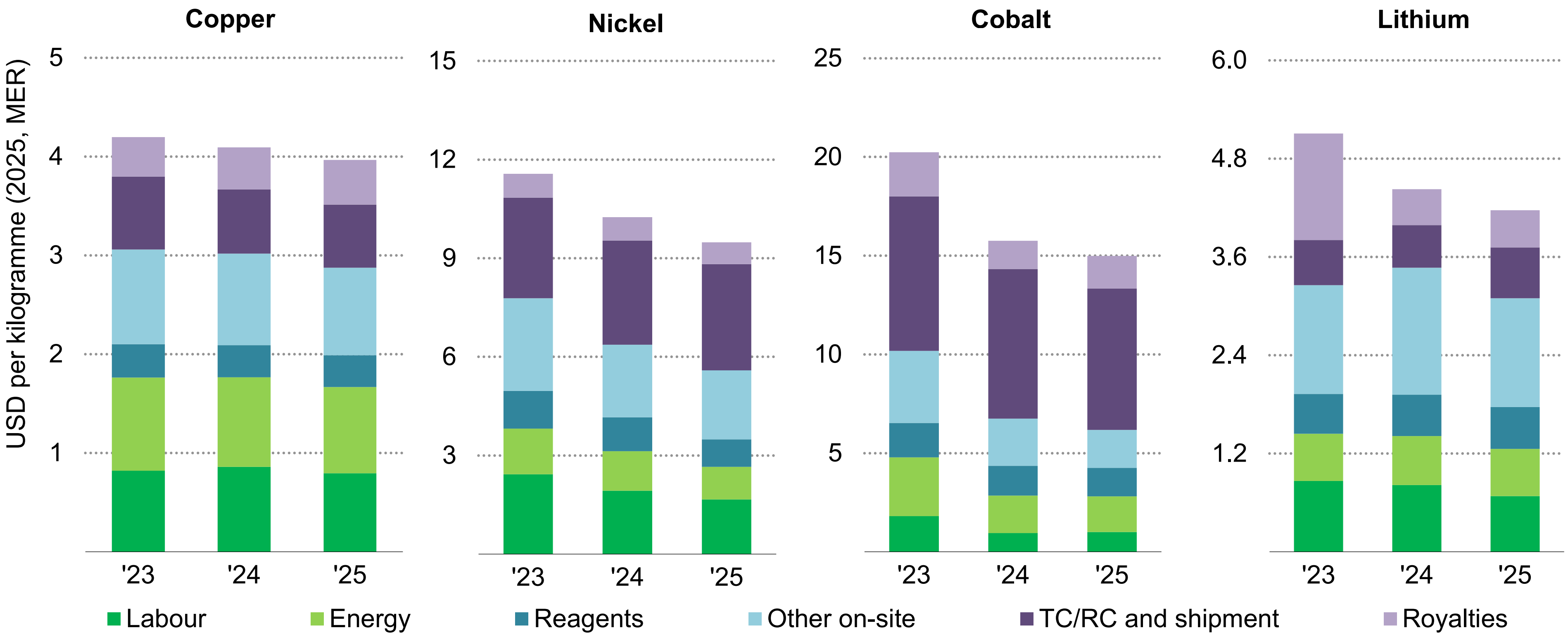
Aggregate financial performance of major mining companies by type



Note: EBIT = earnings before interest and taxes.
Source: IEA analysis based on data from S&P Capital IQ.

In 2025, production costs for copper and battery metals continued to decline, although the pace of reductions slowed for battery metals

Production cash cost trends



Notes: MER = market exchange rate; TC/RC = treatment and refining charges. Production costs are based on the weighted average value of the assets in the 75th quartile.

Source: IEA analysis based on data from S&P Capital IQ.

Declining production costs and rising prices supported margins, although trends diverged across commodities

In 2025, improved market conditions, including rising commodity prices, led to a 5% increase in industry revenues, reversing the downward trend observed since 2023, based on our assessment of 24 mining companies with a strong presence in critical minerals production (see Annex for details). However, the recovery was uneven across company types. Copper-focused companies were the primary drivers, with revenues increasing by around 10%, supported by strong demand growth, higher prices and increased by-product revenues. Profitability also improved markedly, with average operating profit margins rising from 17% to 21% and free cash flow margins increasing from 5% to 7% of revenue, underscoring copper's strong cash-generating position.

By contrast, battery metals companies, including those focused on nickel, cobalt and lithium, experienced some revenue recovery following the downturn in 2024. However, operating profitability declined slightly, with free cash flow generation improving but remaining negative. While these trends indicate some degree of market stabilisation, financial performance remains relatively constrained, reflecting weaker pricing conditions across battery metal markets. Recent price increases are nevertheless likely to provide some support to company financials in 2026.

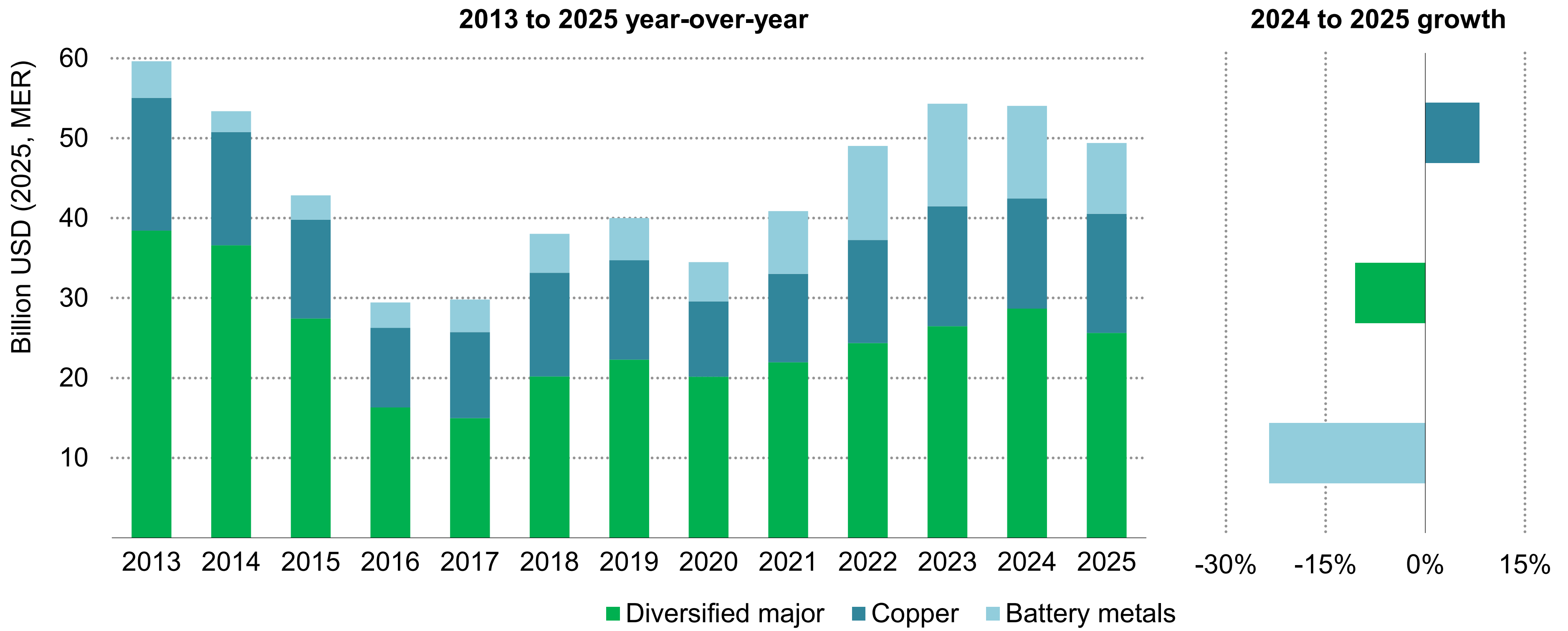
Diversified mining majors continued to demonstrate resilient performance, with aggregate revenues increasing by 4% year-on-year, while operating profit and free cash flow margins remained broadly stable.

Production costs for copper, nickel, cobalt and lithium continued to decline in 2025, extending the downward trend observed since 2024. Copper costs fell gradually over the past three years, while cost reductions for battery metals moderated in 2025 following substantial declines in earlier years. The decline in 2025 was underpinned mainly by lower labour, energy, reagent and other on-site costs, with nickel seeing strong reductions across most categories, while cobalt largely benefited from lower on-site costs. Lithium costs were pulled down by lower labour and on-site costs, although higher treatment and refining charges and shipment costs partly offset these gains. Copper costs saw more modest declines, with lower labour and on-site costs helping to offset rising royalty payments.

Despite recent declines in production costs, supply chain disruptions linked to the Middle East conflict could place upward pressure on costs in 2026. Higher energy prices, freight rates and reagent costs, particularly for sulphuric acid, may increase operating costs across several mineral supply chains.

Critical mineral investment fell in 2025 after several years of growth, with the strongest decline among battery metal companies

Capital expenditure on non-ferrous metal production by major mining companies

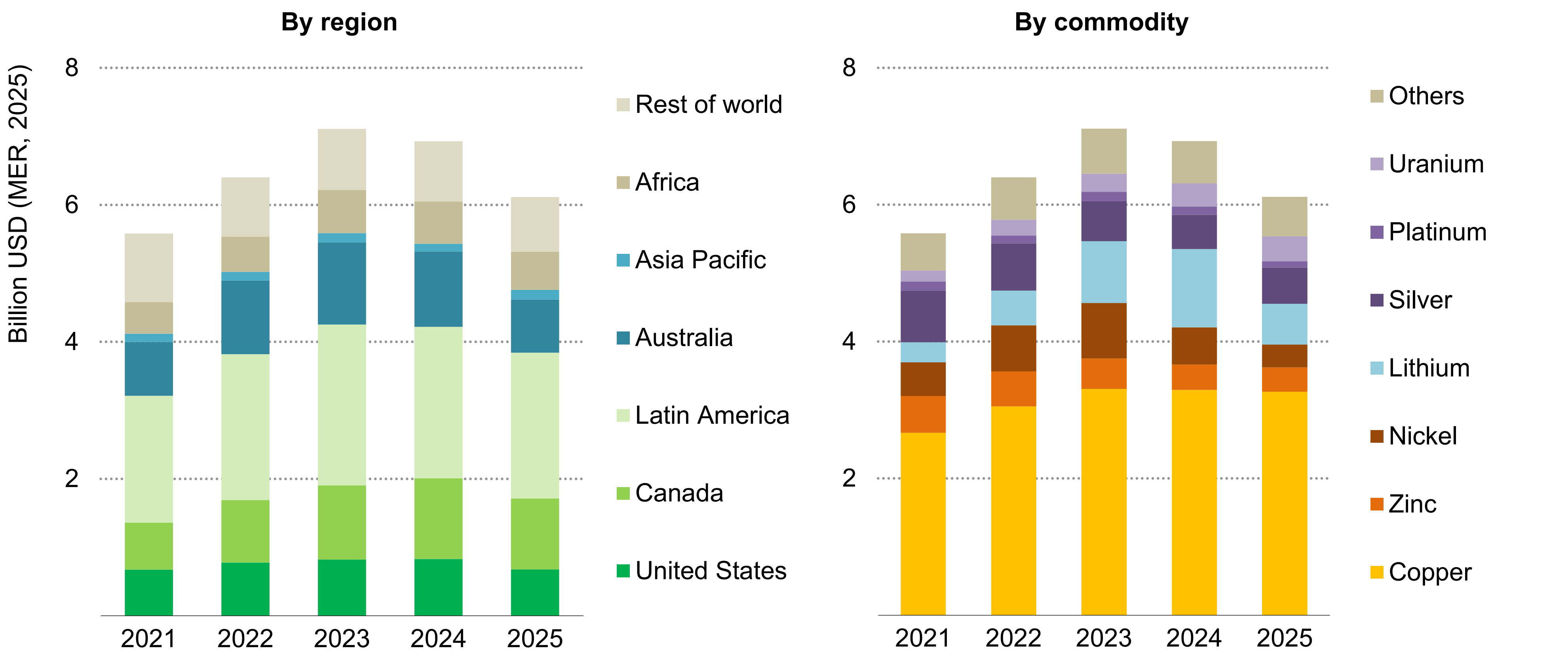


Notes: MER = market exchange rate. Excludes budgets for iron ore, coal, aluminium, gold and diamonds. Based company reporting from 24 major mining companies.

Source: Based on company reporting from 24 major mining companies. The companies are listed in the Annex.

The growth in exploration spending seen since 2021 stalled in 2024 and declined in 2025…

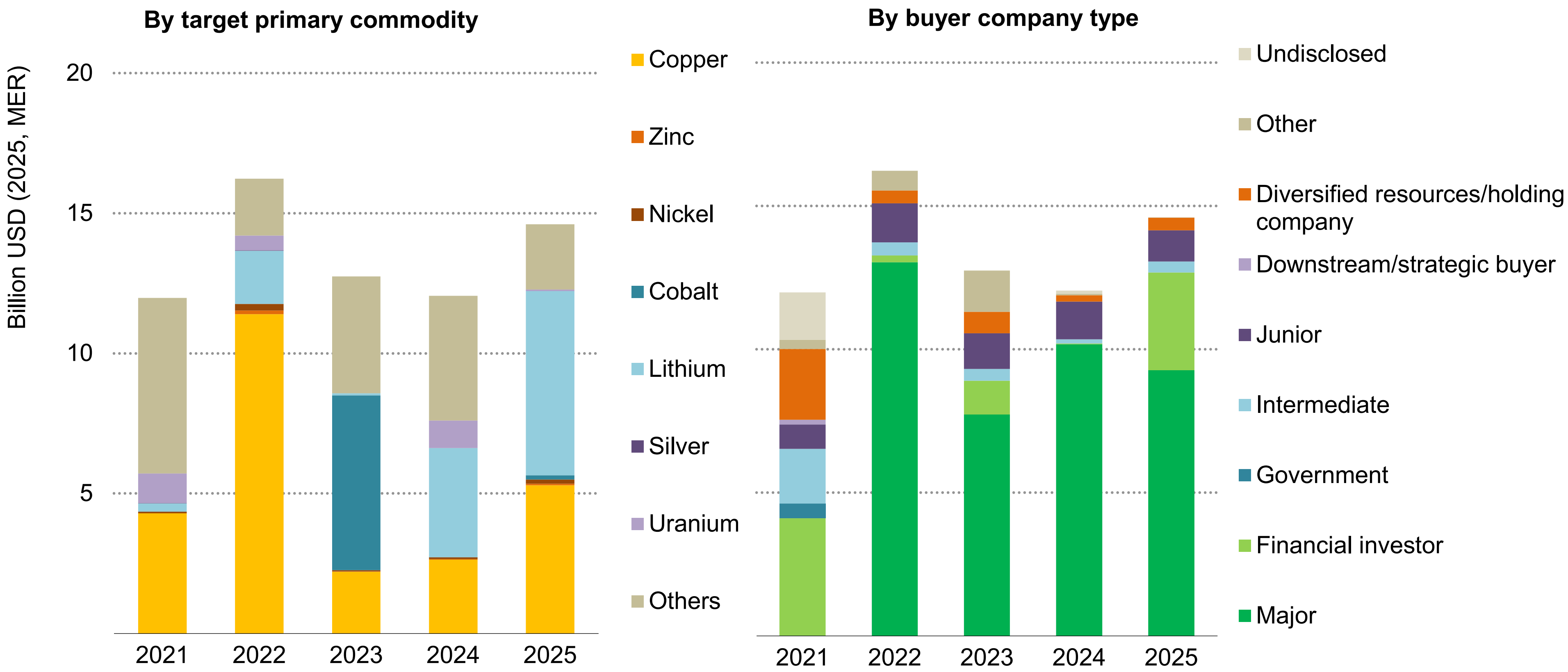
Exploration spending for selected non-ferrous mineral resources, 2021-2025



Notes: MER = market exchange rate. Excludes budgets for iron ore, coal, aluminium, gold and diamonds. Others refer to cobalt, rare earth elements, potash/phosphate and many other minor metals.
Source: IEA analysis based on data from S&P Capital IQ.

…while M&A activity picked up, driven by financial investors and majors acquiring copper assets

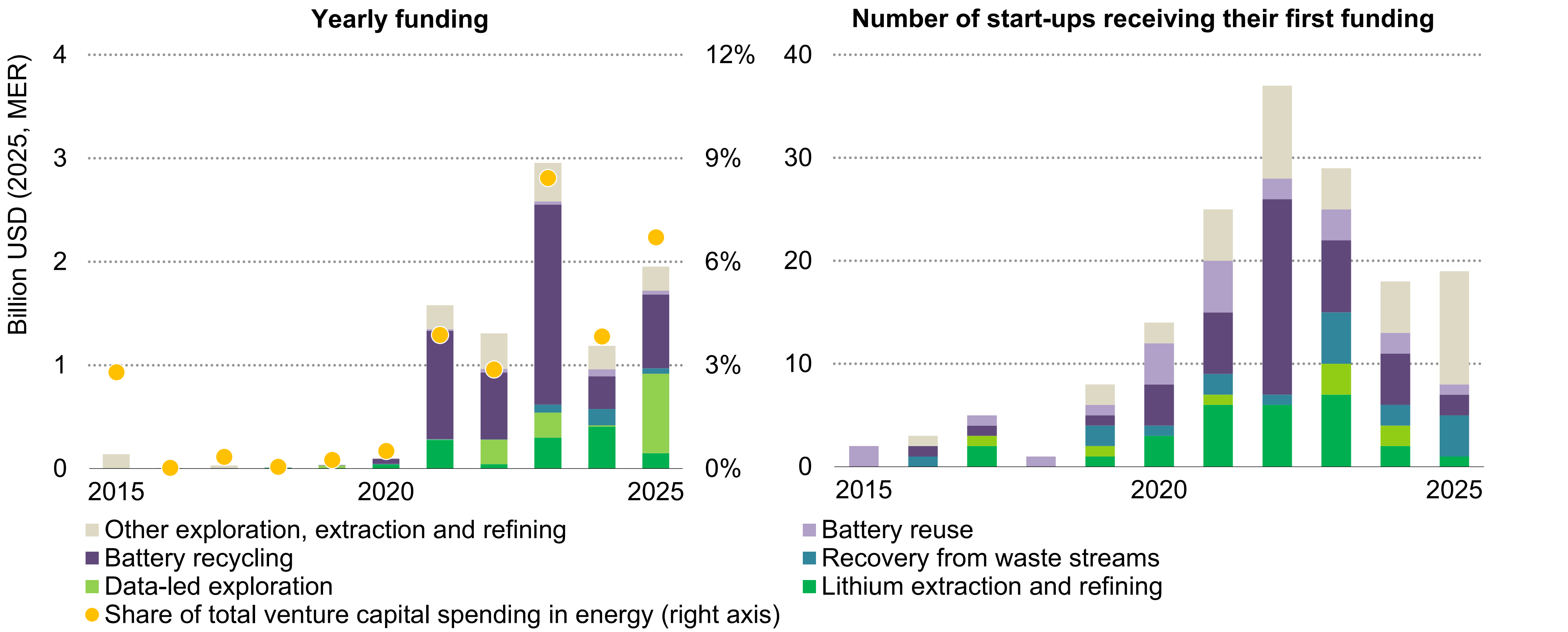
M&A activity for selected non-ferrous mineral resources, 2021-2025



Notes: MER = market exchange rate. M&A activity only considers completed transactions and is categorised according to the primary commodity of the acquired company.
Source: IEA analysis based on data from S&P Capital IQ and company information.

Venture capital spending grew strongest in companies focused on innovative ways to extract minerals

Equity funding of critical minerals technology start-ups, 2015-2025



Notes: MER = market exchange rate. Since the publication of Global Critical Minerals Outlook 2025, a new category for data-led exploration has been added to reflect the growing interest of innovators in the use of artificial intelligence in this area. This category now includes KoBold Metals, whose January 2025 deal has been allocated to 2025 instead of 2024.
Sources: IEA analysis based on data from Cleantech Group and Crunchbase.

Critical mineral investment diverged across segments, with battery metals weakening while copper remained strong, reflecting its central role in electricity systems

Despite improved financial performance, strong underlying demand and a recovery in prices for some critical minerals in 2025, companies and investors remained cautious. This reflects elevated risks associated with market concentration and geopolitical developments, price volatility and uncertainty around future technology pathways.

After several years of rapid growth, investment in critical minerals slowed in 2025. Our assessment of 24 large mining companies indicates that aggregate capital expenditure fell 9% year-on-year, marking the first substantial decline since 2020. The sharp price increases observed between 2021 and 2022, followed by renewed volatility in 2024-2025, exposed structural uncertainties around critical mineral supply chains and complicated investment decisions. Investment trends vary markedly by company type and commodity. Companies focused on battery metals, such as lithium, nickel and cobalt, experienced the largest decline in capital spending in over a decade, falling by over 20%. Lithium specialists in particular reduced investment by around 40%, following several years of strong growth. This retrenchment reflects a combination of shifting battery chemistry preferences, oversupply-driven price weakness and policy uncertainty in key markets, all of which have weighed on investor confidence in battery metal markets.

Diversified majors scaled back their spending more modestly, while companies focused on copper registered an increase of 8% year-on-year, underscoring investor confidence in copper's long-term growth given its central role in electricity systems.

These patterns are also reflected in mineral exploration. Critical mineral exploration spending fell by over 10% in 2025. Again, this slowdown was commodity-specific: copper continued to be the main focus of exploration budgets, with spending remaining broadly steady year-on-year. Lithium and nickel, however, both saw notable drops of around 40%. For lithium, this largely reflects subdued prices following rapid supply expansion in recent years, while for nickel, it is the result of rising uncertainty linked to battery chemistry shifts and policy changes by major suppliers. Across regions, the largest declines in exploration spending were in Australia and the United States, at around 25%, whereas Asia Pacific recorded a 20% increase.

In parallel, China has made substantial domestic investments in geological exploration, exceeding USD 15 billion in 2024 across all minerals, and has continued to expand refining and processing capacity both domestically and through overseas investment, reinforcing its central role across multiple stages of critical mineral supply chains.

Overall M&A deal value rebounded in 2025, though the increase resulted largely from a single USD 6.3 billion deal between Rio Tinto and Arcadium Lithium. Behind this rise, divergence across commodities was very pronounced. Spending on copper assets doubled between 2024 and 2025 owing to consolidation and competition for high-quality resources, reflecting copper's strategic importance and the concentration of high-value assets. In contrast, deal activity in battery metals remained subdued beyond the Rio Tinto-Arcadium transaction, again highlighting weaker investor sentiment.

Venture capital (VC) investments in critical minerals recovered in 2025 and remain concentrated in technologies aimed at extracting more value from resources. Critical minerals have accounted for around 5% of total energy technology VC funding since 2021, up from negligible levels previously. In 2025, critical minerals start-ups raised USD 2 billion in total, almost 1.5-times higher than the 2024 level. This 2025 trend runs counter to the decline seen in energy technology VC in general, and in VC across all economic sectors except AI.

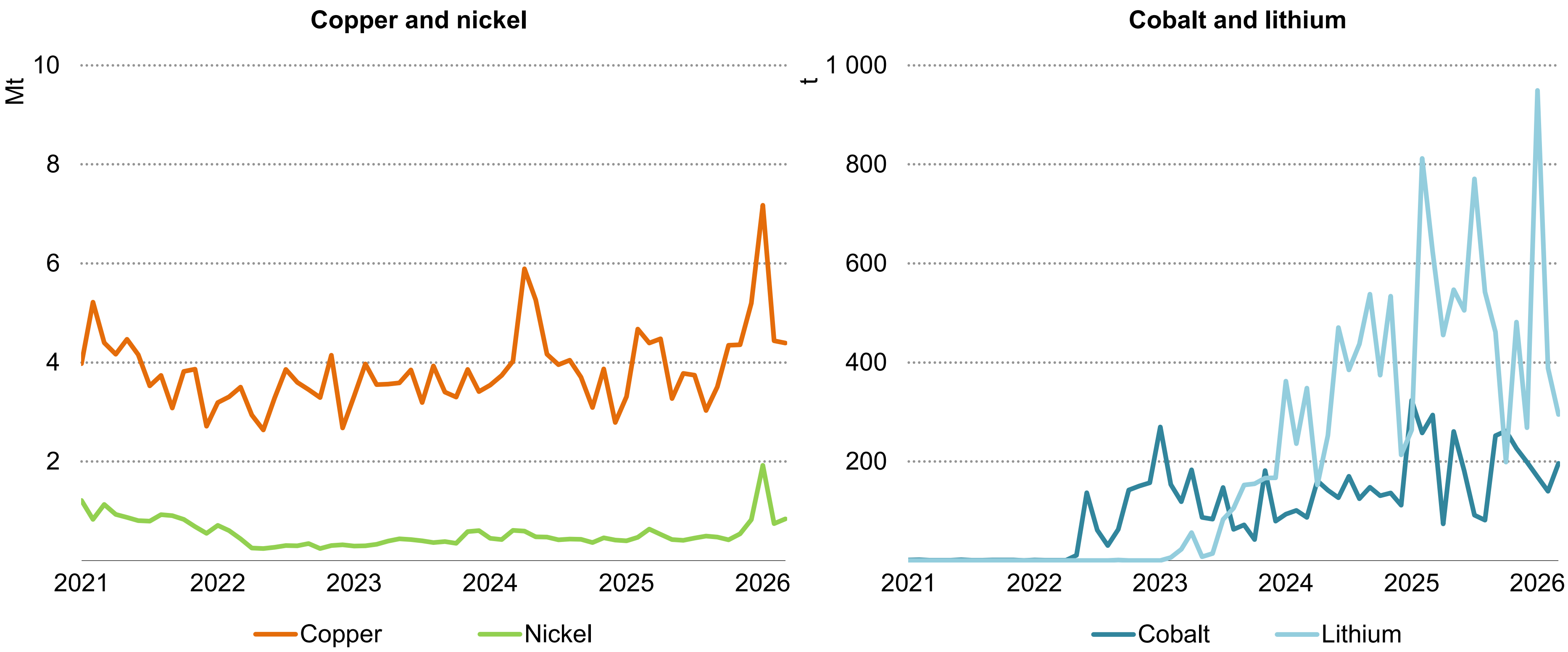
This reflects strong investor interest in new technologies with high perceived market potential, particularly direct lithium extraction, data-led exploration and advanced separation processes. However, funding is not evenly spread across regions, with much of it going to US start-ups. KoBold Metals, a United States-based data-led exploration start-up founded in 2018, alone accounted for one-third of total funding in 2025.

However, funding remains well below the level in 2023, reflecting a more difficult environment for VC fundraising amid higher interest rates and policy uncertainty. These concerns have not eased in 2026, and a near-term rebound in VC for critical minerals to previous levels remains unlikely. This poses a challenge for new start-ups that are being launched and seeking funding. While almost 70 start-ups raised their first round of funding in 2022 or 2023, only 40 did so in 2024 or 2025. They are also raising less money on average, with an average first-round size of USD 12 million in the last year, versus almost USD 20 million two years ago.

Data suggest that it has become more difficult to scale up rapidly. Only three start-ups founded since 2020, Cyclic Materials, Vulcan Elements and Genomines, are among the 40 that have raised more than USD 40 million and account for around 90% of total funding to date. Just three start-ups, Redwood Materials, KoBold Metals and Ascend Elements, account for 50% of funding since 2015. In other energy technology fields, the average share of post-2020 start-ups representing 90% of fundraising is higher, at 20%. Battery recycling start-ups find it especially difficult to scale up quickly, as reliable streams of waste materials and clear standards are not yet developed. Extraction and refining start-ups often face high capital barriers to starting operations.

Trading volumes for lithium and cobalt continue to expand, albeit from a small base, whereas volumes for nickel remain subdued

Daily trade volumes for copper and battery metals at major exchanges



Notes: Trading liquidity indicates the monthly average of daily traded volumes on major metal exchanges: copper (LME, SHFE, Chicago Mercantile Exchange [CME]); nickel (LME, SHFE); cobalt (LME, CME); and lithium (LME, CME). Trading volumes for copper and nickel are around 15% of annual production, while those for cobalt and lithium are less than 1% of annual production. Physical trade volumes through these exchanges are much smaller than those figures.

Source: IEA analysis based on data from Bloomberg.

Lithium markets are experiencing increasing trading liquidity, with growing interest in hedging and price risk management, but remain at an earlier stage of market development

Trading volumes on major metal exchanges reflect the liquidity and maturity of different mineral markets. Copper and nickel remain the most actively traded commodities, with long-established markets on the LME, SHFE and Chicago Mercantile Exchange (CME), supported by their large and diversified industrial demand base. Copper trading activity reached record levels in early 2026, with average daily volumes on the LME (including both futures and options) peaking between January and March due to high price volatility and inventory reallocation driven by policy uncertainty.

Trading activity for battery metals has expanded in recent years but remains at an earlier stage of development. Cobalt and lithium have seen notable trading volume growth on the LME and CME over the last two years, reflecting rising demand and increasing interest in managing price risk. Lithium contracts on the CME in particular saw a sharp increase in early 2026, after the market launched in 2023, as market participants increased their hedging activity amid heightened price volatility.

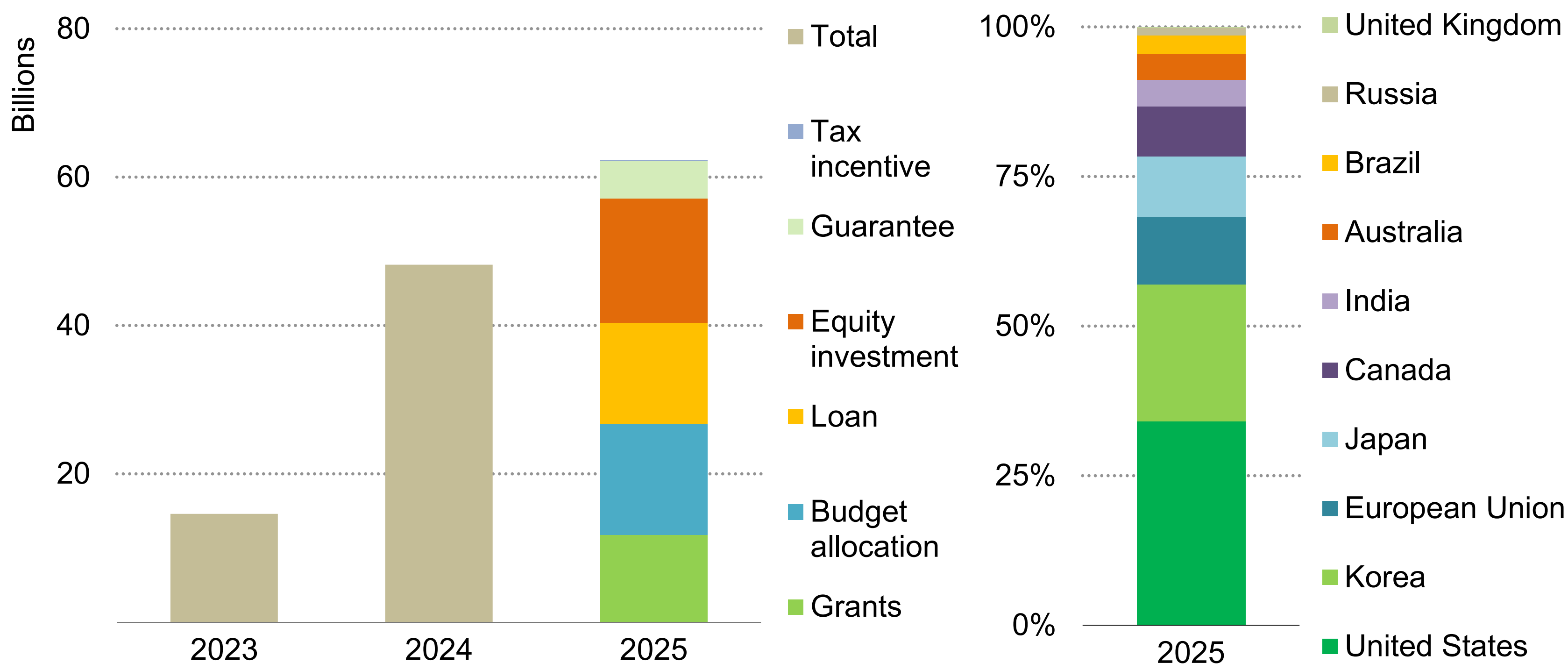
Despite this growth, liquidity in battery metals markets remains significantly lower than in base metals. Exchange-trade volumes account for around 15% of annual copper production and 14% of annual nickel production, but remain below 1% for lithium and cobalt. As a result, exchange prices play a more limited role in price discovery for these materials, although they remain an important benchmark for bilateral contracts.

Exchanges have accelerated efforts to develop more liquid trading instruments in the lithium market. A notable example is the launch of exchange-traded contracts, such as the LME lithium hydroxide CIF based on Fastmarkets prices. However, these contracts remain closely linked to external price assessments and have yet to reach the depth and liquidity of more established metal markets.

More broadly, lithium markets remain comparatively opaque and fragmented, with no single universally accepted benchmark price equivalent to those of traditional base metals. Pricing continues to rely largely on assessments from price reporting agencies, which publish price indexes with different methodologies, regional coverage and use cases. Unlike copper or nickel, lithium markets also lack a mature stockholding function, as trading is still dominated by bilateral contracts, products are not fully standardised and derivatives markets remain illiquid.

Public finance announcements for critical minerals have been rising since 2023, reaching around USD 65 billion in 2025, over four times higher than in 2023...

Types of public sector financing commitments in selected countries, 2025



Notes: Policies included in the analysis are announced public financing commitments specifically targeted at critical minerals value chains and converted to USD. Financing associated with regulatory measures or policies without quantified public support is excluded. Where policies contain multiple financing instruments, financing has been apportioned across instrument types to avoid double counting. Grants cover direct disbursements for production-stage or supply chain projects as well as policy envelopes supporting research, demonstration, pilot and innovation programmes. Budget allocation refers to government budget items used to support national strategies where financing is provided through a broader spending envelope rather than a single disbursement mechanism.

Source: IEA (2025), Critical Minerals Policy Tracker.

…though the direction and pace of disbursements will determine supply chain outcomes

Given the strategic importance of critical minerals and the financing challenges facing many projects, governments are increasingly deploying public finance to de-risk investment across supply chains, particularly in strategically important markets and for early-stage projects. This marks a shift towards more active state participation, mirroring China's longer history of policy-backed financing across the full supply chain.

Based on our assessment of public financing announcements, governments have increasingly deployed blended finance instruments to crowd in private capital for critical mineral supply chains, a trend that has grown markedly since 2023. These include equity funds, concessional loans and co-investment grants, though the mix varies significantly by country and market context. Advanced economies have increasingly combined direct state equity through sovereign funds, export credits, state-owned enterprise participation and development bank co-investment with risk-sharing tools such as loan guarantees and offtake-backed facilities deployed to crowd-in private capital. Concessional and blended finance structures have grown in prominence, particularly in instruments targeting supply chains in geographically diverse regions.

Several governments made headline financing commitments in 2025, signalling a marked escalation in public ambitions for developing critical mineral supply chains in line with their strategic objectives. The United States alone mobilised over USD 7 billion in direct appropriations under the One Big Beautiful Bill Act, covering the National Defense Stockpile, the Industrial Base Fund and Defense Production Act financing, with a further USD 250 billion in loan guarantee authority extended to the Department of Energy's Energy Dominance Financing office. Canada announced a USD 1.4 billion Critical Minerals Sovereign Fund alongside a USD 1.1 billion First and Last Mile Fund, India approved the USD 3 billion National Critical Minerals Mission, and Brazil's BNDES and Finep launched a USD 1 billion fund targeting domestic processing and value chain development. Governments also expanded previously established funds, including USD 163 million for Korea's Supply Chain Stabilisation Fund in 2025 and USD 690 million for Australia's Critical Minerals Facility in 2026. At the multilateral level, the European Union committed USD 3.4 billion under its RESourceEU Action Plan.

The gap between announced commitments and actual disbursements remains considerable, however. Many instruments, including sovereign funds, loan guarantees and blended finance vehicles, were still in the design or early operationalisation phases at the end of 2025, with project pipelines under assessment and eligibility criteria being established. While the scale of headline figures reflects political commitment and signal an important step up in government ambition, the translation of announced commitments into deployed capital remains uneven or uncertain. For example, the EU Critical Raw Materials Act's 47 European Union-based strategic projects selected in 2025 carry an estimated total capital investment requirement of USD 26 billion, yet the CRMA confers strategic project status and access to a financing subgroup – bringing together the European Investment Bank, national promotional banks and private lenders – rather than a direct funding guarantee. Actual disbursements under the RESourceEU Action Plan are similarly still being operationalised.

Where disbursements have been made, they tend to reflect targeted, project-level interventions. Support has included direct equity, such as the US government's USD 400 million investment in MP Materials (acquiring preferred stock convertible into a potential 15% stake) as part of a broader multibillion-dollar public-private partnership to build a domestic rare earth magnet supply chain, and the UK National Wealth Fund's USD 41 million direct investment in Cornish Lithium. Others have deployed concessional financing, loan guarantees and grants to reduce early-stage capital burdens and improve project bankability, such as Australia's USD 1.2 billion concessional loan to Iluka's Eneabba rare earth refinery and France's fiscal support for Caremag, structured as a tax credit, alongside additional backing from Japan. These show a pattern of public financing that functions primarily as a risk-reduction tool at the project level, rather than as a mechanism for broad sectoral capitalisation.

Expanding beyond supply: demand-side interventions

Alongside supply-side measures, governments are looking at deploying demand-side interventions to support investment in mineral supply chains. Approaches such as demand aggregation, strategic stockpiling and facilitated offtake arrangements gained traction in 2025 as tools for improving revenue certainty and reducing commercial risk at the project level. These measures address a fundamental challenge in mineral project finance, where the absence of long-term offtake has been a primary barrier to debt mobilisation. Australia's Critical Minerals Strategic Reserve and the US government's announced price floor commitment to MP Materials are among the clearest expressions of this approach. The US Export-Import Bank also announced a direct loan of USD 10 billion for Project Vault to establish strategic mineral reserves in the country. China's financing model, by contrast, has long embedded demand security structurally rather than instrumentally, with vertically integrated supply chains established by linking overseas upstream production to domestic processing capacity to internalise offtake risk.

The scale of public financing announcements in 2025 is an inflection point in how governments approach critical mineral supply chain development. The central question for markets is not merely the amount of public finance announced, but how, when and where financing will be deployed. For the supply additions that consuming economies are counting on to come online in the coming years, the pace and reliability of public finance disbursement remain consequential.

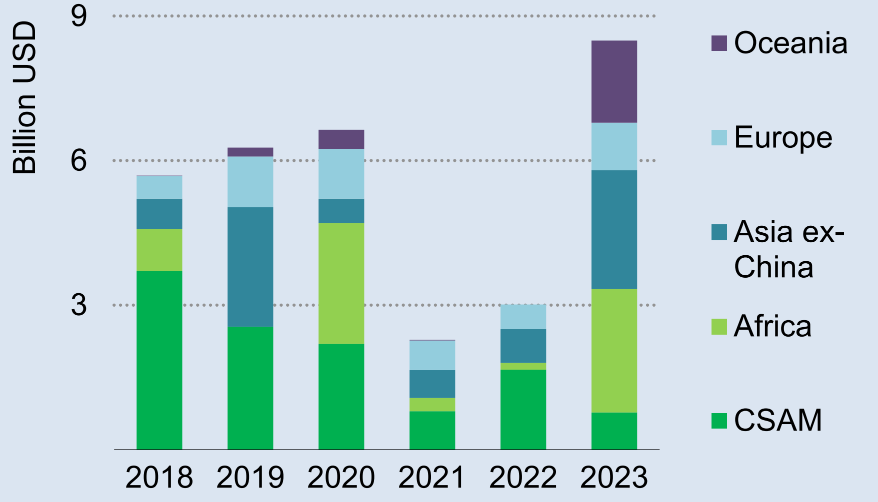
Box 1.1 Investments by China in the last decade

China's position in critical mineral supply chains is the product of sustained, policy-backed investment over decades. It continues to leverage state-backed lending and project finance structures channelled through state-owned commercial banks, policy banks and provincial subsidy programmes. Underpinned by strategic frameworks, including the Belt and Road Initiative and successive Five-Year Plans, and channelled through state-owned commercial banks, such as the Bank of China, these investments have been structurally coherent.

The dominant instrument has been limited-recourse project finance, with lending portfolios supporting upstream project companies, including special-purpose vehicles and joint ventures in which Chinese firms hold equity stakes, across emerging markets and developing economies. This structure ensures that raw or processed mineral outputs from overseas projects are channelled back for further domestic processing, effectively internalising offtake risk and insulating downstream processors from supply disruptions and spot market volatility. Between 2018 and 2023, the country poured over USD 98 billion in upstream investment across copper, nickel, lithium, cobalt, niobium and other minerals in nearly 20 countries.

The pace has since accelerated. Chinese firms deployed an estimated [USD 120 billion](#) in outbound mining investment from 2023 to 2025. China also financed around [USD 24 billion](#) in 363 port projects from 2001 to 2025, around 50% of which serve energy and mineral supply chains. Sixty-three of these projects are located within 500 km of a China-financed mine, anchoring the upstream supply chain. At the domestic level, China has sustained over in geological exploration spending since 2022, with most provincial governments expanding exploration subsidies in 2025.

China state-backed mineral financing by region, 2018-2023



Note: CSAM = Central and South America.
Source: AidData (2026), [Tracking China's Transition Mineral Financing.](#)

Latest policy developments

Policy developments in 2025 reinforced diversification, international partnerships and broader government engagement across supply chains

In 2025, supply risks arising from highly concentrated mineral supply chains materialised at scale. Against this backdrop, many governments intensified efforts to address these vulnerabilities, introducing a wide range of policy measures to strengthen supply security and resilience. Policy developments between 2025 and the first quarter of 2026 illustrate the growing use of government intervention to respond to concentration risks and support supply chain diversification.

The IEA's Critical Minerals Policy Tracker organises government policies around four core objectives: ensuring supply reliability and resilience; promoting exploration, production and innovation; encouraging sustainable and responsible practices; and scaling up recycling. Activity in 2025 was concentrated on the first two objectives, underpinned by expanded public investment and marked growth in international arrangements.

Revised critical minerals lists

Several governments refreshed their official designations of which minerals constitute strategic priorities, with notable shifts in scope and rationale. The United States updated its List of Critical Minerals from 50 to 60 minerals, adding ten new entries, including copper, uranium and lead, and extending strategic designation beyond technology-critical metals to inputs required across the broader industrial economy. The United Kingdom revised its critical minerals list to introduce a second tier of "growth minerals", explicitly linking designations to industrial strategy, energy technology deployment, defence and advanced manufacturing, encompassing industrial minerals, battery minerals, germanium as a technology material and phosphorus as a fertiliser input. South Africa, as a major resource holder, revised its list to prioritise domestically abundant and export-oriented minerals, with an emphasis on industrialisation, beneficiation and greater value capture in global supply chains. New Zealand released its first critical minerals list, covering 37 minerals with potential to be produced domestically and those for which resilient supply will need to be supported.

Refreshed strategies and national frameworks

Some governments issued new or updated overarching minerals strategies in 2025. New Zealand published its Minerals Strategy to 2040, targeting a doubling of its mineral export value to USD 1.69 billion by 2035. The European Commission adopted the ReSourceEU Action Plan to accelerate implementation of the Critical Raw Materials Act, including the designation of 47 strategic projects intended to fast-track development and improve financing access. The United Kingdom's Vision 2035: Critical Minerals Strategy sets quantitative diversification objectives for 2035: at least 10% of aggregate annual demand met through domestic production, 20% from recycling and no more than 60% of annual demand for any individual critical mineral sourced from any one supplier country. This follows similar single-supplier thresholds adopted elsewhere, including the European Union's Critical Raw Materials Act (65% of annual consumption of each strategic raw material) and Korea's 2023 critical minerals strategy (50% by 2030). The Association of Southeast Asian Nations published the Minerals Development Vision 2045 and accompanying Minerals Cooperation Plan 2026-2030, covering integrated value chain development, workforce capacity, investment facilitation and responsible supply principles. Chile adopted its National Critical Minerals Strategy, aiming to strengthen its role as a reliable and responsible global supplier of minerals, with a focus on domestic value addition and international partnerships.

International arrangements and multilateral co-operation

One of the most active areas of policy in 2025 was bilateral and multilateral arrangements between consuming and producing economies, spanning memoranda of understanding (MOUs), dedicated partnership frameworks and joint investment vehicles.

The United States was among the most active parties. By early 2026, the country had concluded more than 20 critical minerals frameworks or MOUs, including frameworks with Australia and India and MOUs with Cambodia, Malaysia, Thailand and Saudi Arabia. Its arrangement with the DRC is notable for explicitly providing priority access for US private sector participants, extending beyond a standard government-to-government model to embed commercial offtake interests within a diplomatic framework. In addition, the United States launched the Forum on Resource Geostrategic Engagement (FORGE) in February 2026 to strengthen multilateral co-operation.

Since 2025, India has concluded MOUs and partnership frameworks and issued joint declarations of intent on co-operation on critical minerals with Argentina, Brazil, Canada, France, Germany, Italy, Japan, the Netherlands, Norway, the United Arab Emirates, the United Kingdom and the United States.

In May 2026, Indonesia and the Philippines formalised a co-ordinated nickel supply corridor under an MOU, committing to move 200 000 tonnes of ore per month from Philippine mines to Indonesian smelters starting June 2026 and establishing a structured partnership between upstream Philippine producers and Indonesia's downstream processing capacity.

Also in May 2026, Australia, India, Japan and the United States announced the Quad Critical Minerals Initiative Framework, advancing the Quad Critical Minerals Initiative launched in July 2025. The framework aims to coordinate investment, policy tools and supply chains across the full minerals value chain and mobilise up to USD 20 billion to reduce reliance on concentrated supply by jointly developing mining, processing and recycling capacity.

Under Canada's presidency of the Group of Seven (G7) in 2025, G7 leaders launched the Critical Minerals Action Plan, building on successive G7 presidencies' work since 2023. Its principal deliverable was the Roadmap to Promote Standards-Based Markets for Critical Minerals, which identifies non-market policies and practices as a core systemic challenge to mineral supply chains and commits G7 members to using available instruments, including procurement, financial incentives, trade measures and price floors, to diversify supply chains. In parallel, Canada launched the Critical Minerals Production Alliance to advance project-level collaboration and financing among like-minded partners. This initiative has been carried forward as the G7 Critical Minerals Resilience and Production Alliance, with further project announcements expected.

In 2026, France assumed the G7 presidency and designated the minerals agenda as a cross-cutting priority. G7 leaders adopted the Declaration on Securing Supply Chains for Critical Minerals in June 2026, escalating collective ambition across industrial co-operation, financing, market structuring, transparency and traceability, stockpiling and recycling. The leaders set a concrete diversification target for rare earths of reducing dependency on a single non-G7 supplier for rare earths and permanent magnets to below 60% by 2030. The Declaration also recognised the IEA's Critical Minerals Security Programme as a key international platform to advance G7 efforts. In February 2026, IEA Ministers acknowledged the significant progress made under the Programme and adopted a Declaration Supporting the IEA's Work on Critical Minerals Security, directing the IEA to reinforce and expand the Programme to support countries in enhancing preparedness for potential supply disruptions and accelerating supply diversification.

Revenue capture and supply management in emerging markets

Governments of producing countries among emerging markets have used policies to capture greater economic value from mineral endowments and, in some cases, to exercise greater control over export flows. Indonesia revised its nickel ore pricing framework in April 2026 to embed the value of battery-relevant by-products, including cobalt, in the government's benchmark formula, a change with direct implications for downstream cost structures and mixed hydroxide precipitate production economics. The DRC, having imposed a cobalt export ban in February 2025, replaced it with an export quota in October 2025, aimed at supporting prices while maintaining export revenue. The Philippines officially enacted the Enhanced Fiscal Regime for Large-Scale Metallic Mining in September 2025, introducing a royalty structure to increase government revenue from mineral extraction. Raw mineral export restrictions more broadly, including Malaysia's ban on raw rare earth elements, remained a feature of the policy landscape in 2025.

Strategic reserves

Governments are increasingly complementing investment and partnership strategies with dedicated stockpiling and reserve mechanisms, reflecting concerns about near-term supply disruption risk. In February 2026, the United States announced Project Vault – formally, the US Strategic Critical Minerals Reserve. The initiative is structured as an independently governed public-private partnership and is described as a demand-driven reserve backed by up to USD 12 billion, including roughly USD 10 billion in financing from the Export-Import Bank of the United States and about USD 2 billion from private capital. Rather than relying on centralised government forecasting, the programme is intended to stockpile critical minerals based on manufacturer commitments and supply-chain needs, with rare earth elements receiving early emphasis. Complementary instruments include equity stakes in mining companies, bilateral price-floor frameworks, and offtake-linked financing.

Australia's Critical Minerals Strategic Reserve is oriented towards supply-side investment facilitation for selected critical minerals: antimony, gallium and rare earth elements. It has a range of financial tools to secure supply, sell and selectively stockpile critical minerals, allowing it to de-risk investment in projects where private finance is constrained, mitigate supply shocks and address market distortions. The Reserve has AUD 1 billion (Australian dollars) available for transactions as part of an expanded AUD 5 billion Critical Minerals Facility. A further AUD 150 million has been allocated for selective stockpiling of minerals.

The Democratic Republic of the Congo (DRC) has also adopted a strategic reserve mechanism for critical minerals. In April 2026, the government established a strategic reserve for cobalt, coltan and germanium, administered by the Regulatory and Control Authority for Strategic Mineral Substances. The reserve complements the existing export quota and allows the government to acquire, hold and market strategic minerals, providing an additional instrument to influence supply availability and respond to market imbalances.

Traceability and transparency

Traceability is gaining traction as a policy instrument, with governments across both consuming and producing economies moving to establish or strengthen systems for monitoring mineral flows through supply chains. The G7 Roadmap reflects this momentum at the multilateral level, calling for interoperable digital credentials and digital product passport compatibility aligned with the United Nations Transparency Protocol. At the national level, India has announced the development of a dedicated traceability system under the National Critical Mineral Mission, signalling that major emerging economy consumers are integrating traceability into their broader minerals security frameworks. Among producing countries, Zambia launched the Zambia Integrated Mining Information System in February 2025. The digital platform consolidates mining-related transactions, including applications for mining and non-mining rights, payment of area charges and submission of statutory reports, with the objectives of increasing transparency, streamlining licensing processes, reducing corruption and enhancing inter-agency collaboration. In Indonesia, the SIMBARA platform, established in 2022 to integrate government oversight of mineral and coal flows, was required to be expanded in 2025 to include cobalt tracking, extending its monitoring across additional critical minerals.

Sustainability performance tracking

Sustainability risks continue to disrupt supply, underscoring the need for monitoring amid gradual overall improvement

Recent developments in 2025 highlight that social, environmental and governance-related risks continue to pose material threats to critical mineral supply chains. At the operational level, regulatory non-compliance has led to abrupt supply disruptions. Crackdowns on illegal mining, licence revocations and asset seizures in some producing countries have temporarily removed supply from the market. For example, in October 2025, Mali revoked over 90 mining exploration permits and Ghana revoked over 270 small-scale mining licenses due to regulatory non-compliance. In September 2025, Indonesia suspended 190 coal and mineral permits due to compliance deficiencies. Sourcing minerals from conflict-affected areas can also disrupt supply, as seen in rare earth supply chains when the Kachin Independence Army seized parts of Myanmar in 2024. These events illustrate how governance-related risks can translate directly into physical supply constraints.

Labour violations or disputes also disrupted supply in 2025 and 2026. Workplace fatalities in Chile, Indonesia and Kazakhstan led to temporary halts in production. In the DRC, a labour strike at CMOC's Tenke Fungurume copper mine temporarily disrupted operations in June 2026. These events illustrate how poor labour standards can lead to strikes or government stop-work orders that affect the steady supply of minerals.

Climate-related risks also continue to affect production in key regions. Water stress, extreme weather events and changing environmental conditions pose rising challenges for mining operations. Over the past decade, excessive rainfall in Australia has disrupted transportation links and forced copper mines to reduce production, while in Chile, water scarcity has continued to cause declining production at mines. In Canada, forest fires forced a halt in operations at Hudbay Minerals' Snow Lake mine in summer 2025. Climate or environmental risks can disrupt production directly, delay project development and increase operational costs. They can also affect financing and investment: in September 2025, Norway's state pension fund divested its stake in Eramet over alleged environmental damage and Indigenous rights violations at the PT Weda Bay Nickel site in Indonesia.

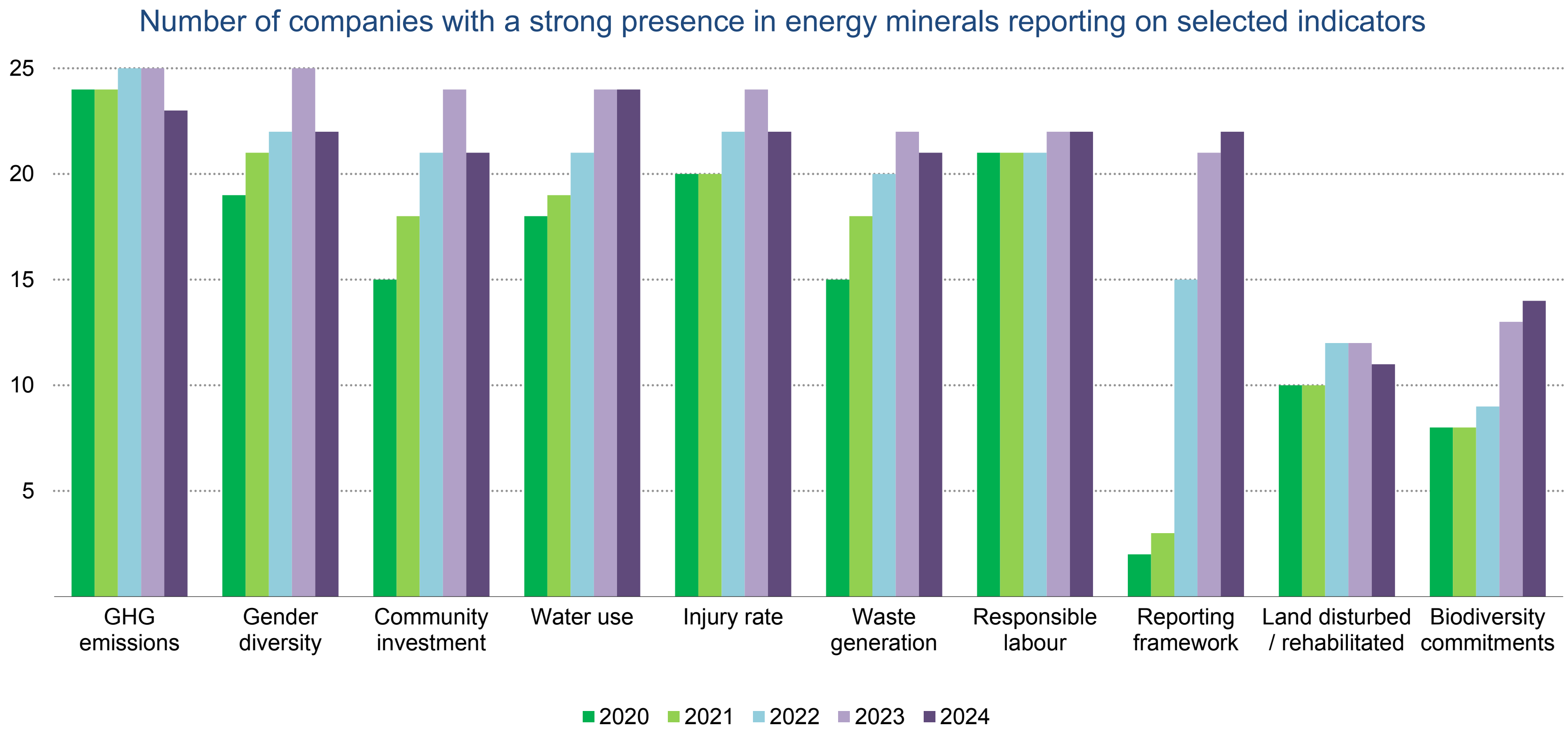
At the same time, social opposition and community-related risks remain a key source of disruption. Project delays linked to permitting challenges, legal appeals and local stakeholder opposition continue to affect timelines across multiple jurisdictions. For example, the Resolution Copper project in the United States faced significant permitting delays owing to legal challenges and community objections. In Indonesia, four nickel mining permits were revoked in Raja Ampat over environmental violations after public protests. In

Peru, road blockades by informal miners in 2025 disrupted the transportation of copper, highlighting how social tensions and informality can constrain the movement of mined output. In some cases, companies have sought to mitigate these risks through increased stakeholder engagement, benefit-sharing agreements and local partnerships, although outcomes remain mixed.

Sustainability performance is also increasingly being integrated into mineral trade flows. Many consuming economies are rolling out policy measures that seek to encourage responsible practices in mineral supply chains. For example, due diligence requirements are increasingly common, requiring large downstream companies to identify, assess and mitigate adverse impacts in their supply chains. Examples include the European Union's Batteries Regulation and Corporate Sustainability Due Diligence Directive, France's Duty of Vigilance Law and Germany's Act on Corporate Due Diligence Obligations in Supply Chains. Government policies that link market access to high sustainability performance are also increasingly common. For example, forced labour import bans are now in force in Canada, Indonesia, Mexico and the United States, with Canada announcing an expanded ban in June 2026 and the European Union planning to implement a new forced labour regulation in 2027. High greenhouse gas (GHG) emissions performance is also increasingly a condition for market access in importing countries, for example through carbon border adjustment mechanisms in the European Union and the United Kingdom or through the European Union's Deforestation Regulation. While some of these policies have recently been pared down, for example in the European Union, companies continue to face sustained regulatory expectations to prevent or minimise adverse impacts within their supply chains.

Taken together, these developments underscore the importance of continued monitoring and redress of sustainability-related risks. Strengthening transparency, utilising voluntary reporting standards, improving operational practices and enhancing traceability will be critical to mitigating supply disruption risks and ensuring resilient and responsible mineral supply chains.

After several years of improvement, sustainability reporting slowed in 2024 across major producers

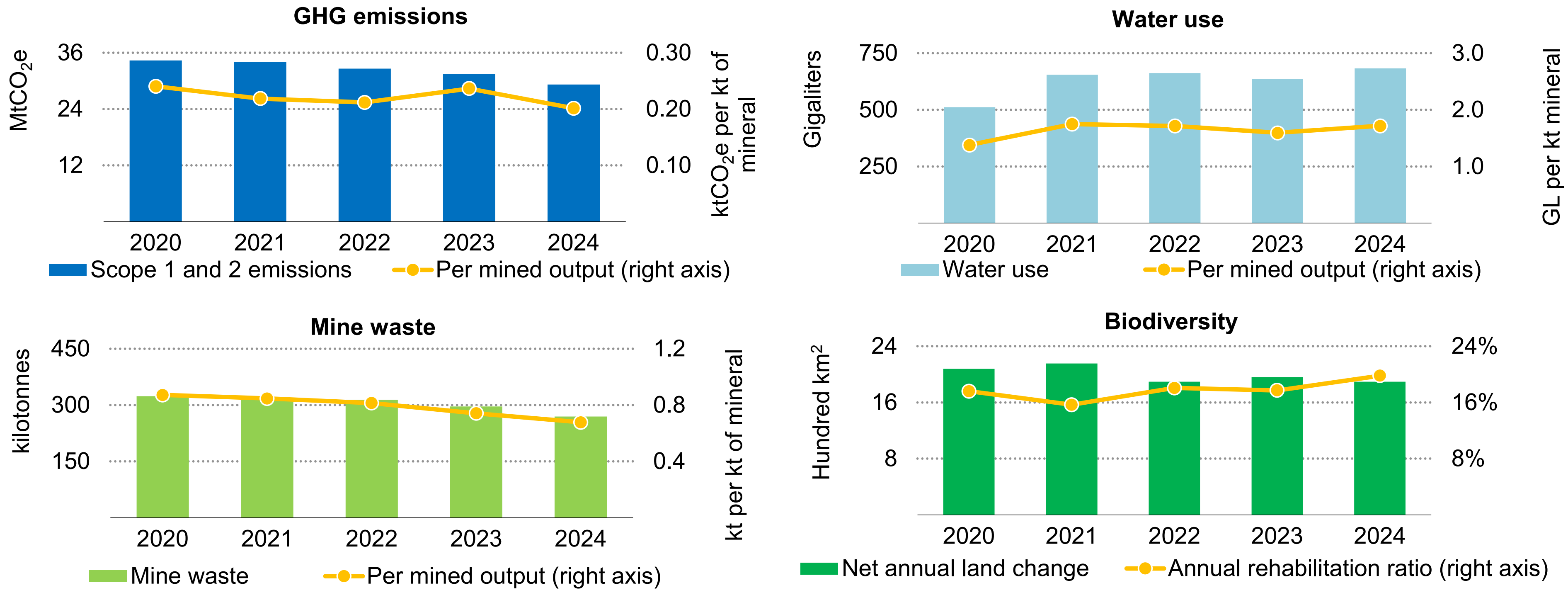


Notes: Data from 25 companies were reviewed from 2020 to 2024, with two subsidiaries counted separately despite M&A. GHG emissions refer to reporting on total scope 1 and 2 emissions; gender diversity refers to the share of women in the workforce; water use considers total water withdrawals; responsible labour refers to policies to prevent child and forced labour; and biodiversity commitments refer to “no net loss” or “net positive impact” targets. Reporting numbers in the chart are based on whether a given company disclosed a metric or policy for the relevant category in its annual sustainability report.

Sources: IEA analysis based on data from 2020-2024 sustainability reports from 24 major mining companies. Companies are listed in the Annex.

Environmental indicators show mixed results across key mineral producers, with improving biodiversity and waste outcomes but stagnating emissions and water performance

Industry performance across environmental indicators, 2020-2024

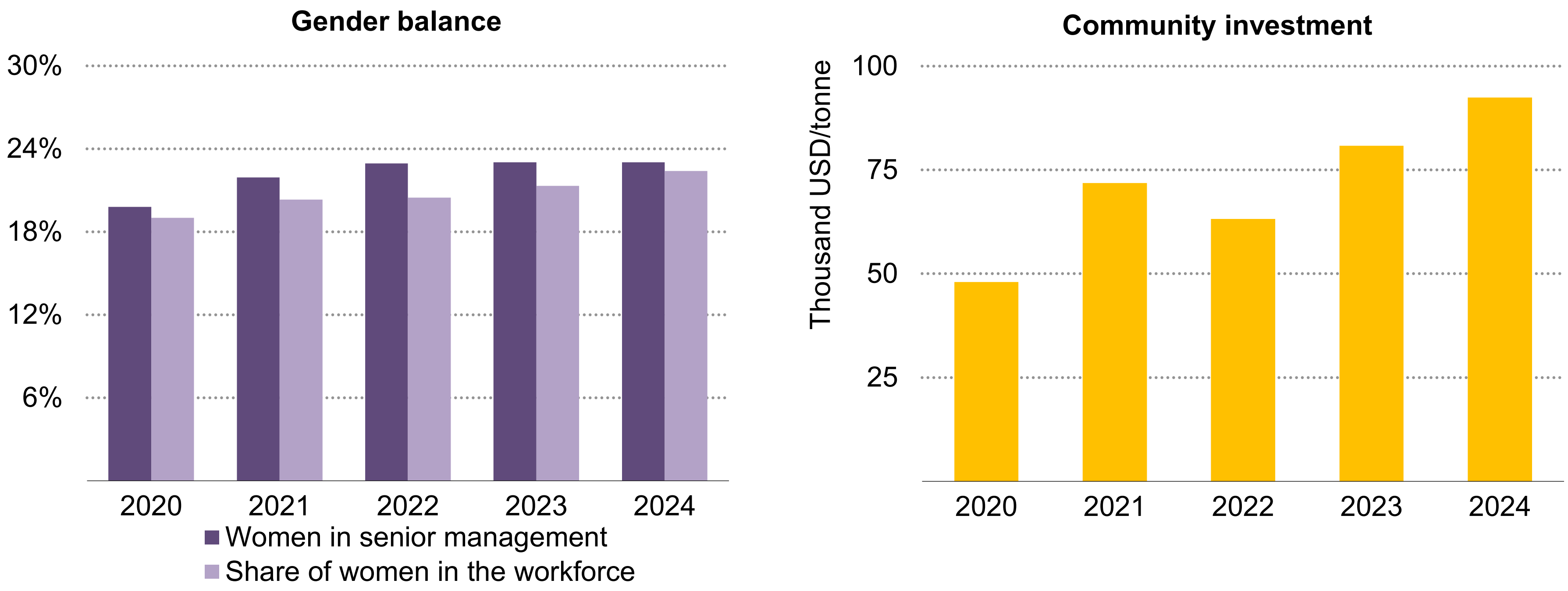


Notes: Left-axis values for GHG emissions, water use and mine waste are calculated as the production-weighted averages across companies, using mineral production data reported in sustainability disclosures. For GHG emissions and biodiversity indicators (net annual land change and annual rehabilitation), values for 2024 include estimates for companies that reported in 2023 but not in 2024.

Source: IEA analysis based on 2020-2024 sustainability reports.

Gains in women's workforce participation and community investment contrast with stagnating progress in senior leadership diversity

Industry performance on gender balance and community investment, 2020-2024



Notes: Social indicators are based on publicly reported data from major mining companies and may be subject to differences in reporting scope and methodology. Coverage varies across indicators and years. Community investment figures are reported in nominal terms.

Source: IEA analysis based on 2020-2024 sustainability reports.

Sustainability reporting weakened in 2024, while industry environmental and social performance remained mixed

Momentum on sustainability reporting across major mineral producers showed signs of slowing in the 2025 reporting cycle (which covers activities during the 2024 calendar year), with progress becoming more uneven. After years of steady expansion in coverage and disclosures, this trend has moderated, even as companies continue to recognise that stronger sustainability performance helps mitigate financial risks and ensure compliance.

To assess how companies are performing on sustainability reporting, we selected six priority areas relating to sustainability, namely water, GHG emissions, biodiversity, human rights, communities and corruption. We then examined whether companies are disclosing specific quantitative metrics relating to these six priority areas in their annual sustainability reports, enabling comparison across companies and over time. While human rights and corruption were identified as priority areas, analysis was limited to the presence of corporate policies due to limited comparable quantitative data. Overall, major producers did not consistently disclose the same metrics for the 2025 cycle, with some operators providing less information than in previous years. This suggests that, while reporting has not lost relevance, momentum has weakened, reflecting a reprioritisation of company resources and evolving regulatory uncertainty.

Among companies that reported, the quality and scope of disclosures improved in some areas, although gaps remain in the consistency and comparability of reported data. For example, comparability required the use of externally estimated production data. For biodiversity indicators, fewer companies reported relevant metrics than in previous years, even where they had previously disclosed annual land rehabilitated and land disturbed. Similar comparability challenges are observed for gender balance indicators, as companies report these using differing definitions and scopes, for example focusing only on board-level diversity, reporting the share of women in management, or combining multiple categories of staff, such as middle, senior and executive management, relative to total employees. This variation reflects the flexibility in existing reporting frameworks, as reporting standards provide general guidance on disclosing gender composition across governance bodies and employee categories but do not prescribe a single, harmonised methodology. This reinforces the case for standardising reporting frameworks across companies and jurisdictions, facilitating comparison of performance among major producers.

Third-party verification has continued to strengthen, particularly at the mine-site level. An increasing number of operations are participating in independent assurance mechanisms, with five sites announced as commencing audits under the Initiative for Responsible Mining Assurance (IRMA) in Q1 2025, compared with the announced completion of three audits in the previous year. Similarly, the number of sites undergoing Copper Mark assurance has expanded, increasing from around 50 independently verified operations in 2023 to approximately 100 participating sites in 2024, of which around three-quarters had already been verified. In 2025, membership of the International Council on Mining and Metals expanded for the first time since 2021, with Hindustan Zinc and Maaden joining the group, and both companies also joined the Extractive Industries Transparency Initiative, reflecting growing alignment with recognised standards and principles.

China-owned mining companies, which had shown notable improvements in disclosure in the 2024 cycle, did not sustain the same pace of progress in the latest cycle, in part reflecting delays in reporting. Among these, CMOC continues to stand out as a leading discloser, maintaining relatively comprehensive reporting across waste and energy indicators, whereas disclosures on social and governance indicators are comparatively less standardised in quantitative terms and rely more on qualitative reporting. Other Chinese companies have shown limited updates, with variations in both the depth and timeliness of disclosure.

Performance trends

Despite mixed progress in reporting coverage, the underlying performance indicators present a varied picture. Recent disclosures suggest that some social performance indicators have shown steady improvement since 2020. For example, in 2024, reported figures for community investment were up 20% from 2020 and, after a downturn in 2022, up 12% from 2023. Worker safety has also improved. Gender balance shows mixed performance, with the share of women in the workforce growing from 19% in 2020 to 22% in 2024, although the share of women in senior management has stagnated since 2021.

At the same time, indicators related to environmental performance continue to show gradual efficiency gains. Companies report improvements in mine waste intensity, pointing to continued operational optimisation across major key mineral producers. Biodiversity-related indicators indicate gradual improvement, with land rehabilitation increasing relative to annual land disturbed. The rehabilitation ratio increased from 18% in 2020 to 20% in 2024, notwithstanding year-to-year variations. However, performance has been less favourable for other environmental dimensions: water-use intensity shows signs of deterioration, and scope 1 and 2 GHG emissions (both in absolute terms and on an intensity basis) are stagnating. These patterns reflect persistent structural challenges, including expanding mining operations, declining ore grades and an increasing reliance on lower-quality deposits, which continue to place upward pressure on absolute levels of resource use and environmental disturbance.

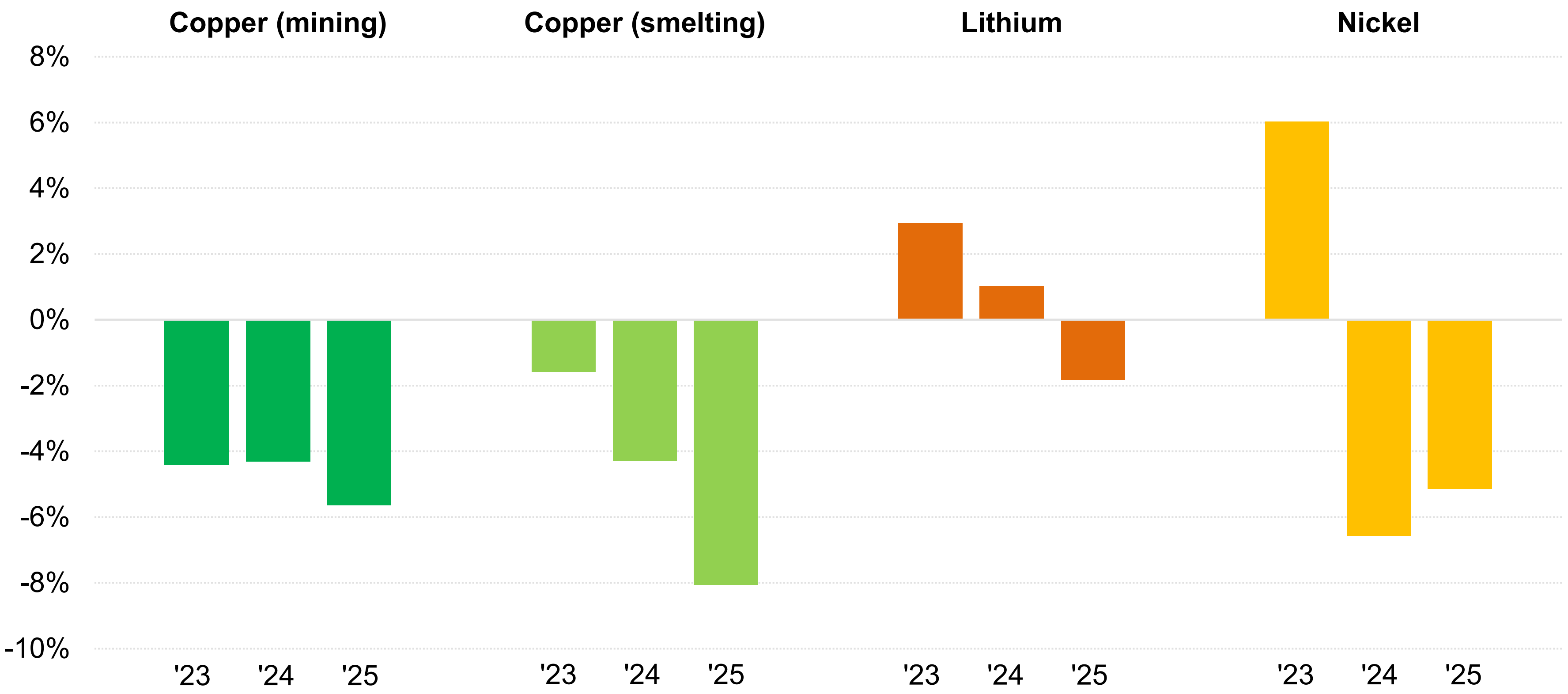
Developments in regulations and standards

Regulatory developments also contributed to uncertainty in 2024 and may have influenced corporate reporting practices in 2025. Progress has varied significantly across jurisdictions, with regulatory momentum strengthening in some countries while slowing or reversing in others. In several jurisdictions, policy makers have sought to recalibrate or streamline corporate reporting and due diligence requirements. In the European Union, the Omnibus I Package narrowed the scope and simplified the reporting requirements under the Corporate Sustainability Reporting Directive and the Corporate Sustainability Due Diligence Directive, with extensions also made to compliance timelines. In the United States, the Securities and Exchange Commission proposed rescinding its 2024 rules on climate-related disclosures, though California is set to enforce its regulation on GHG emissions reporting beginning in 2026. In Canada, the Canadian Securities Administrators paused the development of a new mandatory rule on climate-related disclosures, with a view to supporting Canadian markets and issuers. There was forward momentum in Australia, with its mandatory climate reporting standards coming into effect for eligible companies on 1 January 2025.

Despite growing regulatory uncertainty, voluntary standards continue to emerge and strengthen responsible mining, with an increasing focus on harmonisation and alignment between existing standards. For instance, the Global Reporting Initiative's Sector Standard for Mining came into effect on 1 January 2026. The Initiative for Responsible Mining Assurance is updating the IRMA Standard to broaden coverage across the mining value chain and strengthen requirements for responsible mining. In addition, the Consolidated Mining Standard Initiative is developing a global standard that consolidates the Copper Mark, the International Council on Mining and Metals' Mining Principles, the Mining Association of Canada's Towards Sustainable Mining and the World Gold Council's Responsible Gold Mining Principles, which is expected to launch in early 2027. In 2026, the China Chamber of Commerce of Metals, Minerals & Chemicals Importers & Exporters also opened a global public consultation for the development of a Sustainability Mining Code, with a view to aligning it with international responsible mining standards.

For some key energy minerals, the pace of decline in production-related emissions intensity accelerated in 2025

Change in emissions intensity associated with critical minerals production



Note: Changes in emissions intensity are based on scope 1 and scope 2 GHG emissions from mining and refining activities.
Source: IEA analysis based on data from Wood Mackenzie.

Declining emissions across key energy mineral production highlight progress towards company decarbonisation targets

GHG emissions intensities for copper, lithium and nickel production declined overall in 2025 compared with the previous year. Copper continued the downward trend observed since 2023, with emissions intensities for mining falling by 6% year-on-year in 2025 and by 8% for smelting. The reduction in copper smelting was the most pronounced. For lithium and nickel, growth in emissions intensity slowed or shifted into decline in 2025. Emissions intensity for nickel continued the reduction trend observed in 2024, while lithium shifted into declining intensity in 2025.

The drivers of lower emissions varied across commodities. In copper mining, the decline was led by lower emissions from purchased electricity for milling, which accounts for one of the largest shares of emissions in this segment. In copper smelting, lower emissions from purchased power also contributed to the decline. Facility-level disruptions may also have played a role: for example, the Philippines' sole copper smelter, PASAR, was taken offline for part of 2025 amid unfavourable market conditions. For lithium, emissions related to diesel use at mine sites, which increased from 2023 to 2024, declined in 2025, contributing to the overall reduction. For nickel, lower emissions from coal use and purchased electricity in the smelting segment supported the reduction in 2025.

These trends are taking place alongside a growing number of companies setting medium- and long-term decarbonisation targets. Among the companies covered, 20 have established net zero or equivalent targets for 2050, while 14 have set interim targets for 2030. However, variation in target scope and underlying methodologies continues to limit comparability and assessment of progress against these goals.

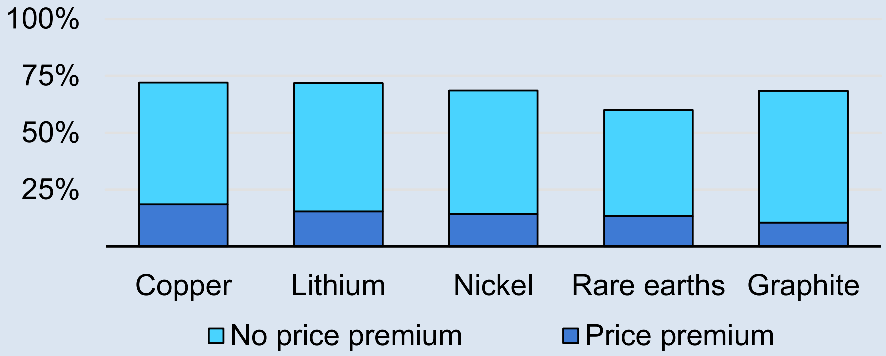
Box 1.2 Traceability to support market differentiation and responsible supply chains

Traceability is a foundational tool for the development of sustainable and responsible supply chains. Implementing traceability systems can enable the collection of information on sustainability metrics, such as GHG emissions, corruption risk or compliance with labour standards. This can allow upstream producers with higher standards to differentiate their products from those associated with poorer practices, supporting the emergence of performance-based purchasing by midstream and downstream companies. In turn, this could support the emergence of "high-performance price premiums" or "low-performance grey discounts".

IEA analysis indicates that traceability is on the rise: in a joint survey conducted by the IEA and the OECD, two-thirds of surveyed companies reported having some form of traceability system in place. Yet companies still face many obstacles to traceability implementation. Major obstacles reported by companies include high implementation costs, a lack of interoperability and limited incentives for sharing information along the supply chain. Price signals also remain weak: only one-quarter of respondents reported receiving some form of premium for differentiated materials. Further, most companies collect core provenance and ownership data, while far fewer collect the broader performance-related and corporate transparency information needed to underpin performance-based purchasing.

Governments can help accelerate uptake of traceability systems by providing financial support for traceability infrastructure, harmonising traceability standards and strengthening incentives for data sharing along the supply chain. Strengthening traceability systems through government intervention can help develop standards-based markets, which in turn can unlock supply in non-incumbent countries and mitigate the risk of supply disruptions associated with poor practices.

Share of companies that indicated receiving price premiums across five focus minerals



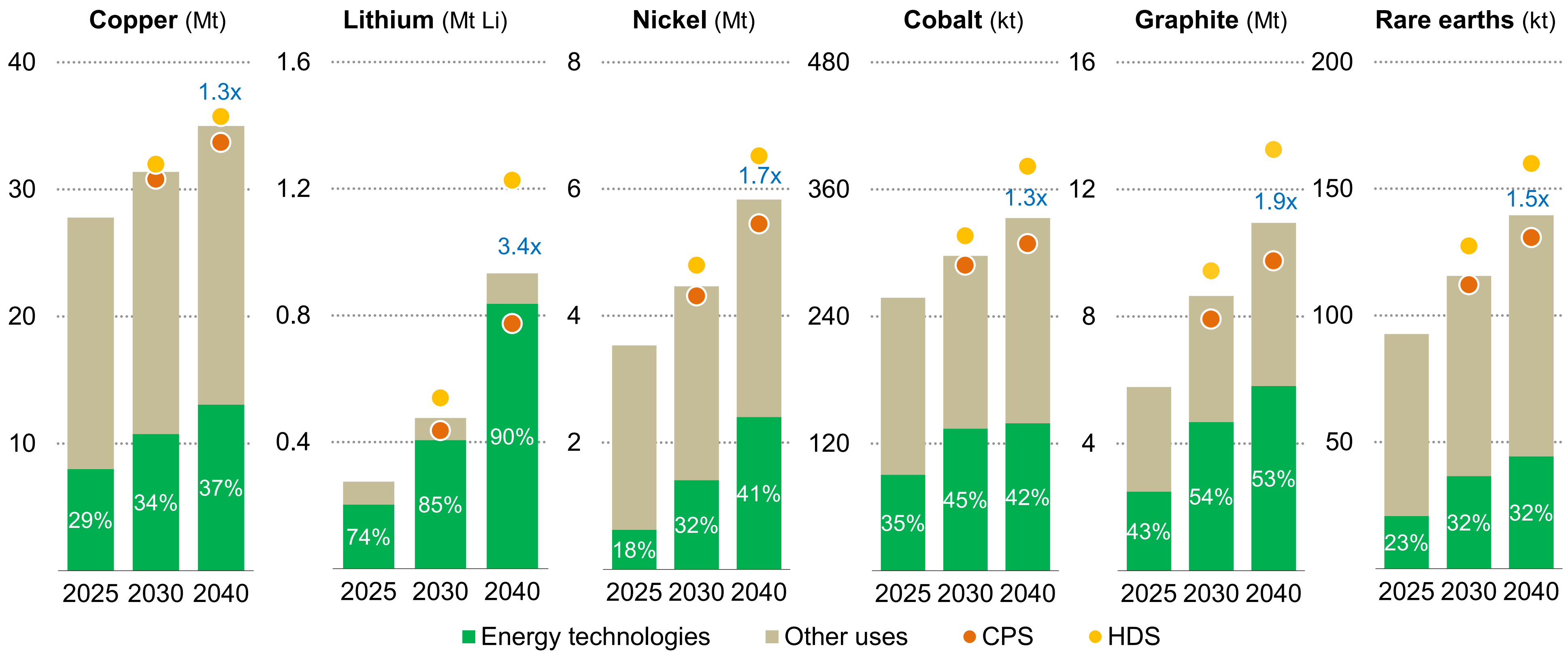
Notes: "Price premium" refers to companies that indicated receiving a price premium based on origin, low GHG emissions or material with social audit certificates. "No price premium" refers to companies that expressly stated that they do not currently receive a price premium for traced material. The remaining percentage refers to companies that either reported discounts for non-traced material, provided their own response (e.g. "n/a" or "not yet tracked") or did not answer.
Source: IEA-OECD joint survey, October 2025.

2. Outlook for key minerals Part 1

Outlook overview

Energy technologies continue to drive strong demand growth for critical minerals across all scenarios

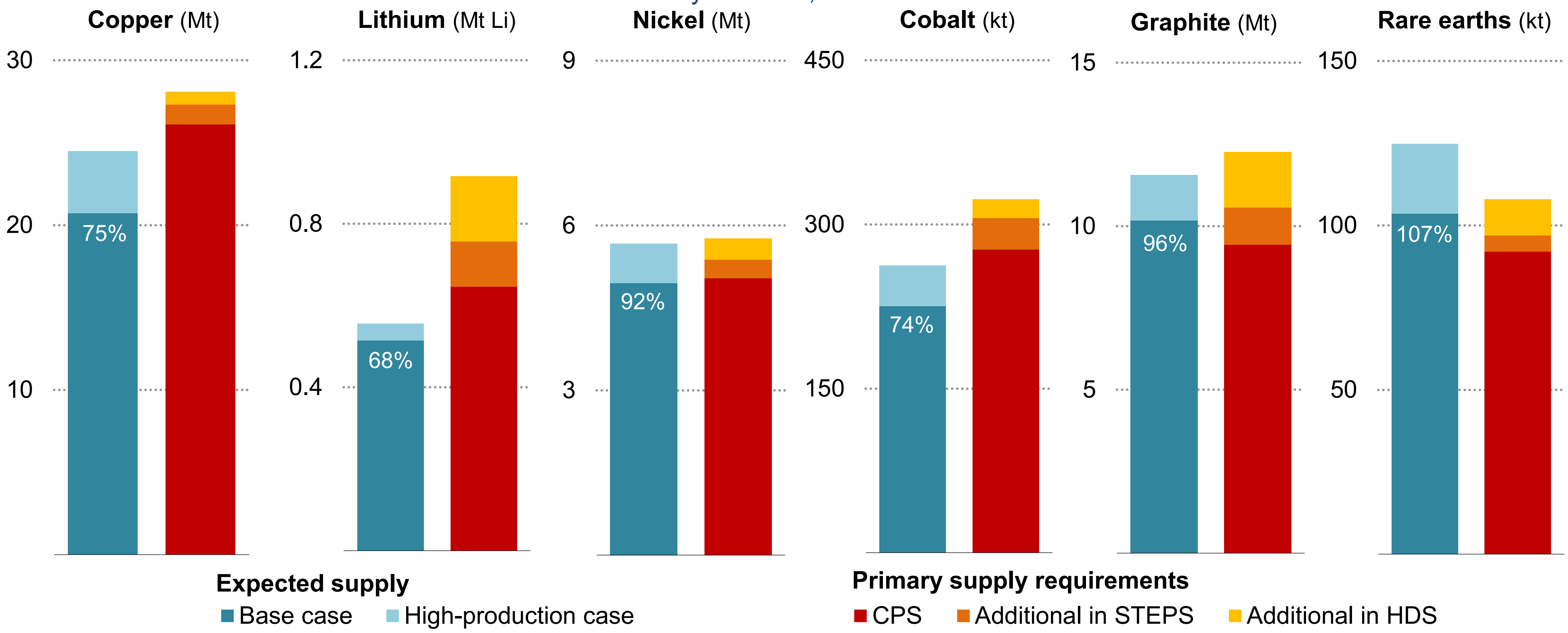
Global critical minerals demand in the STEPS, 2025-2040



Notes: CPS = Current Policies Scenario; HDS = High Demand Scenario; kt = kilotonnes; Li = lithium; Mt = million tonnes; STEPS = Stated Policies Scenario. The figures for copper are based on refined copper demand (excluding direct-use scrap). Rare earths refer to magnet rare earth elements only. Growth rates (in blue) are between 2024 and 2040.

Accounting for recycling, global supply gaps persist through 2035 for copper and lithium and widen slightly for nickel

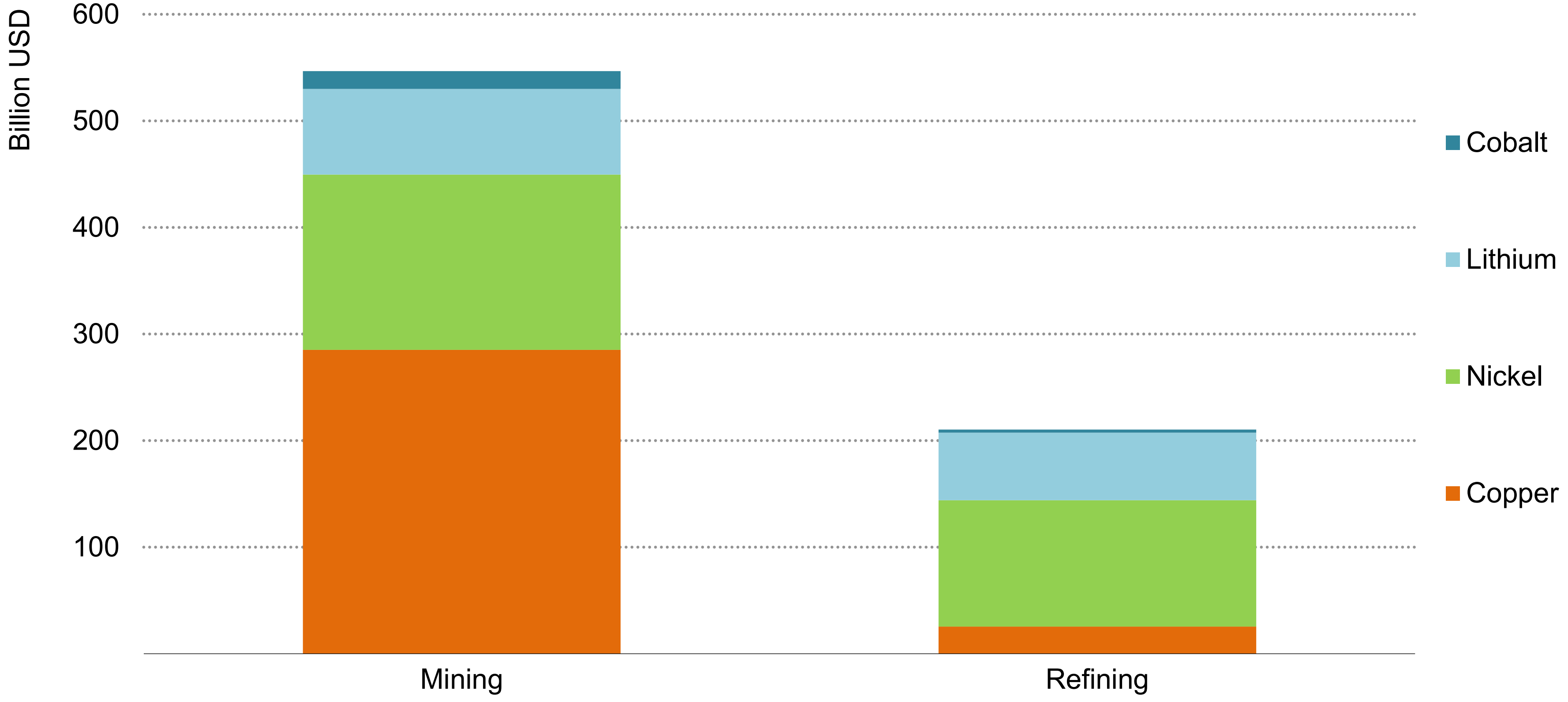
Expected mine supply from existing and announced projects and primary supply requirements for key energy minerals by scenario, 2035



Notes: CPS = Current Policies Scenario; HDS = High Demand Scenario; STEPS = Stated Policies Scenario. The percentage values indicate the share of base case supply against 2035 primary supply requirements in the STEPS. Expected supply is based on mined or raw material output based on announced projects, except for graphite, where the figure refers to the sum of natural flake graphite and synthetic graphite supplies. Primary supply requirements are calculated as total demand net of secondary supply, also accounting for losses during refining operations. Rare earths refer to magnet rare earth elements only.

Over USD 750 billion in investment is required across key energy mineral value chains to meet demand

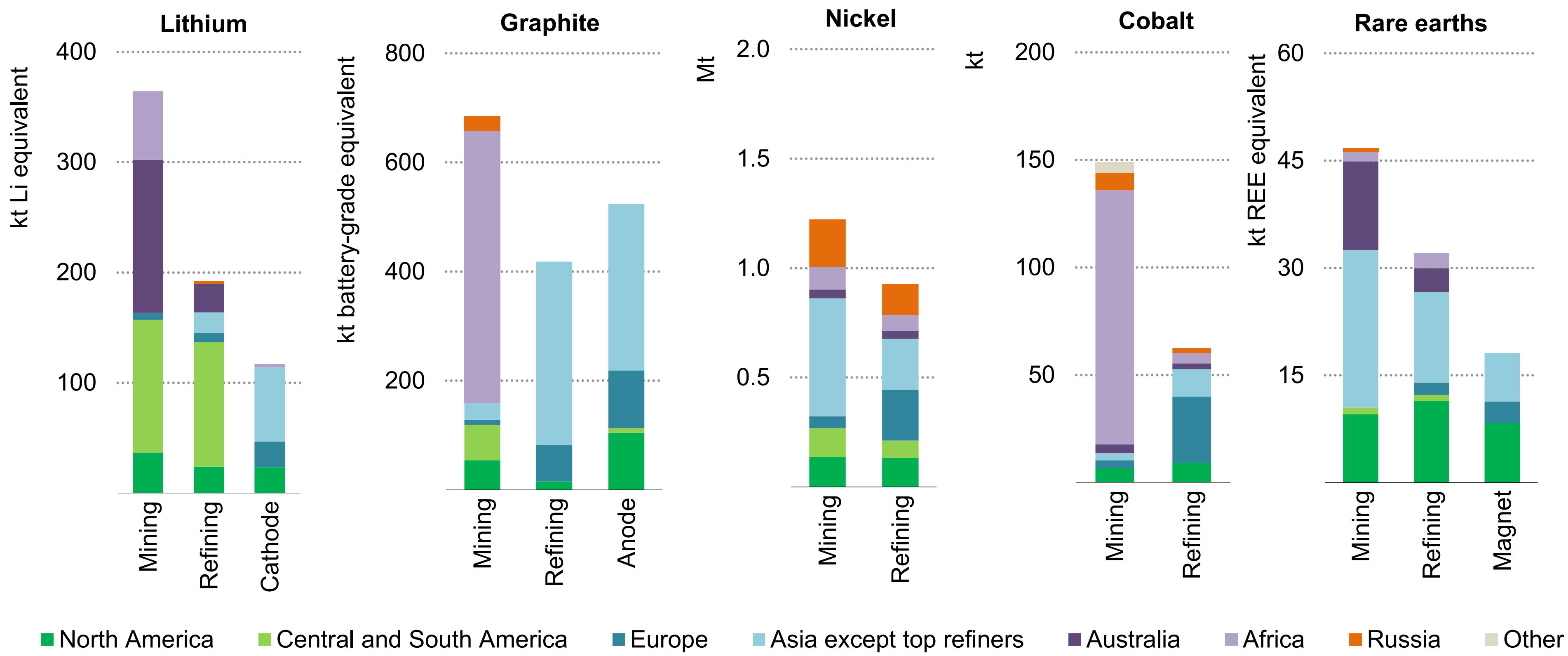
Cumulative capital requirements for mining and refining in the STEPS, 2026-2040



Notes: STEPS = Stated Policies Scenario. Capital requirements cover greenfield and brownfield mining, refining expansions and sustaining capital. Requirements are derived from projected production gaps to 2040 and assume rising capital intensity over time, reflecting declining ore grades.
Sources: IEA analysis based on data from company reports and S&P Capital IQ.

Project pipelines reveal a structural imbalance in diversification efforts, with limited refining and downstream capacity in the project pipeline

Estimated 2035 production from existing and announced projects outside top refiners



Notes: REE = rare earth element. Supply estimates are for base case.The top refiners include Indonesia and China for nickel and China for others. Rare earths refer to magnet rare earths only. For downstream sectors, the values respectively reflect the contained volume of lithium (in kt Li equivalent), spherical graphite (in kt battery-grade equivalent) and rare earths (in kt REE equivalent) in battery cathodes, battery anodes and permanent magnets manufactured. Graphite mining is in kt battery-grade equivalent, accounting for processing losses.

Processing bottlenecks persist despite a strong critical mineral demand outlook

Demand outlook

Critical mineral demand continues to grow strongly in the Stated Policies Scenario (STEPS), which reflects today's policy settings. The deployment of electric vehicles (EVs), battery storage, renewables and electricity networks keeps energy technologies at the centre of demand growth for a wide range of minerals through to 2040.

Strong growth is also evident across the broader range of scenarios, including the Current Policies Scenario (CPS), which provides a more conservative outlook for energy technology deployment, and the High Demand Scenario (HDS), which assumes more rapid adoption of low-emissions energy technologies. Demand in the CPS is around 10% lower than in the STEPS by 2040, while demand in the HDS is around 16% higher.

Lithium experiences the strongest growth, with demand increasing well over threefold by 2040 in the STEPS. Demand for graphite doubles over the same period, while nickel demand grows by 65%. Demand for rare earth elements rises by around 50%, and copper demand increases by over 25%, adding around 7 million tonnes (Mt) by 2040. Energy technologies account for an increasing share of total demand across all major minerals. For example, energy applications account for around 18% of nickel demand today, but this share rises to around 40% by 2040.

The assessment also reflects ongoing technology evolution. For cobalt, demand growth is moderated by the increasing adoption of lithium iron phosphate (LFP) battery chemistries. While the share of energy technologies in total cobalt demand rises from 31% today to 43% by 2030, it subsequently declines towards 2040. Nevertheless, total cobalt demand still increases by over 30% between today and 2040 in the STEPS.

Supply outlook

Supply projections are derived from a detailed, asset-by-asset assessment of announced mining and refining projects. Reflecting the latest project developments, this year's analysis updates both the base case and the high-production case.

The base case includes output from existing operations, assets under construction and projects considered highly likely to proceed, based on factors such as secured permits, committed financing and established offtake agreements. The high-production case incorporates projects at a relatively advanced stage of development that are still seeking financing and/or permitting approval. Neither scenario includes speculative projects or projects that remain at an early stage of development.

In recent years, the number of announced projects targeting key energy minerals has continued to increase, signalling the potential for a notable expansion in future mining and refining capacity. Nonetheless, expected supply from existing and announced projects suggests that supply gaps for copper and lithium persist through 2035, while the gap for nickel is slightly tighter than in last year's *Global Critical Minerals Outlook*. A supply gap also emerges for cobalt in this year's assessment, driven almost entirely by the export quota introduced by the Democratic Republic of the Congo (DRC).

Investment requirements

Meeting the rising demand for critical minerals requires substantial investment. In the STEPS, just over USD 750 billion in capital investment is required for both mining and refining between now and 2040. This reflects the upfront capital needed to develop new mines and refineries, as well as capital for brownfield expansions and sustaining capital expenditure. It also captures rising capital intensity for new projects, driven by declining ore grades, particularly in more mature markets such as copper.

Among the minerals, copper accounts for the largest capital requirements at about USD 310 billion, reflecting the sizable projected supply gap, which requires significant investment to bring new mining capacity online, expand existing operations and address rising capital intensity as ore grades decline. Nickel also faces USD 280 billion in investment needs, primarily in mining, as supply gaps begin to emerge after 2030. By contrast, although lithium also faces supply gaps, its relatively lower capital intensity limits overall investment requirements, while cobalt's small market size means that only modest investment is required to meet demand.

Supply chain imbalances

This year's analysis places a stronger focus on pathways to supply chain diversification, examining the extent to which projects outside the leading countries could reduce vulnerabilities associated with highly concentrated supply chains. The assessment covers mining and refining activities, as well as selected downstream processing segments, including battery chemicals and permanent magnets. Across several minerals, the project pipeline points to a structural imbalance between upstream supply growth and midstream and downstream manufacturing capacity. While mining projects are expanding across geographically diverse regions, the pipeline for refining and downstream capacity remains relatively small, creating potential bottlenecks in the event of supply disruptions.

Rare earth elements illustrate these challenges. By 2035, announced projects are sufficient to reach close to 50 kilotonnes (kt) of rare earth element content in mining capacity outside the leading producer. However, planned refining and separation capacity amounts to less than 40 kt, with activity concentrated primarily in Malaysia and the United States. Downstream capacity is more constrained. Announced projects for rare earth metals, alloys and magnets total only around 18 kt on a rare earth element content basis as of early 2026, equivalent to about half of the mining capacity in the pipeline.

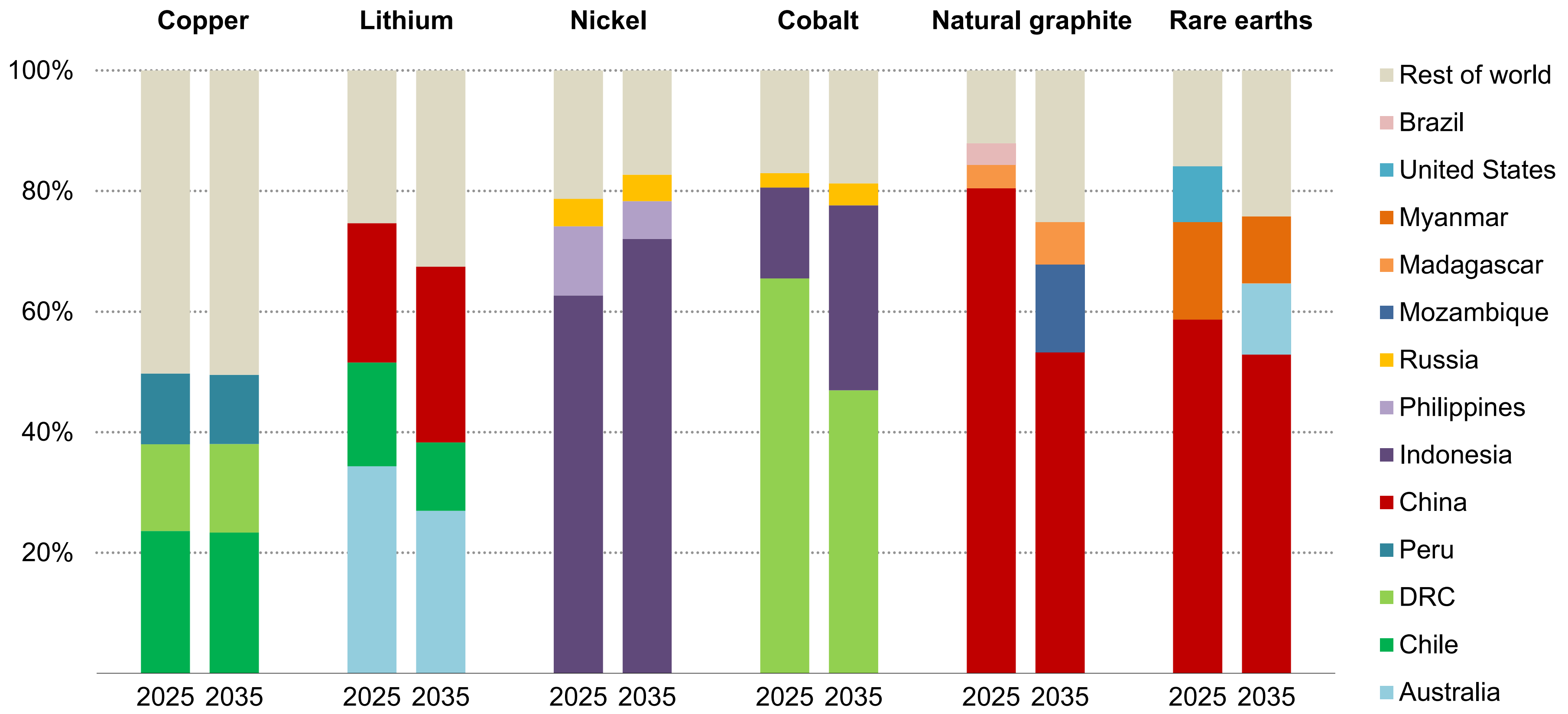
A similar pattern is evident in lithium supply chains. Mining projects located outside the dominant supplier point to potential supply growth well above 350 kt by 2035, but announced refining capacity remains below 200 kt. At less than 120 kt, cathode material capacity outside the dominant supplier is even smaller. For graphite, battery-grade processing capacity outside the dominant supplier also lags behind mining supply growth. Similar trends are visible for nickel and cobalt, where downstream processing expansion remains smaller relative to upstream supply. In the case of cobalt, refining capacity outside the dominant supplier amounts to only below 40% of projected mined supply.

This imbalance should also be interpreted in light of different investment timelines across the supply chain: mining projects generally require longer lead times for permitting and construction than refining or processing facilities, so their announcements tend to appear earlier.

This leaves room for policy action to change the picture, as timely measures to reduce investment risks and support strategic capacity in refining and downstream manufacturing could help ensure more balanced supply chain development (see Chapter 3).

Except for nickel, announced projects suggest gradual progress towards diversification of mining supply sources across regions…

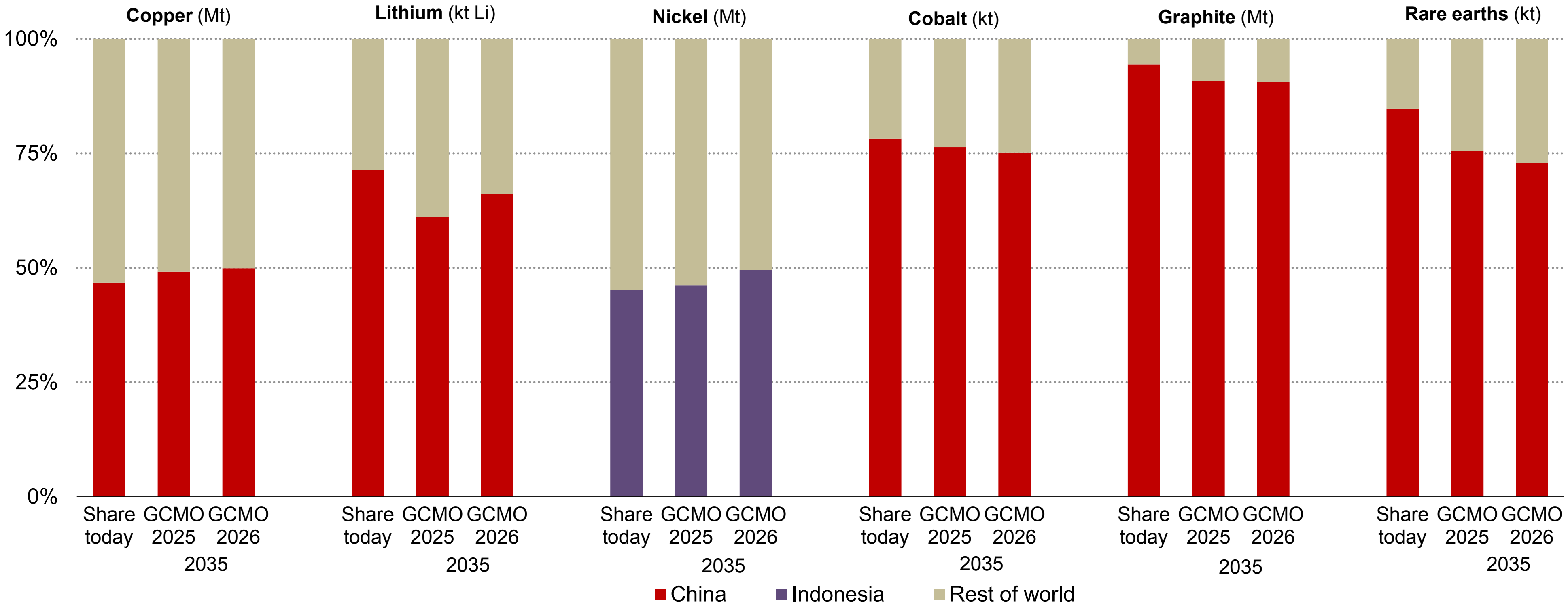
Geographical distribution of mined or raw material production for key energy minerals in the base case, 2025-2035



Notes: DRC = Democratic Republic of the Congo. Graphite mining is for natural flake graphite. Rare earths refer to magnet rare earth elements only. The figure shows the production shares of the top three producing countries in the given year.

… while refining shows a starker picture, with diversification momentum emerging for rare earths but remaining limited across most other minerals

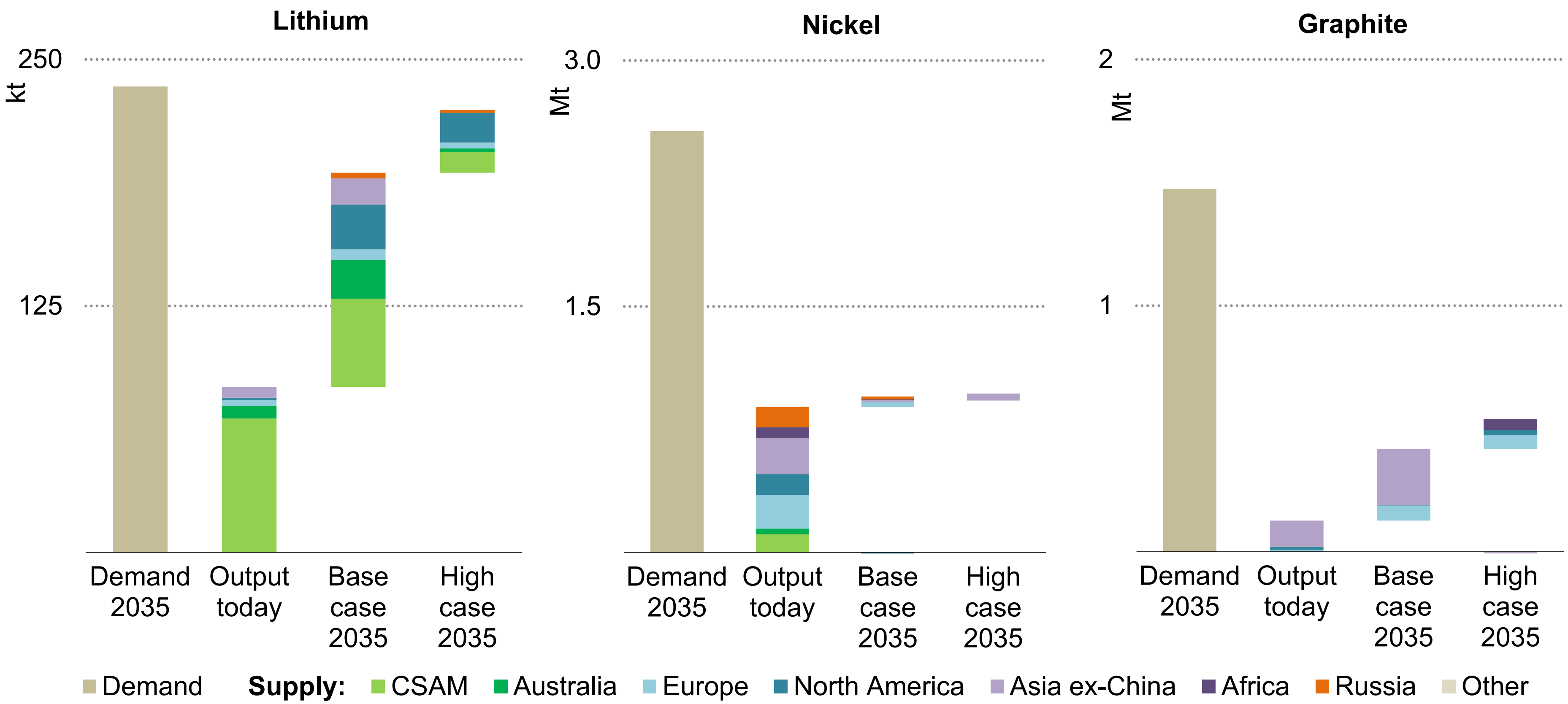
Share of the top refiner of key energy minerals in the base case, 2025-2035



Notes: GCMO = Global Critical Minerals Outlook. Figures for graphite are based on battery-grade graphite, including spherical graphite and synthetic graphite. Rare earths refer to magnet rare earth elements only.

Meeting demand outside the dominant supplier requires additional refining projects to emerge across both upstream and end-market geographies

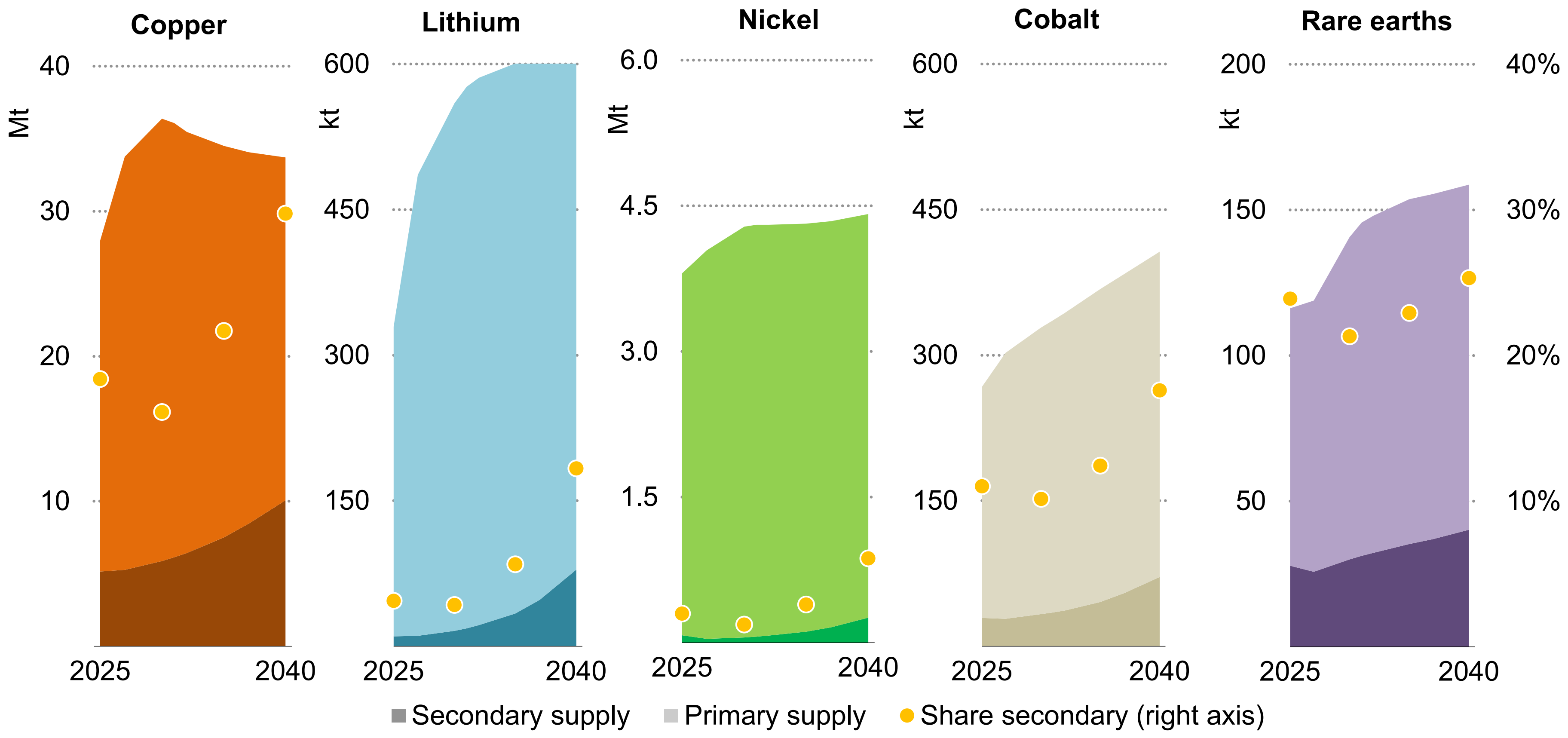
Demand and refined supply outside the dominant suppliers for selected minerals, 2035



Notes: CSAM = Central and South America. N-1 supply excludes production volumes from the largest refiners from the total global supply, and N-1 demand excludes consumption of those countries from total global demand. Graphite considers only battery-grade requirements and battery-grade supply, covering both spherical and synthetic materials.

Secondary supply could double its share, with recycling rates rising from around 10% on average today to close to 20% by 2040 under today's policy settings

Primary and secondary supply of key energy minerals in the STEPS, 2025-2040



Notes: STEPS = Stated Policies Scenario. The figure includes recycled volumes from end-of-life equipment and manufacturing scrap. For copper, direct-use scrap is excluded. Rare earths refer to magnet rare earth elements only.

Mining diversification improves, but refining concentration remains high and graphite and nickel reveal persistent "N-1" challenges

Supply concentration

Mining supply shows some signs of diversification, though progress remains uneven across different minerals. Except for nickel, a pipeline of new project announcements offers some optimism for a more diversified geographic base in mining. Since 2021, the IEA has tracked supply concentration using the combined share of the top three producing countries. On average, these countries account for around 76% of global mine production today, and this share is projected to decline modestly to 73% by 2035. Lithium supply is expected to become more diversified as growing production in Africa and continued investment in Argentina reduce the combined share of Australia, Chile and China from around 75% to below 70%. Graphite and rare earths follow a similar trend. Cobalt supply concentration remains broadly stable as the share of the DRC declines, offset growing production in Indonesia and uncertainty over the extent to which DRC supply will reach the market under current export restrictions. Nickel is the notable exception, with concentration increasing further as Indonesia's share of global supply rises above 70%. The top three producers are expected to remain largely unchanged over the next decade, with two exceptions: in graphite, Tanzania is set to overtake Madagascar, while in magnet rare earths, Australia and the United States switch position.

The picture for refining is considerably starker. Refining remains significantly more concentrated than mining, with China maintaining dominant positions across multiple midstream segments. Today, China accounts for just under 50% of global copper refining capacity, 70% of lithium refining, 75% of cobalt refining, 85% of magnet rare earth separation and over 90% of battery-grade graphite production. Last year's *Global Critical Minerals Outlook* pointed to a modest decline in top-refiner concentration, from around 70% today to 67% by 2035, and recent project announcements have done little to alter the broader picture. New rare earth separation projects outside China provide some diversification momentum, but structural inertia remains strong across most value chains. For many minerals, refining capacity remains closely linked to established chemical processing infrastructure, accumulated technical expertise and proximity to downstream manufacturing. As a result, even as mining becomes more geographically diversified, midstream bottlenecks persist, reinforcing supply chain vulnerabilities and strategic dependencies.

N-1 assessment and security implications

High levels of supply concentration create the risk of significant supply shortfalls if production from the largest supplier is disrupted for any reason. A common approach to assessing such vulnerabilities is the "N-1" framework, which evaluates how a system would function in the absence of its largest participant. Applied to critical minerals, this framework helps illustrate how markets would operate without the dominant supplier. Under this approach, N-1 supply refers to global supply excluding the largest producing country, while N-1 demand excludes consumption from that same country. Comparing N-1 supply and demand provides a useful indication of the extent to which markets outside the dominant supplier can meet their own needs.

Current project pipelines suggest that significant gaps between N-1 supply and demand could persist for several minerals, particularly nickel and graphite, highlighting continued exposure to disruptions in the dominant supplier. Closing these gaps would require substantial additions of refining and processing capacity, both in upstream resource-rich economies and in downstream manufacturing and consumer markets. The N-1 framework provides a practical lens for assessing diversification progress and identifying remaining vulnerabilities.

- For lithium, announced lithium chemical projects suggest the potential to roughly double refined output outside China. This expansion is geographically distributed between upstream-linked facilities in Latin America and Australia and downstream-oriented projects in North America. Despite a sizeable overall supply gap, the N-1 gap is relatively modest.
- For graphite, project announcements indicate strong ambition to reduce the current level of concentration. In the base case, production outside the dominant supplier could increase nearly fivefold, rising to as much as ninefold in the high-production case, driven primarily by new capacity in Asia and additional projects in Europe. However, even with this rapid expansion, a sizeable N-1 gap remains.
- For nickel, diversification prospects remain more limited. Refining capacity outside China and Indonesia is projected to meet only around one-third of N-1 demand, reflecting a relatively modest pipeline of new projects.

Secondary supply

Secondary supply from recycling can play an increasingly important role in easing primary supply constraints and strengthening system resilience. There is potential for its contribution to roughly double, with average recycling rates rising from around 10% today to close to 20% by 2040 in the STEPS. However, prospects vary considerably across minerals, reflecting differences in product lifetimes, collection systems, manufacturing scrap availability, and technical and economic feasibility.

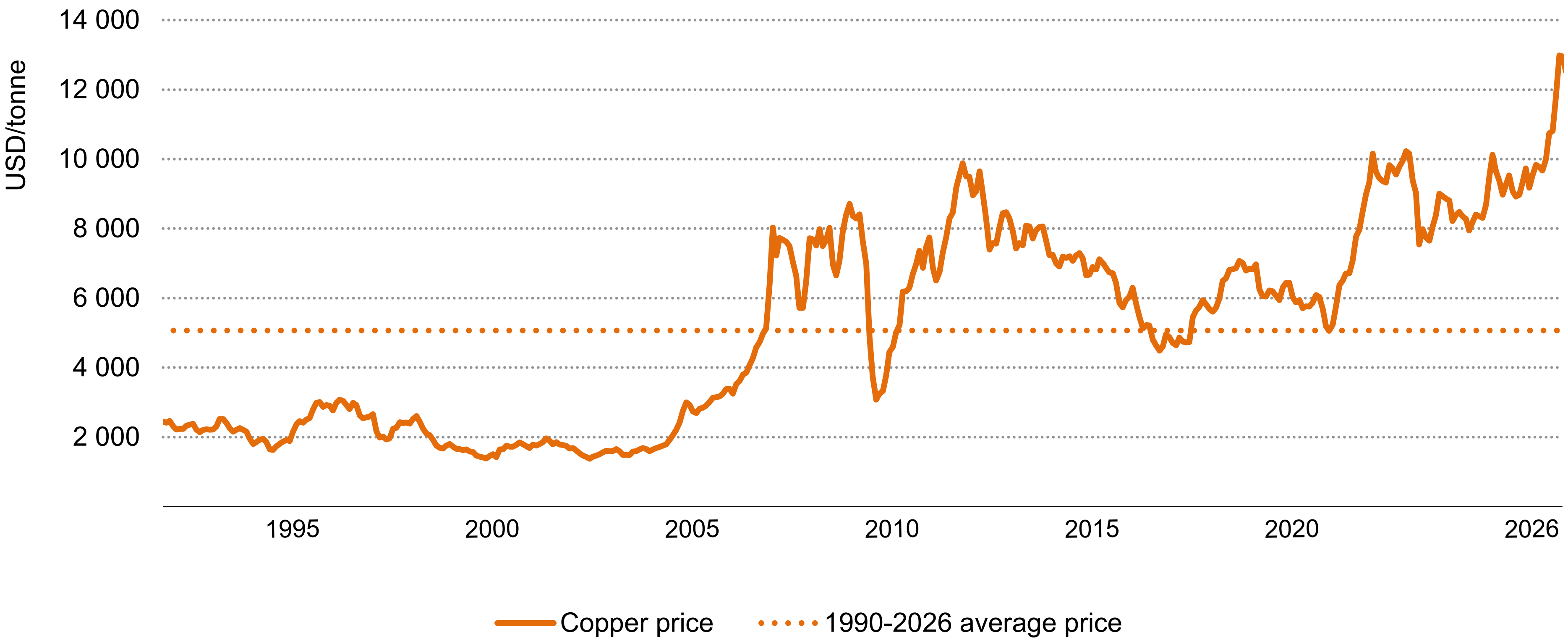
Cobalt and copper already benefit from relatively well-established recycling streams, with recycling rates of around 16% and 10%, respectively (excluding direct use of copper scrap). These could increase to approximately 25% for cobalt and 20% for copper by 2040, supported by improvements in collection, sorting and processing systems. Rare earth magnet recycling remains dependent on manufacturing scrap from magnet production, with only limited end-of-life recovery today. However, the retirement of early generations of EVs and wind turbines is expected to create a significant new source of recyclable material.

For lithium and nickel, recycling remains at an early stage, with current rates below 5%. Despite this, rapid market growth and rising concerns over supply security provide strong incentives for the expansion of recycling capacity. Overall, secondary supply could account for a substantially larger share of future demand by 2040, provided that supportive policies, investment in recycling infrastructure and sustained end-market demand are in place.

Outlook for copper

Copper prices hit record highs in 2026 as structural and short-term pressures converge

Copper monthly average price, 1990-2026



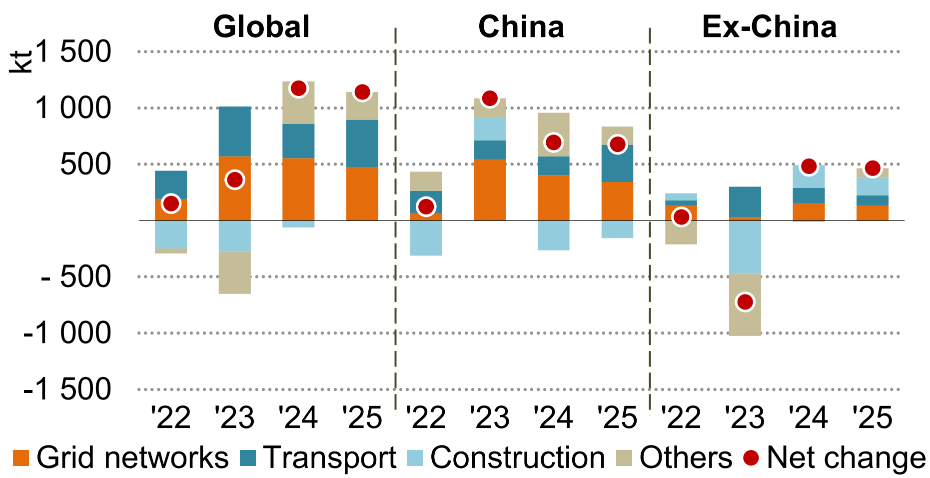
Notes: The copper price is the LME Copper Grade A Cash price. Prices are nominal.
Source: IEA analysis based on data from S&P Capital IQ.

Copper prices surge due to major supply disruptions, acid supply risks from the Middle East conflict and structural challenges

Copper prices rose sharply throughout 2025, surpassing USD 12 000 per tonne for the first time in December, and surged further to record highs in 2026, exceeding USD 14 000 per tonne in May. Initially, the unprecedented price levels were driven by several important short-term developments, including supply disruptions at several major mines and a build-up of US copper inventories due to tariff uncertainty in 2025. However, they were also underpinned by underlying factors such as challenges in developing new copper mines and the anticipation of strong demand growth from electrification and data centre construction. Lower interest rates, a softer US dollar, a broader investor shift into physical assets and significant financial speculation also amplified upward pressure on prices. However, with the closure of the Strait of Hormuz in February 2026, new pressures emerged around sulphuric acid, a critical input for primary copper leaching, solvent extraction and electrowinning (SxEw) operations, given the Gulf's role as a major sulphur supplier and the Strait's importance as a key trade route. This was amplified further by China's ban on sulphuric acid exports, fuelling increasing supply concerns and price rises.

Global demand for refined copper reached almost 28 Mt in 2025, a robust increase of 3.7% from 2024. India, Saudi Arabia and Malaysia continued to record strong demand growth, while Viet Nam also saw a major increase in demand, driven by rapid industrial and infrastructure development. Although volumes remain relatively low, Africa was the fastest-growing region of demand. Demand in China grew by almost 5%, led by particularly strong demand from the industrial and manufacturing sector.

Change in annual copper consumption by sector and region



Note: Includes direct-use scrap.

On the supply side, there were major supply disruptions of 1.5 Mt in 2025, equivalent to over 6% of global mined supply for the year. This tipped the refined market into deficit and was the primary driver of the exceptional copper price rises. There were disruptions at two major mines, Grasberg in Indonesia and Kamoa-Kakula in the DRC. Grasberg is the second-largest copper mine in the world, accounting for almost 4% of global mined copper production in 2024. A disastrous mudflow in September 2025 caused major disruption and fatalities, causing production in 2025 to be around half that in 2024. Significant disruptions are expected throughout 2026, with a full recovery only anticipated in 2028. At Kamoa-Kakula, the largest copper mine in the DRC and the fourth-largest copper mine in the world by 2024 production, seismic activity caused severe flooding and infrastructure damage, leading to a production cut of almost one-third in 2025 relative to guidance. Rehabilitation requirements and timelines mean that 2026 production guidance is expected to remain below 2024 levels.

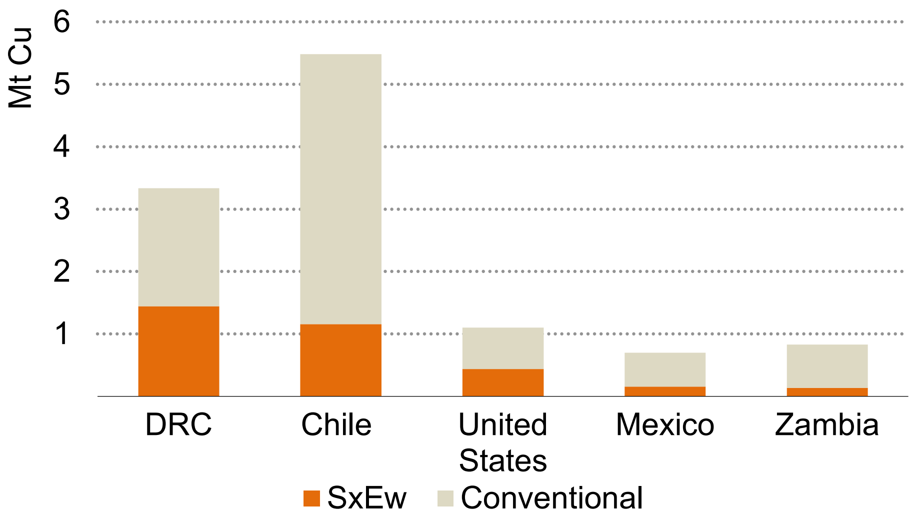
Impact of the conflict in the Middle East and China's ban on sulphuric acid exports

The conflict in the Middle East and effective closure of the Strait of Hormuz caused a supply shock for sulphur and sulphuric acid, with consequences for metals and fertiliser markets. Around half of global seaborne sulphur trade passes through the Strait of Hormuz, while Gulf countries and Iran account for a quarter of global sulphur supply. Compounding this effect, China implemented a ban on sulphuric acid exports from May 2026 until the end of the year, affecting almost a quarter of ex-China acid needs.

Sulphuric acid is a critical input to primary copper leaching, affecting production through SxEw methods. Over 15% of global primary copper output is produced via this route. There are major leaching operations relying on sulphuric acid in the DRC (almost 1.5 Mt) and Chile (1.2 Mt), which are the most vulnerable to the acid export ban and any supply shortages. The DRC is particularly vulnerable, with almost 45% of its total copper production using sulphuric acid leaching, compared to 20% for Chile. For an average SxEw facility, acid accounts for 13% of costs, but the DRC has higher cost exposure, at 20%, due to the higher carbonate content of the ore. Mexico, the United States and Zambia are also exposed as significant producers relying on acid leaching for copper production. With existing pressure from sulphur supply challenges in the Middle East now combined with China's restrictions on sulphuric acid exports, copper producers are facing significant headwinds. Sulphur or acid inventory levels in some producers are reportedly down to 30-60 days, with warnings of potential production cuts growing.

At the global level, reduced acid availability from a prolonged acid ban or sustained high prices would result in global SxEw production curtailments, adding considerable supply stress to an already tight copper supply market. Copper prices are already near record highs, and further supply strains are likely to drive prices higher, with impacts on a range of strategic sectors and electrical technologies that depend on copper, including grids, energy technologies, transport, data centres, industrial equipment, defence and construction.

Copper SxEw production based on sulphuric acid leaching, 2025



DRC = Democratic Republic of the Congo.
Source: IEA analysis based on data from Wood Mackenzie.

Despite relatively low volumes, Iran is the leading copper producer in the Middle East, at over 400 kt in 2025, but these volumes are unable to access the global market due to the closure of the Strait. Damage to the copper production infrastructure in the Middle East remains limited, as most of the main mines are inland and away from the conflict zones. Nevertheless, planned project developments are likely to be hindered by financing and construction risks.

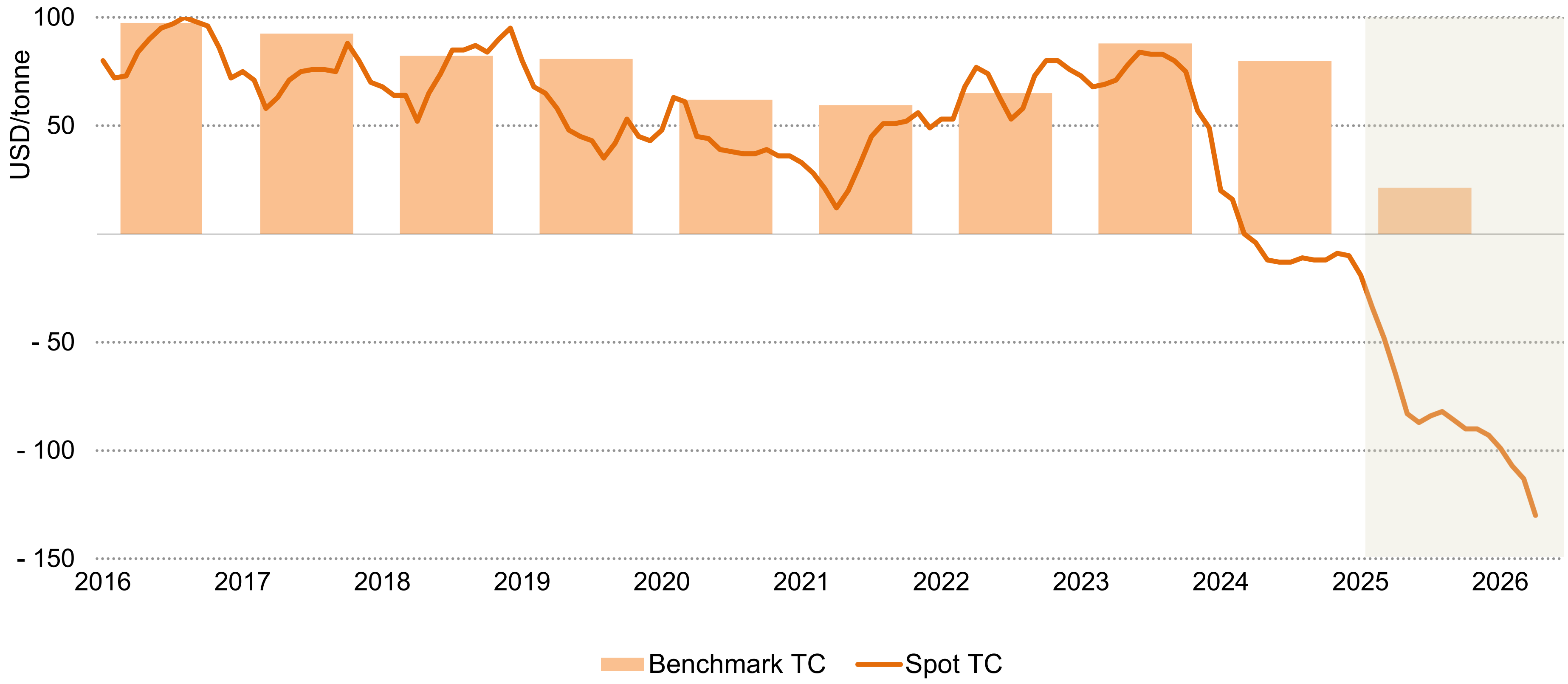
Trade developments

The United States implemented tariffs on semi-finished copper products and copper-intensive derivative products in 2025. Refined copper (cathode) was excluded from these tariffs but was under consideration. The prospect of tariffs on copper cathode led to net imports of 1.5 Mt of cathode to the United States and a build-up of 0.5 Mt on the COMEX, while inventories fell to low levels at Asian and European exchanges. This inventory building in the United States reflects front-loading of demand in anticipation of potential tariffs, regional stock relocation and precautionary stock holding. There was significant arbitrage between the London Metal Exchange (LME) and the Chicago Mercantile Exchange (CME) amid expectations of US tariffs. Recently renewed concern over tariffs has again increased arbitrage and is expected to increase cathode imports to the United States.

There has also been a shift in copper scrap trade flows in recent years. China originally tightened rules on low-grade copper scrap imports, leading to the development of significant processing capacity in Southeast Asia to upgrade scrap from the United States and other countries before it entered China. However, countries in Southeast Asia, such as Viet Nam and Thailand, have tightened their rules on scrap imports in recent years, leading to India and Pakistan emerging as two of the leading hubs for low-grade scrap processing.

Despite record copper prices, smelter fees have fallen to record lows, underscoring deepening risks for the midstream sector

Copper smelter treatment charges, 2016-2026



Notes: TC = treatment charge. The shaded area shows the period of exceptionally low TCs. Spot TC shows monthly miner selling terms to traders in the Far East spot market (CIF Asia). Benchmark TC refers to the annual TC benchmark. For treatment and refining charges, a refining charge is added to the TC and is closely correlated with it. In 2026, both the benchmark TC and refining charge fell to USD 0/tonne.

Source: IEA analysis based on data from Wood Mackenzie.

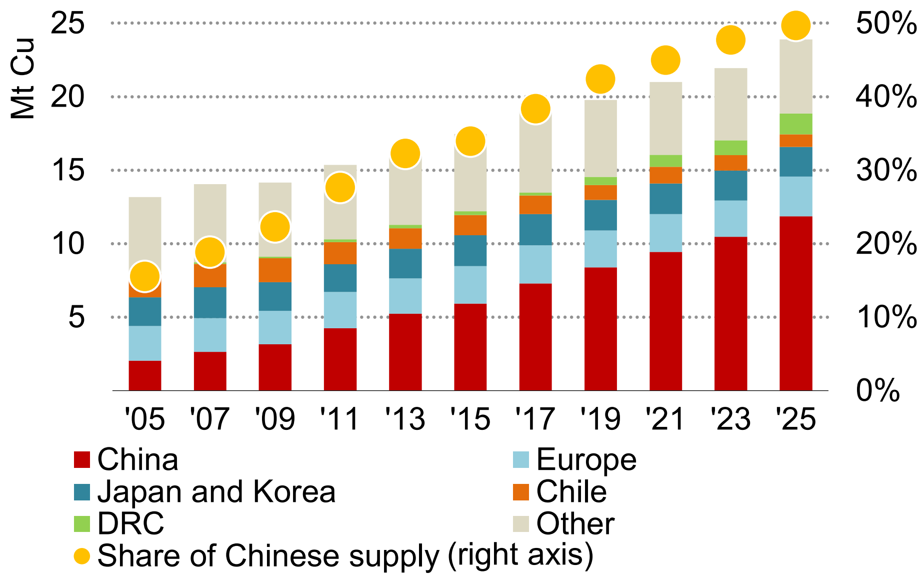
Strategic pressures rise for copper smelters

Despite record-high copper prices, the copper midstream market is facing growing challenges. Smelter fees for processing copper concentrate, known as treatment and refining charges (TC/RCs), have hit all-time lows. The annual TC/RC benchmark, which is based on an agreement between Chilean miner Antofagasta and major Chinese smelters, settled at USD 0 per tonne in January 2026, the lowest level ever agreed in annual negotiations. Meanwhile, spot TC/RCs have been negative since 2024 and have fallen to all-time lows.

The annual TC/RC benchmark is used to settle the majority of smelter contracts, with a smaller share using the spot price, although benchmark usage has been declining. The annual TC benchmark settling at USD 0 per tonne in 2026 means that copper smelters using this benchmark would effectively be eliminating any processing income.

These lows have been driven by a surge in smelter capacity additions from China, which has significantly outstripped growth in copper concentrate production, sharply weighing on smelter fees. Since 2005, China has accounted for over 90% of growth in global copper smelter output, lifting its share from around 15% to half of global supply in 2025.

Copper smelter production by region, 2005-2025

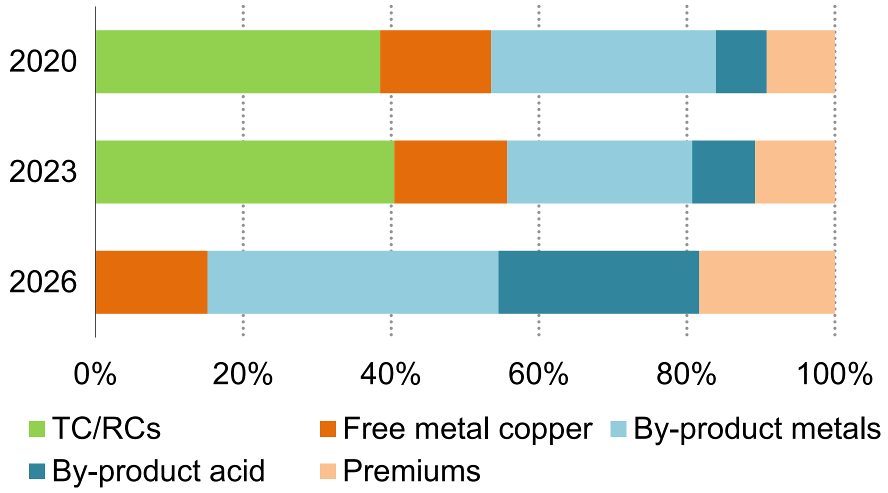


Note: DRC = Democratic Republic of the Congo.
Source: IEA analysis based on data from Wood Mackenzie.

Despite the sharp decline in TC/RCs, many smelters remain profitable for now. This is largely due to revenues from selling by-products, such as gold, silver, free metal and sulphuric acid. With prices for these by-products recently at record highs, smelters with access to by-product-rich concentrate and the ability to maximise recoveries are still generating robust profits, offsetting losses from low TC/RCs. However, increasing volatility and recent declines in precious metal prices raise questions about how long this protective buffer can be sustained in the medium term. The smelter revenue structure, which has historically relied heavily on TC/RCs, has become much more dependent on by-products and premium markets, both of which are inherently more exposed to volatility.

Surging acid prices from the conflict in the Middle East have recently supported smelter economics. China's acid export ban is also likely to drive a bifurcation in acid prices between China and ex-China markets, a dynamic that is already emerging. There is recent upward pressure on acid prices outside China, supporting ex-China smelter economics, while prices have been falling in China due to the surplus domestic acid supply that cannot be exported.

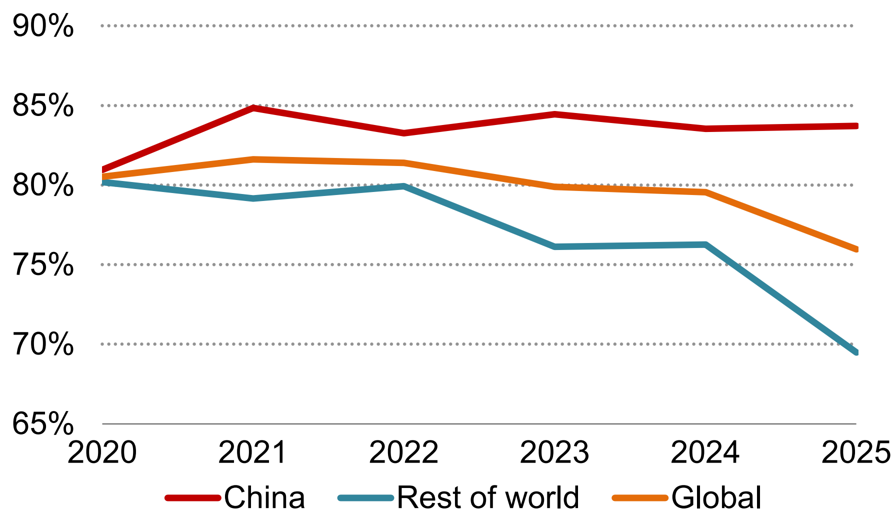
Copper smelter revenue structure, 2020-2026



Note: TC/RCs = treatment and refining charges.
Source: IEA analysis based on data from Benchmark Minerals Intelligence.

Custom smelters are likely to be more affected by the tight concentrate market and depressed TC/RCs than integrated smelters, which can secure a large share of their concentrate internally from affiliated mining operations. Some custom smelters outside China have already been forced to cut production, and others have received emergency government support to prevent closure. Some are reducing primary operations but expanding recycling operations.

Average copper smelter utilisation rates, 2020-2025



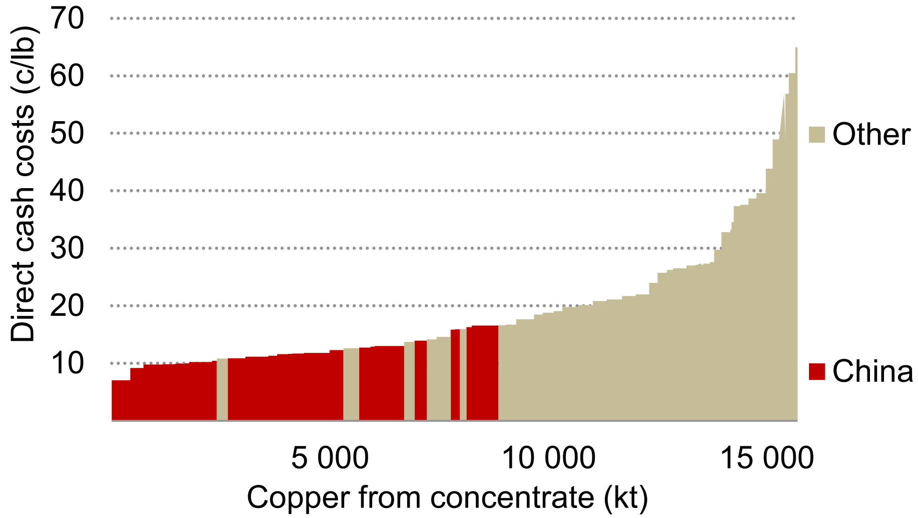
Source: IEA analysis based on data from Wood Mackenzie.

There is already a large disparity in utilisation rates for smelters inside and outside China. All smelters operated at around 80% utilisation in 2020, but by 2025 utilisation had diverged, falling to below 70% for ex-China smelters, while Chinese smelters operated at 85%. Smelters in China generally benefit from lower capital and operating costs than those outside China, reflecting lower labour and construction costs, greater economies of scale and newer smelters with higher energy efficiency, greater yields, and lower maintenance and refurbishment requirements. Most Chinese smelters are state-owned enterprises, some of which may also benefit from government support during periods of low TC/RC income. These factors make leading Chinese smelters more competitive and typically more resilient to periods of depressed TC/RCs than many custom smelters outside China. Nonetheless, low TC/RCs are also recognised in China as one of the most pressing challenges facing the domestic copper smelting industry.

There is broad consensus that low TC/RCs are likely to persist over the medium term. A structural increase in TC/RCs would require either a major boost in concentrate supply or a meaningful reduction in smelter capacity. Most new concentrate supply growth in the pipeline is linked to integrated or semi-integrated smelters, while custom concentrate supply is already declining, making a surge in freely available concentrate unlikely.

This leaves smelter cuts or closures as the main mechanism to balance the market. China's top smelters have agreed to cut production capacity by over 10% in 2026, and the government has halted around 2 Mt of planned new smelting capacity to address the issue. However, these cuts are not enough to meaningfully balance the market. Moreover, China remains a net importer of refined copper, making large-scale smelter closures unlikely. In the first two months of 2026, output actually increased by almost 10%, and some smelters are planning to raise or maintain output this year. However, if acid prices in China fall because of the export ban, Chinese smelters may bring forward planned maintenance to mitigate the risks from lower by-product revenues and acid inventories, which could provide some short-term relief to TC/RC pressure.

Copper smelter production cost curve, 2025

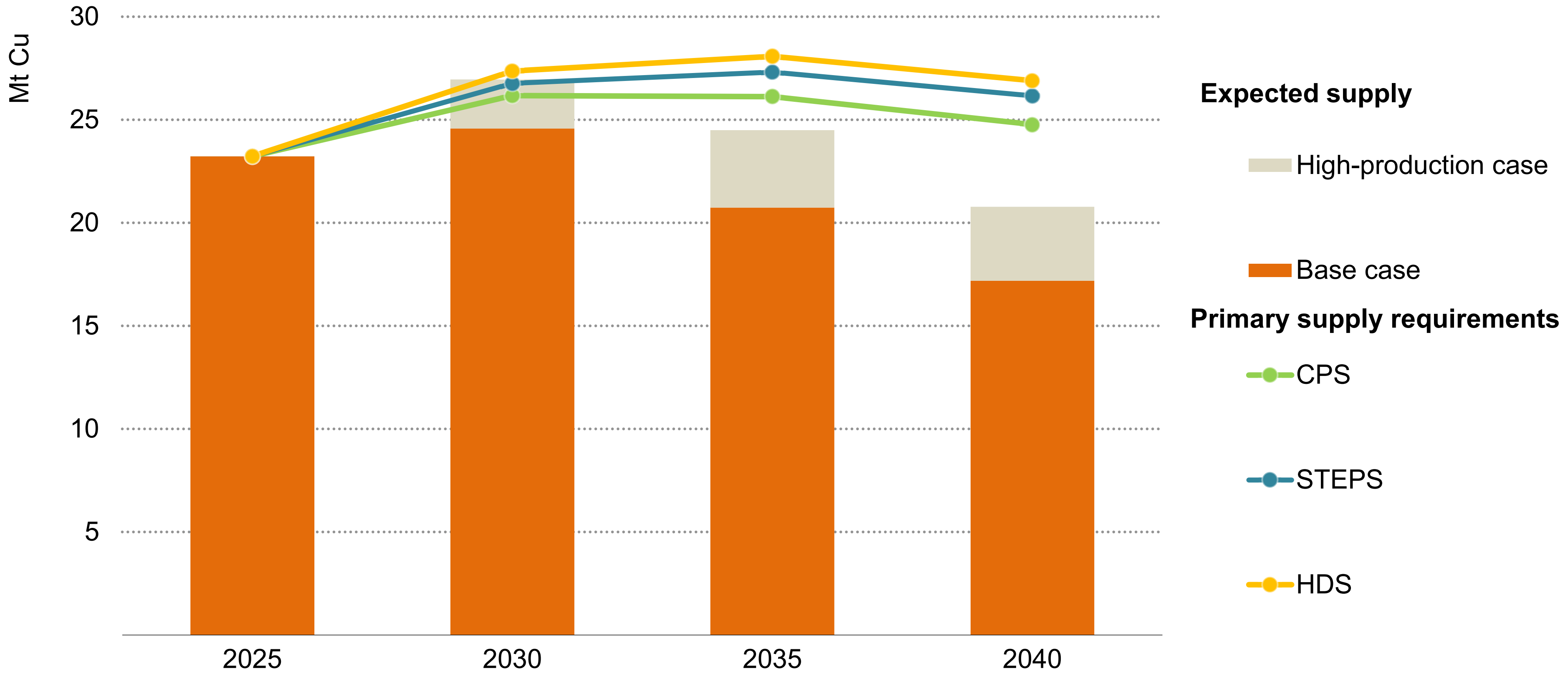


Note: c/lb = cents per pound.
Source: IEA analysis based on data from Wood Mackenzie.

If the low TC/RC environment persists and by-product prices fall, many custom smelters outside China could face significant economic challenges. Should these conditions materialise, the copper market could follow a pattern seen for some other critical minerals: oversupply drives low prices, rendering production outside China uneconomic, in turn resulting in curtailment or rationalisation, and eventually increasing China's market concentration. This recently played out in the nickel market, where a flood of supply from Indonesia, predominantly developed with Chinese investment, drove the market into sustained oversupply, rendering projects around the world uneconomical, while rapidly increasing the concentration of supply in Indonesia. It is becoming increasingly crucial to pay close attention to growing midstream concentration risks in copper supply chains. Consideration may also need to be given to whether the current TC/RC framework remains fit for purpose in a changing market structure.

The large primary supply deficit remains the greatest challenge for copper markets, but there has been some progress in project development

Mined copper supply from existing and announced projects and primary supply requirements by scenario



Notes: CPS = Current Policies Scenario; HDS = High Demand Scenario; STEPS = Stated Policies Scenario. Based on mined output. Primary supply requirements are calculated as total demand net of secondary supply, also accounting for losses during refining operations. See the Introduction section for definitions of the base and high-production cases.

The copper supply gap remains sizeable at around 25% in 2035, slightly narrower than last year, due to new project development

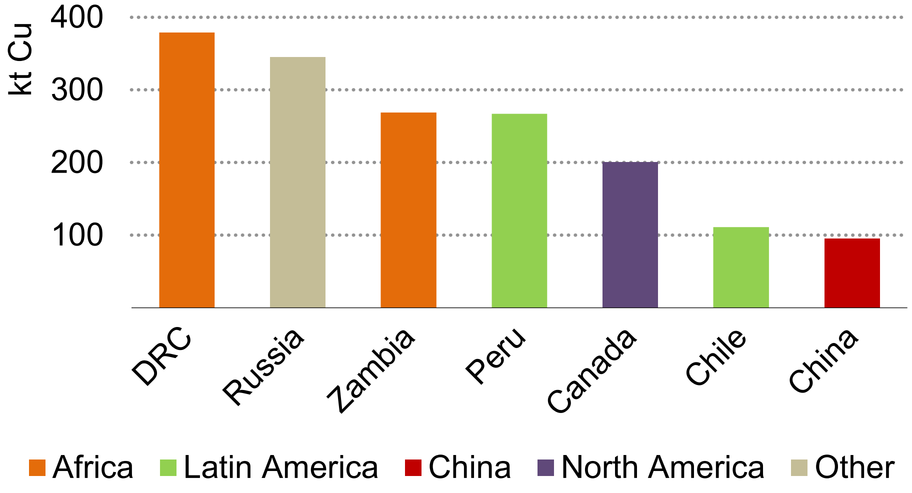
Copper is one of the most strategically important metals, playing a fundamental role across strategic sectors including energy, transport, construction, data centres and defence. However, despite a strong demand outlook, the key challenge for the copper market remains the difficulty of developing new mined supply. Despite record-high copper prices, project development remains insufficient. Based on the project pipeline, global primary copper supply could face a 25% deficit in 2035 under today's policy settings.

One of the key challenges in developing new copper supply is declining copper ore grades, with the average global grade of copper mines having decreased by 40% since 1991, increasing capital costs and project complexity. The average capital intensity for expanding existing projects (brownfield) has also increased by 65% since 2020, approaching levels typically associated with new greenfield projects. These challenges are compounded by a rapidly declining rate of new resource discoveries. Of all the copper deposits discovered in the last 35 years, only 5% have been discovered in the last decade. Finally, lead times for new copper projects are long, at around 17 years from discovery to production, and many major projects have recently experienced significant delays and cost overruns. These dynamics suggest a structurally tighter market for copper concentrate, raising risks for supply security and underscoring the need for supply- and demand-side measures.

Recent project development progress in the DRC, Zambia, Peru and Canada

There has, however, been some notable progress in project development in the last year, increasing the number of projects with a higher chance of materialising. This has led to a slight narrowing of the projected deficit, from 30% in last year's Outlook to over 25% in this year's base case for 2035. Africa is the greatest source of increased supply, with the DRC and Zambia together adding almost 650 kt in 2035 compared to last year's Outlook. In the DRC, this increase is primarily driven by higher projected output from Chinese-backed Malachite ore operations. There are also significant project expansions, such as the Kisanfu mine expansion, operated by China's CMOC Group. In Zambia, growth has been primarily driven by a major expansion at the Lumwana mine, owned by Canada's Barrick Gold, planned for production by 2028, as well as a number of new smaller operations.

Increase in 2035 mined supply outlook relative to last year's Outlook



IEA. CC BY 4.0.

Note: DRC = Democratic Republic of the Congo.

Peru also shows a major increase of almost 300 kt, primarily through the life extension of the large Antamina project and the long-delayed Tia Maria SxEw project from Southern Copper. However, in April, the permit for Tia Maria was revoked before being reauthorised 11 days later, demonstrating the uncertainty and challenges in bringing major new copper projects online. In the United States, the large-scale Resolution project remains tied up in legal proceedings and is therefore too uncertain to include in either the base or high-production case. Russia could add almost 350 kt, primarily through the major Baimskaya project, though it faces some development challenges. Canada adds 200 kt, primarily through the life extension approval for the major Highland Valley Copper mine operated by Teck Resources.

Despite a slightly improved long-term outlook, the short- and medium-term supply outlook appears to have worsened considerably. Constraints on sulphuric acid availability pose a significant risk to SxEw production. Coupled with slower-than-expected recoveries from disruptions at major mines and an already tight market, the copper market faces a strong set of near-term challenges.

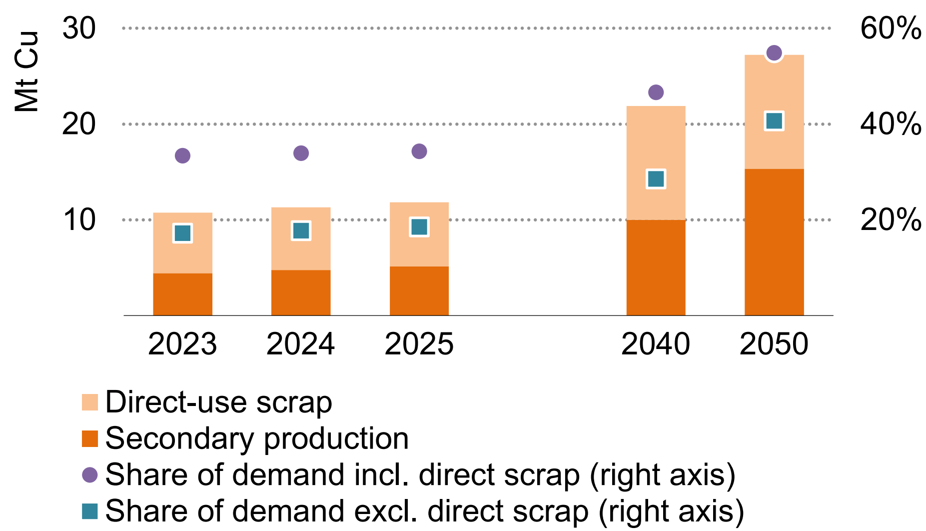
Substitution efforts could stall, but copper scrap presents some opportunity

Aluminium is the leading substitute for copper, with substitution already occurring in some applications, such as overhead power lines, heat exchangers and certain EV cabling. However, beyond performance constraints, such as lower conductivity (around 60% of copper), reduced safety and greater maintenance requirements, aluminium is now also facing significant supply challenges and a tighter market. With 8% of aluminium supply coming from the Middle East, conflict in the region is constraining exports and pushing prices higher. A price ratio of 3 to 1 between copper and aluminium was often heralded as the threshold for significant substitution of copper by aluminium. However, the price ratio has exceeded 3.5 to 1 for much of the past five years without triggering a major tipping point for substitution. If aluminium supply challenges persist, there will likely be a slowdown in substitution efforts.

Copper scrap, however, presents a significant but underexploited source of supply. The share of demand met by secondary supply increased in 2025 to 18%, from 17% in 2024, following the increase in copper prices. In 2026, this share is expected to increase further given the surge in copper prices to record levels this year. Nevertheless, the collection rate for end-of-life copper products remains relatively low, particularly compared with aluminium. If collection rates are significantly increased through targeted policy support, secondary supply could become a major source of global copper supply, potentially meeting over a third of global copper demand by 2050 in the STEPS.

Construction remains the largest source of end-of-life copper scrap across all scenarios to 2050. However, copper from EVs and storage is the fastest-growing source of end-of-life scrap. The higher copper intensity of EVs compared with internal combustion engine vehicles, from the batteries and motors, results in greater copper volumes becoming available when EVs reach end of life, compared with the displaced copper from conventional internal combustion engine vehicles. Copper volumes from end-of-life EVs are set to become available particularly in the major current EV markets of China, Europe, the United States and Southeast Asia. Key policy priorities for increasing secondary copper production include increasing collection rates for legacy copper applications, such as old buildings and cables, strengthening recycling mandates, improving sorting systems and investing in new secondary smelters.

Recycled copper volumes outlook, 2023-2050

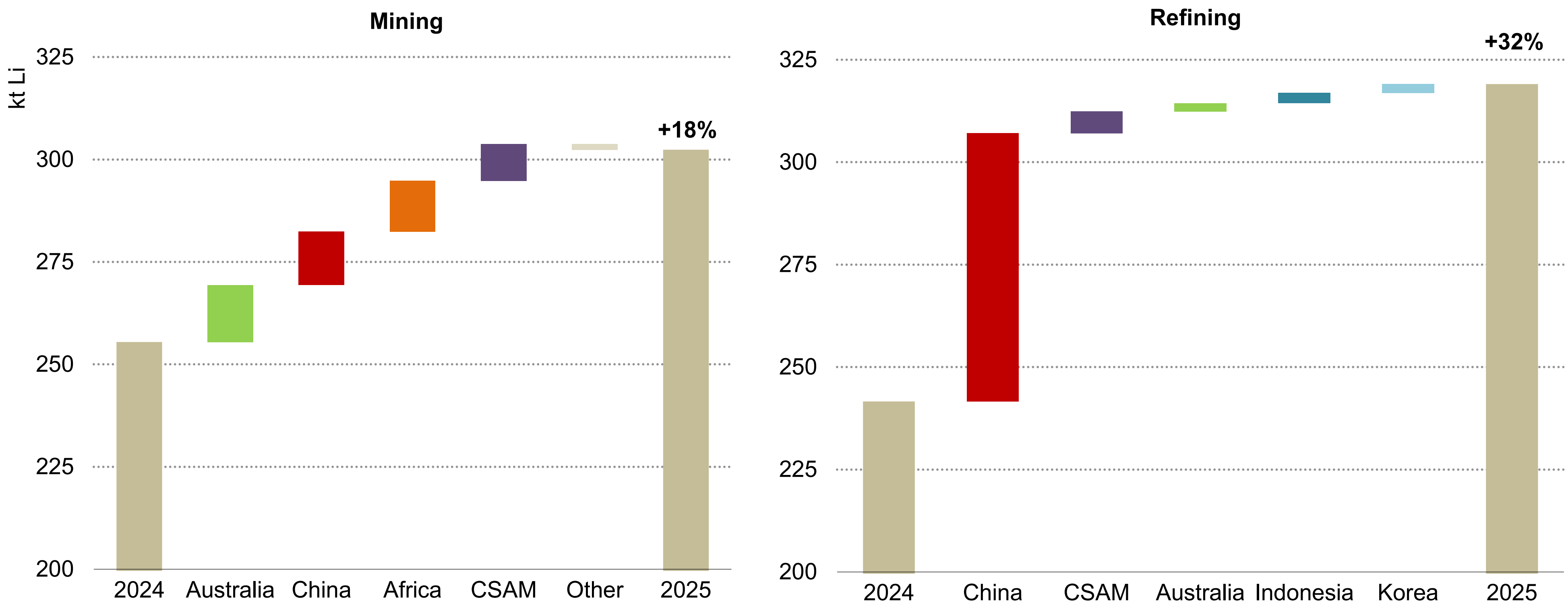


Note: Recycled copper volumes detail the volumes recovered from recycling from secondary production and direct-use scrap, accounting for collection and recycling process yield losses.

Outlook for lithium

Lithium chemical output continued to expand strongly in 2025, driven by new Chinese capacity additions and outpacing growth in mine supply

Change in mined and refined lithium output by region, 2024-2025



Notes: CSAM = Central and South America. Volumes are in elemental content (kt Li) unless otherwise stated. Raw materials cover the extraction of lithium from hard rock ore, as well as from clays and brines. Lithium chemicals cover the first production of lithium carbonate, hydroxide, sulphates and chlorides, and exclude reprocessing.

Changing lithium markets in 2025: lithium demand from battery storage grew by 60%, while output from Africa expanded markedly by 44%

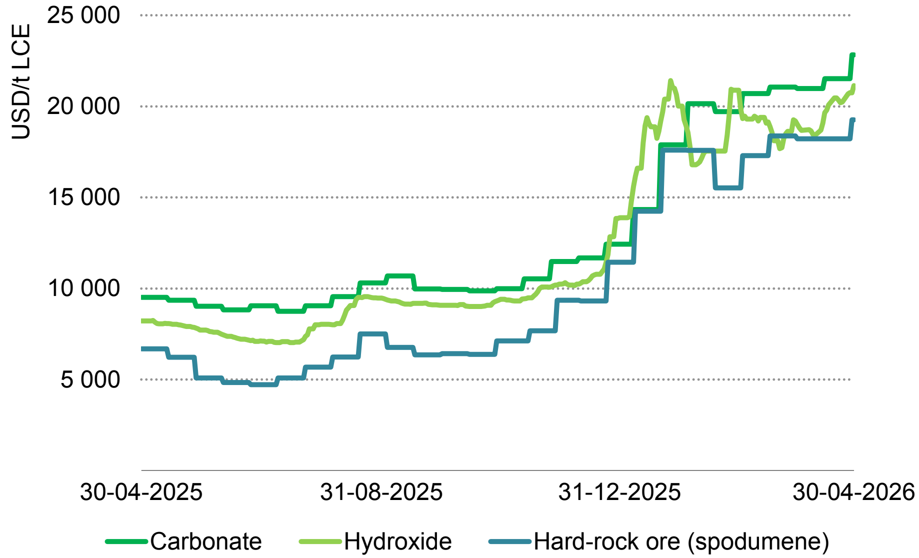
China and energy storage: keywords for sustained lithium demand growth

Lithium demand continued to expand rapidly in 2025, reaching more than 275 kt. This represents a 23% year-on-year increase: a slight moderation from growth in 2024, but still well above the growth rates seen in most other commodity markets. The expansion reflects the continued acceleration of electrification. Demand from EVs rose by 20% to 170 kt, while demand from battery storage reached 30 kt. China accounted for about 90% of the increase in global lithium demand, followed by Korea (+4.2 kt) and Central Europe (+1.4 kt), where battery material production capacity is being developed.

Lithium prices back on the rise

Lithium prices rebounded sharply in early 2026, with lithium carbonate prices nearly doubling over a short period to about USD 20 000 per tonne of lithium carbonate equivalent. This reflected tightening upstream supply conditions caused by overseas bans on ore exports by Zimbabwe, as well as tighter permitting in China's Jiangxi region. Restocking by downstream cathode buyers also added to price pressure. This marked a recovery from two years of weak market conditions, when oversupply and destocking pushed prices down.

Lithium carbonate, hydroxide and spodumene prices, April 2025-April 2026



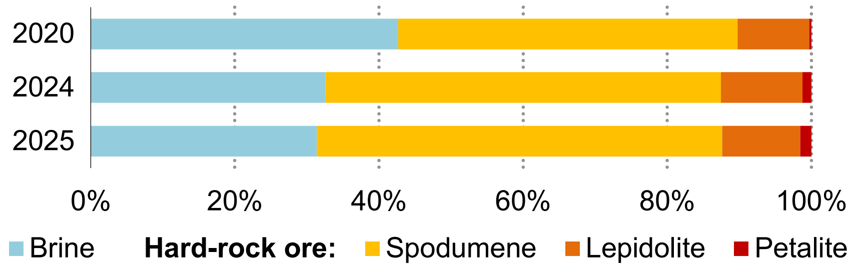
Source: IEA analysis based on data from S&P Capital IQ and Bloomberg.

Current prices remain moderate compared with the peaks observed in 2022, when they reached USD 80 000 per tonne of lithium carbonate equivalent. A fall back in lithium prices remains possible, which could typically be caused by a resumption of lepidolite mining in China, a stabilisation of lithium ore trade flows or a rise in inventories at cathode production plants.

Growing strains on hard-rock lithium supplies

Hard-rock ore, and particularly spodumene, is increasingly becoming the dominant source of lithium supply compared with brine-based resources. The market for hard-rock ores tightened significantly over the course of 2025, due to strong feedstock demand and mining supply constraints. In 2025, lithium chemical output grew by 32%, whereas mined output grew by 18%.

Lithium raw material supply by type, 2020-2025



Diversifying lithium mining driven by African suppliers

In 2025, Argentina saw faster growth output than the historical major producers, Chile, China and Australia. New entrants are reshaping the supply landscape, particularly in Africa: mined output from the continent grew by 44%, helping diversify supply but also involving challenges related to infrastructure and logistics. While three regions, the South American "lithium triangle", China and Australia, account for the majority of lithium supplies today, African nations now represent 14% of global supplies, a 26-fold increase from 2020. While contributing to the diversification of mining supply, this trend could, however, reinforce the dominance of the top refining country, as over 65% of new lithium mining capacity on the continent is owned by companies headquartered in China. With the rise of regional output, the importance of small-scale mining is slowly expanding, bringing its own challenges.

This year, significant steps were also taken to increase European output. In 2025, Finland's Keliber mine began operating, with a planned annual capacity of 2.5 kt before 2030, sufficient to meet 90% of European demand for cathode production in the short term. France is also accelerating strategic mining projects, such as the Allier hard-rock lithium and Alsace brine projects.

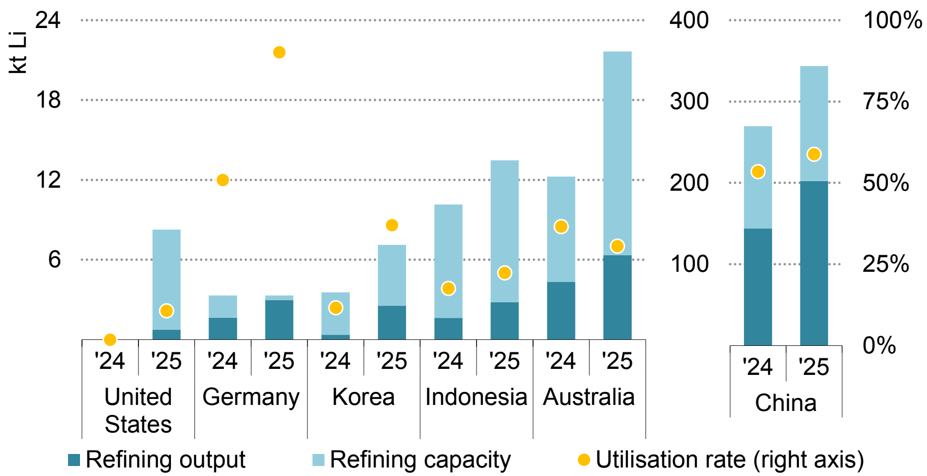
Increasing lithium refining concentration

Global lithium refining output grew rapidly in 2025, with Chinese output expanding by close to 40% year-on-year due to the ramp-up of new capacity, such as Ganfengs's new Dazhou plant (7.2 kt of capacity each), as well as increased utilisation. Some new capacity also emerged in the United States, Korea, Indonesia and Australia but has yet to ramp up, as average utilisation rates remain well below those of China. Overall, this led to increased concentration in lithium refining output, with China's share rising from 70% in 2024 to 75% in 2025.

The first half of 2026 was marked by the start of the first lithium refining plant in Africa, with the ramp-up of a China-owned Zhejiang

Huayou factory in Zimbabwe. The plant, at a total investment cost of USD 400 million, is designed to refine about 6.5 kt in the form of sulphate, which can then be further refined overseas into carbonate or hydroxide and then battery chemicals.

Lithium refining output and capacity, 2024-2025



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Market conditions remained uneven across products. Lithium hydroxide, a chemical used in nickel-rich chemistries, continued to perform less strongly than carbonate, due to the rise of LFP chemistries. This continued to weigh on hydroxide refineries, as well as those converting carbonate into hydroxide, and led to curtailments outside China, including at Australia's Kemerton plant.

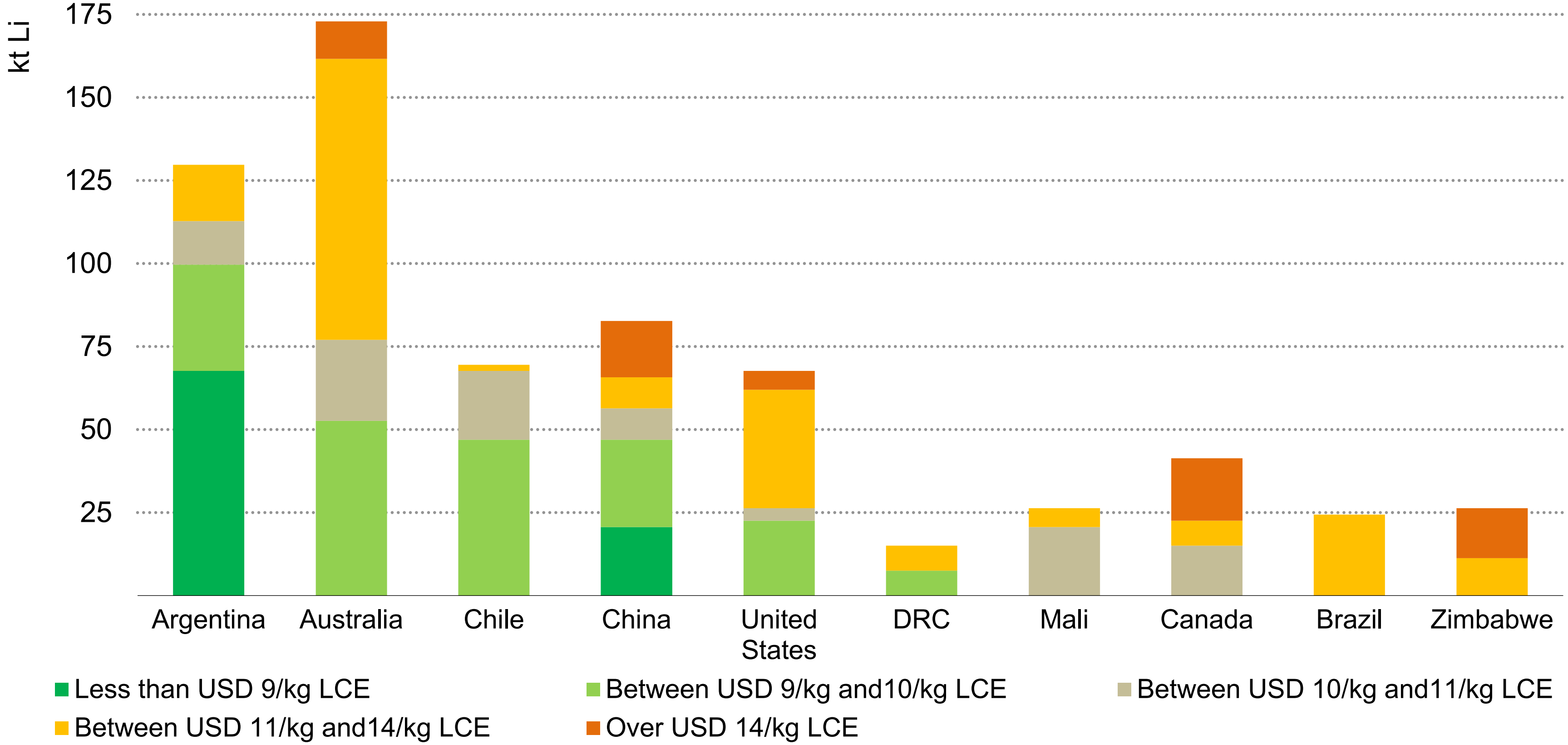
Recycling and market maturity

Secondary supply continues to scale rapidly, with recycled volumes increasing by over 40% year-on-year in 2025. However, it still accounts for only around 5% of total supply, highlighting both its growing importance and its current limitations in materially contributing to overall supply growth.

The lithium market is gradually becoming more structured, as reflected in record trading volumes for lithium futures and the development of forward pricing tools. Downstream players are increasingly securing long-term supply, as illustrated by recent deals involving MinRes and POSCO, as well as Pilbara Minerals and Canmax.

Cost competitiveness is becoming increasingly important amid volatile lithium prices, with Latin American production leading the lowest-cost supply

Existing and projected lithium mining capacity to 2035 by country and production cost

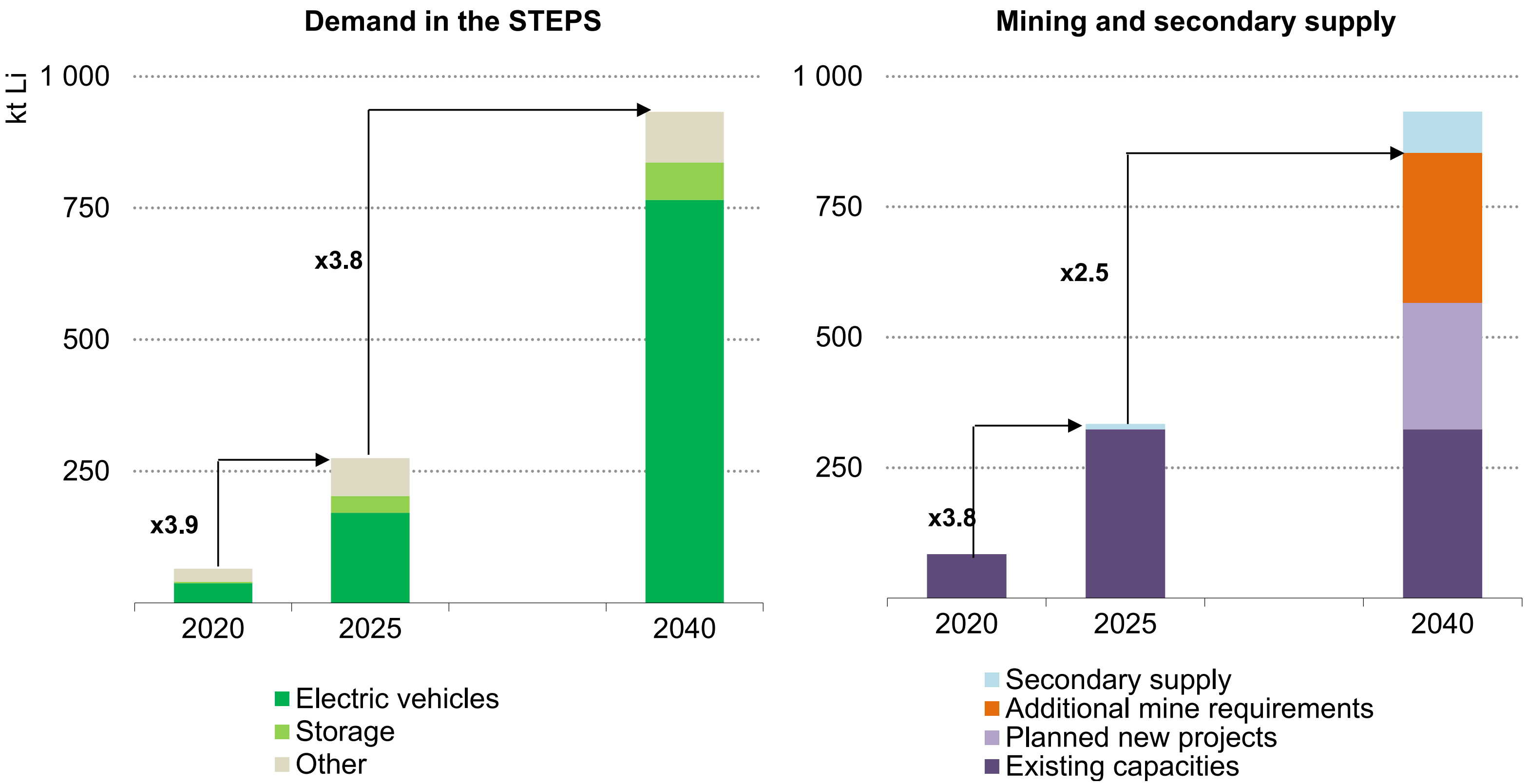


Note: DRC = Democratic Republic of the Congo, LCE = Lithium carbonate equivalent. Production costs are C3 costs, which include operating expenditure and capital expenditure costs accounting for depreciation and amortisation, interest and royalties, in current US dollars.

Source: IEA analysis based on data from Benchmark Minerals Intelligence, S&P Capital IQ and Wood Mackenzie.

Lithium is the fastest-growing critical mineral, with demand quadrupling between today and 2040 and requiring a 2.5-fold increase in mined output

Lithium demand and supply requirements in the STEPS, 2020-2040



Notes: STEPS = Stated Policies Scenario. Based on raw material output covering the extraction of lithium from hard rock ore, clays and brines. Planned new projects are based on the base case supply projection.

In a context of surging lithium demand, the project pipeline highlights the continued need for new mines, as well as opportunities for diversification on the refining side

Lithium demand is set to continue rising strongly over the next two decades. In the STEPS, demand in 2040 is 3.5-times higher than in 2025 and around 14 times higher than in 2020. EVs remain the main source of growth as their deployment continues to expand across major markets. At the same time, energy storage is becoming an increasingly important source of demand growth. In the STEPS, lithium demand from energy storage rises to around 70 kt in 2040 and reaches 90 kt in 2050, around three times today's level. In the HDS, demand from storage reaches 120 kt in 2050, underlining the growing role of batteries in power systems with rising shares of variable renewables.

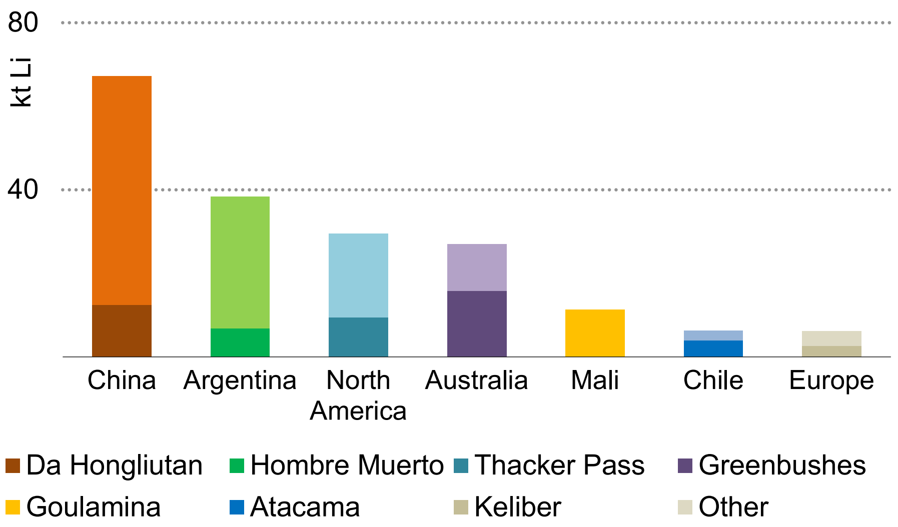
Lithium recycling to rise 25-fold, moderating mining needs

Secondary lithium production from recycling reaches around 250 kt in 2050, around 25 times higher than today, as larger volumes of end-of-life batteries become available and collection and processing systems improve. In the HDS, which assumes stronger recycling rates, secondary supply rises further to around 560 kt in 2050. This growing contribution from recycling does not remove the need for large-scale investment in new supply, but it helps ease pressure on primary production and improve supply security over time.

Ten more median-sized lithium mining projects are needed to fill the long-term supply gap

Even after accounting for the growing contribution of recycling, lithium mining needs to expand substantially to keep pace with rising demand. In the STEPS, primary lithium supply requirements (demand net of contributions from secondary supply) rise to around 850 kt by 2040, implying that mined output needs to increase by around 2.5 times from current levels. The current project pipeline points to roughly 500 kt of mining output by 2035 in the base case, or around 550 kt in the high-production case. Around 40% of additional output in the base case is located in China, 222% in Argentina, 16% in Australia and 14% in North America, with smaller additions planned in Europe, Africa and elsewhere in Latin America.

Additional lithium mining output in the base case by region and top additional project, 2025-2035



IEA. CC BY 4.0.

Note: Base case projects = dark colour. Top additional projects = light colour.

This still leaves a sizeable gap between projected primary supply requirements and the current pipeline. Closing this gap of around 25% would require the emergence of about 10 additional median-sized projects. While challenging, this is not out of reach: lithium mining output has grown nearly fourfold over the past five years, and recent technological progress, including the ramp-up of direct lithium extraction by Eramet in Argentina, points to stronger prospects for unlocking new resources.

Growing prospects for lithium refining diversification

The refining project pipeline also suggests potential for diversification. The project pipeline in the base case is broadly sufficient to process projected mining output, but additional projects would still be needed to meet demand requirements in the STEPS. Over the projection period, refining concentration eases from today's elevated levels, with the dominant supplier's share falling from around 75% to 66% by 2035. While more than half of additional refining capacity in the base case is still planned in China, a growing number of chemical plants are expected elsewhere. Argentina is set to play a stronger role, supported by rising brine supply, and could account for around 10% of global lithium chemical capacity by 2035. It is followed by the United States, with projects including Tesla's Corpus Christi, Lithium Americas' Thacker Pass, Albemarle's Silver Peak and Standard Lithium's lithium development, and by Australia, where Kwinana and a possible Kemerton restart could support renewed growth, alongside additions in Indonesia and Chile.

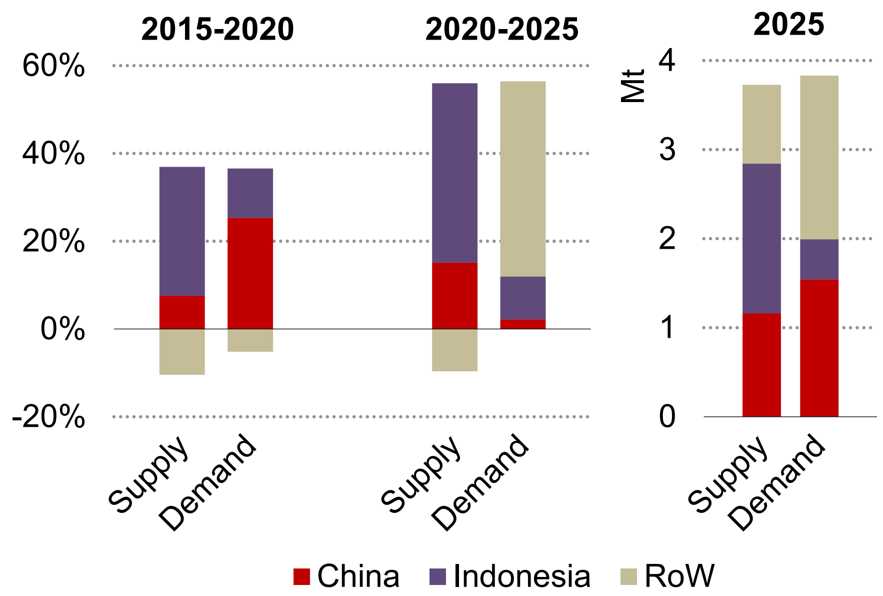
Outlook for nickel

The nickel market is well supplied in the short term, but policy and cost pressures are emerging in the leading producer, Indonesia

The nickel market remained in a 200 kt surplus in 2025, keeping prices subdued throughout the year. Global production increased by 9% year-on-year in mined output and 7% in refined output, driven primarily by Indonesia, which remains the world's largest producer of both mined and refined nickel. Outside Indonesia, persistently low prices continued to weigh on output, with production in the rest of the world declining by over over 10%% in mined production and just under 3% in refined production. At the same time, global nickel demand rose by almost 3% in 2025 to 3.5 Mt, largely supported by growth in nickel use in battery applications, particularly in nickel-rich chemistries for EVs.

The global nickel market has become increasingly concentrated in Indonesia, which now accounts for almost two-thirds of mined supply and just under half of refined output. This reflects structural advantages, including a large laterite resource base, an integrated processing ecosystem, strong state support focused on industrial policy, Chinese capital and technology, economies of scale and access to relatively low-cost coal-based energy. As a result, policy developments in Indonesia are increasingly shaping global market dynamics. Despite continued physical oversupply, nickel prices began to rise towards the end of 2025 and into early 2026 following a series of policy announcements in Indonesia.

Nickel supply and demand growth, 2015-2025 (left), and market balance, 2025 (right)

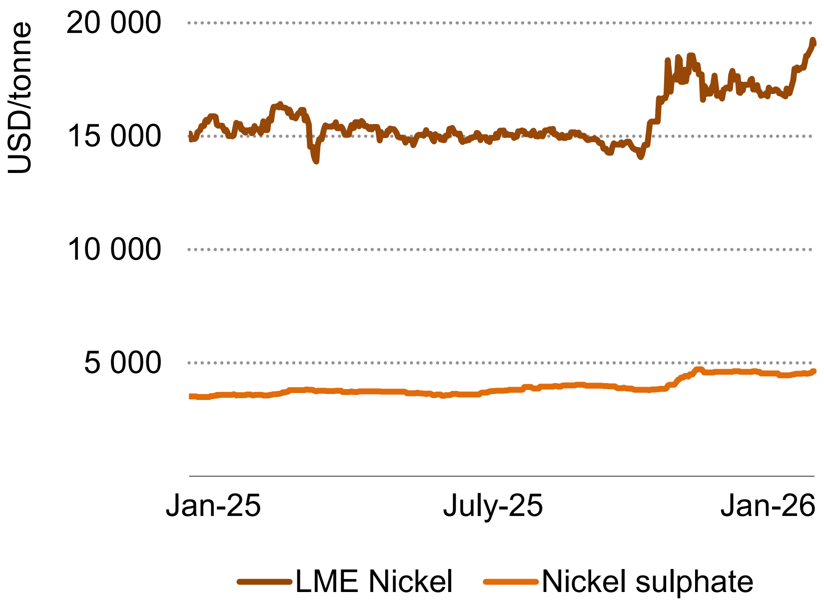


Notes: RoW = rest of world. Supply and demand are for refined nickel supply.

Indonesia's mined nickel output is governed by production quotas (RKAB), introduced in 2023 as three-year allocations. This framework was revised in October 2025, shortening quotas to one year and requiring companies to reapply for quotas covering 2026 and 2027.

Shortly after, Indonesia's Minister of Energy and Natural Resources announced plans to curb nickel output in 2026 to support prices and government revenues. These measures followed the revocation of in September 2025 due to non-compliance with rehabilitation or production requirements. Taken together, these developments tightened expectations around future supply availability and contributed to a 20% increase in nickel prices between December 2025 and mid-2026.

Nickel prices, January 2025-April 2026

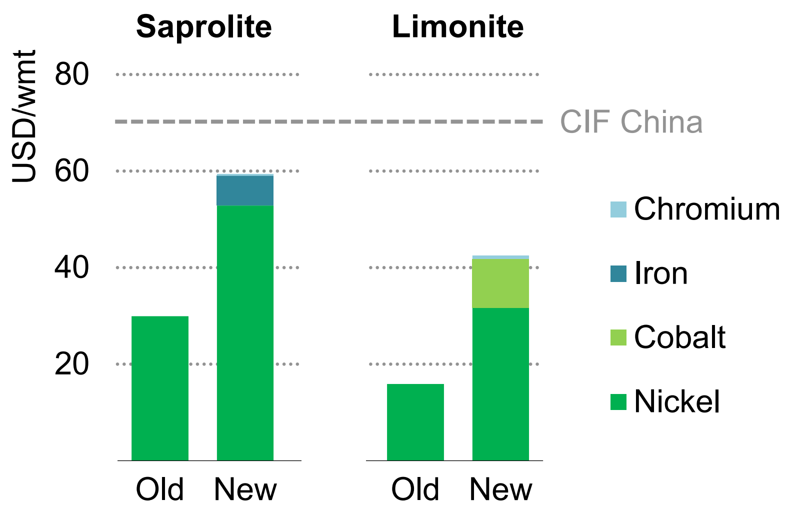


Note: The nickel sulphate price refers to China nickel sulphate, with a minimum nickel content of 22% and a maximum cobalt content of 0.4%.
Sources: IEA analysis based on data from S&P Capital IQ and Bloomberg.

As policies increasingly restrict access to domestic ore and aim to support higher prices and royalties, Indonesian smelters have increasingly turned to imported feedstock, importing almost 300 kt of nickel metal equivalent from the Philippines in 2025, up by almost 50% from 2024. The Philippines is the world's second-largest holder of nickel reserves, largely limonite ore, which feeds into high-pressure acid leaching (HPAL) processing facilities and enables the production of battery-grade intermediates. Co-operation between the two countries was recently formalised through the IndoPhil Nickel Corridor, which aims to provide stable feedstock supply for Indonesia's expanding HPAL capacity.

The Indonesian government also revised the mineral ore benchmark price (HPM) in April 2026. The HPM serves as Indonesia's official floor price for nickel ore, ensuring a minimum price for mines while increasing royalty revenues and limiting the ability of smelters, which are mostly Chinese-owned, to push domestic ore prices too low. Previously, higher-grade saprolite (1.5-2.7% nickel content) had a higher HPM floor price, while limonite (typically 0.8-1.8% nickel content) was priced lower. Under the revision, limonite and saprolite floor prices were brought closer into alignment, with the adjustment raising the limonite floor price relative to its nickel content. Although this provides support to domestic miners, it also increases feedstock costs for HPAL operations. The revision was reportedly introduced to strengthen fiscal revenues, support domestic miners and provide upward pressure on nickel prices.

Composition of new versus old mineral ore benchmark price (HPM) compared with Chinese ore price



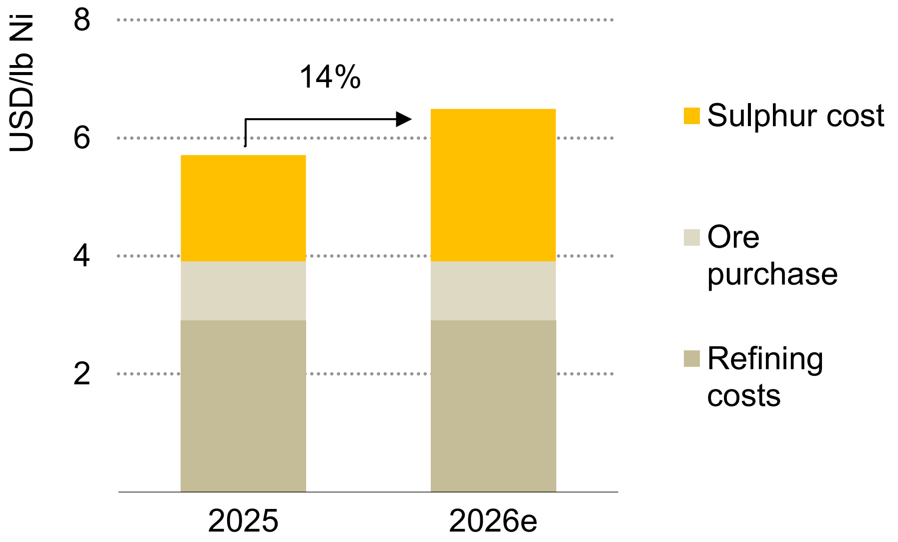
Notes: CIF = cost, insurance and freight; wmt = wet metric tonne.
Sources: IEA analysis based on data from Wood Mackenzie and Bloomberg.

A key structural feature of the nickel market is the two main processing routes for laterite ores, each with distinct cost profiles and end-use applications. Rotary kiln electric furnace technology, which dominates in Indonesia, produces nickel pig iron and ferronickel for stainless steel applications and generally benefits from lower capital intensity. In recent years, part of this nickel pig iron output has been further processed into nickel matte, enabling conversion into battery-grade products and creating an additional pathway into the battery value chain. This has provided some producers with flexibility to redirect part of their output between stainless steel and battery markets, depending on the relative economics and demand conditions.

By contrast, high-pressure acid leaching enables the production of battery-grade intermediates, such as mixed hydroxide precipitate (MHP), but is significantly more capital-intensive and highly sensitive to input costs, particularly sulphur. While recent policy changes in Indonesia have contributed to higher ore benchmark prices and tighter market conditions, they have also weakened HPAL project economics, compounded by rising sulphur costs resulting from a tighter global market. Requiring approximately 9 tonnes of sulphur per tonne of contained nickel, an 80% increase in sulphur prices raises operating costs for HPAL facilities by roughly USD 1.7 per kilogramme of nickel, pushing up marginal production costs for intermediates such as MHP. As a result, there has been additional strain on some operations, causing some HPAL facilities to decrease output and tightening availability of battery-grade intermediates.

However, although nickel matte production also relies on sulphur, its intensity is around three times lower, resulting in a much smaller cost impact. As a result, the nickel pig iron and ferronickel market remains relatively well supplied, with elevated inventories continuing to moderate price pressures.

Impact of rising sulphur costs on Indonesian HPAL producers



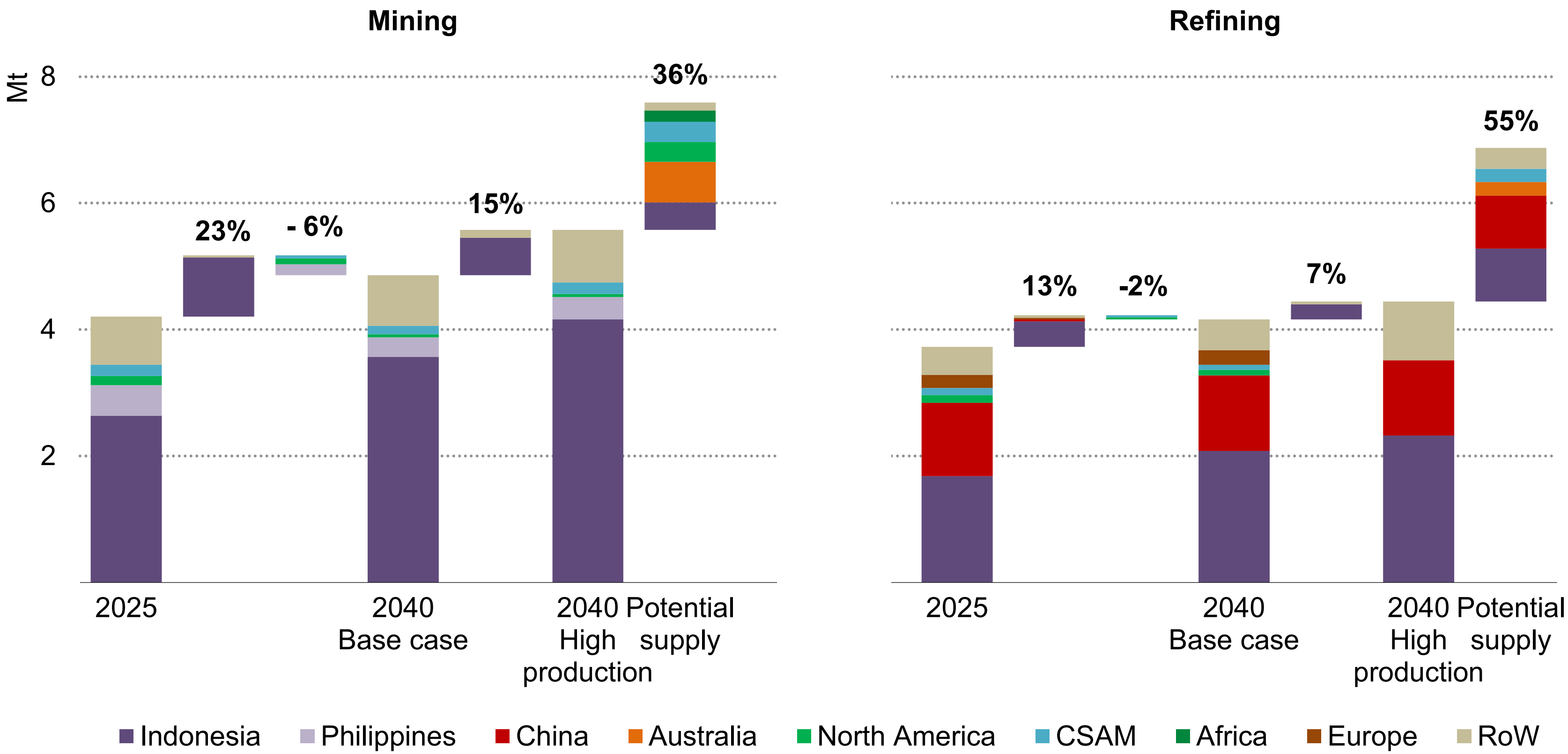
Notes: 2026e = 2026 estimated costs. Costs are based on an average of HPAL costs across two projects in Indonesia. The 2026 estimates assume an 80% increase in sulphur costs.
Sources: IEA analysis based on data from company reporting and Wood Mackenzie.

A key question is whether Indonesia will expand domestic HPAL facilities to produce nickel sulphate in line with its downstreaming strategy, given its importance for precursor and cathode manufacturing. At present, HPAL facilities produce mostly intermediates, and Indonesian nickel sulphate capacity remains limited relative to downstream battery cell manufacturing capacity. Indonesia produces only 10% of global nickel sulphate and continues to export intermediate products such as MHP to China for further processing. China remains the dominant battery-grade nickel sulphate producer, accounting for 75% of production.

In 2025, Indonesia exported 75 kt of nickel mattes, about 25% of its total supply, to China, where they were further refined. This export of Indonesian intermediate products to China for further processing explains why Indonesia still has a smaller market share in refining than in mining, despite bans on the export of unprocessed ore.

Supply concentration increases across nickel mining and refining as Indonesia continues to drive supply growth, while projects in geographically diverse regions face challenges

Mining and refining supply additions from 2025 to 2040 and early-stage projects



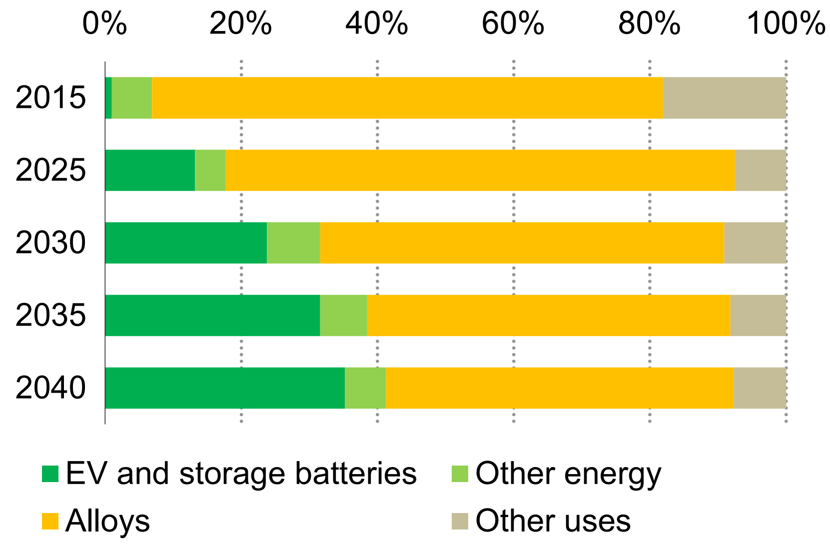
Notes: CSAM = Central and South America; RoW = Rest of world. Refined nickel includes all final products. Potential supply includes supply from projects outside the base or high-production case and at the exploration, scoping, prefeasibility, permitting, financing, feasibility or construction stage, as well as those on hold or on care and maintenance.

Despite robust demand growth, the nickel market is expected to remain well supplied, although Indonesia's policy shifts could alter the outlook

The nickel market is expected to remain in surplus over the next few years, with excess supply persisting before 2030 despite continued demand growth. Based on announced projects, Indonesia continues to drive production expansion, accounting for over 100% of the supply growth in mining and 80% in refining to 2030 in the base case. Indonesia's production share is set to rise further to almost 75% in mining and around half in refining by 2035, from almost two-thirds and 45% today, respectively, reflecting structural advantages.

At the same time, demand continues to grow at a robust pace. By 2035, batteries are expected to account for 30% of total nickel consumption, accounting for almost two-thirds of demand growth. China, Indonesia, Japan and Korea represent the bulk of incremental demand as battery manufacturing and downstream capacity continue to expand. Although the shift towards LFP chemistries moderates nickel demand relative to last year's *Outlook*, nickel-rich chemistries are expected to retain an important role, particularly for battery makers outside China and in markets such as North America and Europe, where consumers prefer long-range vehicles.

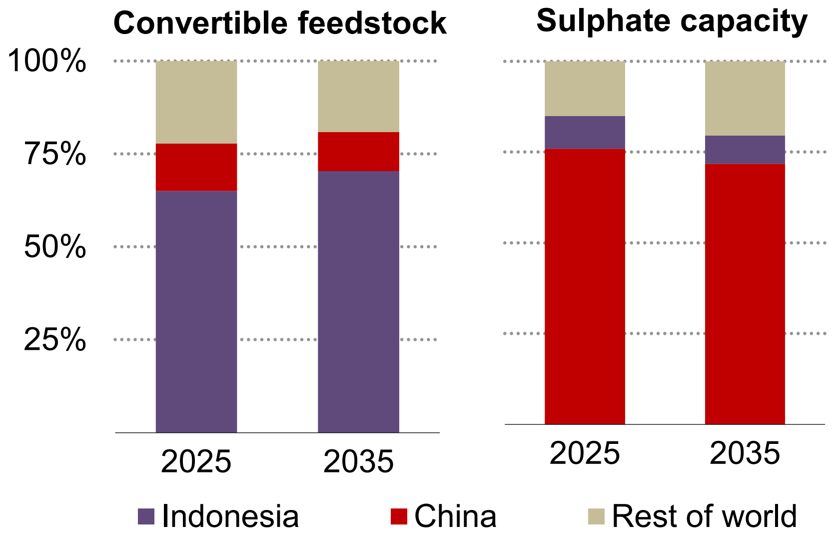
Nickel demand use by sector in the STEPS, 2015-2040



Notes: STEPS = Stated Policies Scenario. Other energy includes nickel use for renewables and hydrogen.

Supply gaps start to emerge beyond in the late 2020s in the base case, with a 1.9 Mt gap emerging by 2040. The high-production case closes over 600% of this shortfall but depends on sustained expansion in a limited number of jurisdictions, mainly Indonesia. Despite this, a number of projects remain on hold or under care and maintenance. In addition, almost 2 Mt of early-stage mining projects exist across Indonesia, Australia, North America and Latin America, which could provide additional supply if economic conditions support development and help narrow supply gaps.

Concentration in the battery-grade nickel market, 2025 and 2035



Notes: For these purposes, convertible feedstock refers to any nickel product that can be used to produce nickel sulphate, even if a further processing step is required, such as nickel pig iron or mixed hydroxide precipitate.
Source: IEA analysis based on data from Wood Mackenzie.

However, many projects in geographically diverse regions have struggled to emerge or recover following prolonged periods of low prices, given persistent and structural challenges. Higher energy and operating costs, stricter environmental standards, smaller project scale and slower ramp-up profiles limit competitiveness at prevailing prices. Both brownfield expansions and greenfield developments outside today's dominant producers require higher incentive prices to proceed.

The largest concentration risks in the nickel market are closely linked to the battery value chain, where supply disruptions or policy shifts can have outsized impacts on the availability of battery-grade nickel products. Battery production requires nickel sulphate, which can be produced either from Class I nickel metal or from nickel intermediates, such as MHP and nickel matte. While Indonesia has rapidly expanded production of these intermediates and is expected to account for just over 70% of the global market by 2035, China is expected to remain the dominant supplier of nickel sulphate, accounting for 70% of the market by 2035.

Outlook for cobalt

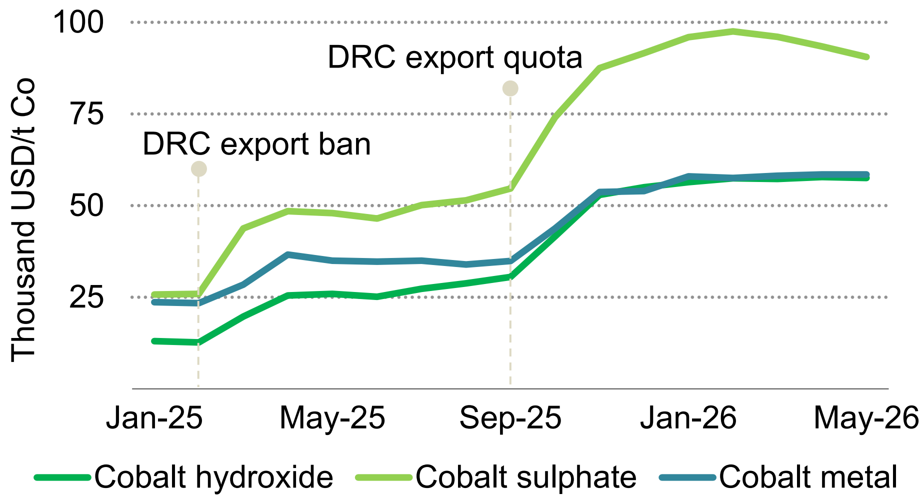
The cobalt market is expected to shift into deficit from 2026 due to DRC export restrictions, with the outlook increasingly shaped by policy developments in the DRC and Indonesia

In 2025, mined cobalt production stood at around 320 kt, similar to production levels in 2024. However, trade in cobalt intermediates (unrefined cobalt), particularly cobalt hydroxide, saw a notable reduction following the introduction of export controls by the Democratic Republic of the Congo (DRC), the world's largest mined cobalt supplier.

Following several years of oversupply and depressed prices, the DRC implemented an export ban on cobalt, including cobalt hydroxide, the country's prevalent export form, in early 2025. Later in 2025, this was followed by a quota system capping cobalt exports at 96 600 tonnes, less than half of 2024 production volumes. These measures led to supply tightness in intermediate feedstocks and contributed to upward pressure on prices. Cobalt metal prices approached USD 58 000 per tonne in the first quarter of 2026, more than three times as high as the previous year. However, refined cobalt inventories remained elevated, resulting in differing price dynamics between intermediates and refined products. In early 2026, prices of cobalt hydroxide approached those of cobalt metal. Strong demand growth from the batteries and electronics sectors in 2025 widened the price premium of cobalt sulphate and cobalt tetroxide over cobalt metal.

Meanwhile, Indonesia has emerged as a significant alternative supplier, producing cobalt as a by-product of nickel operations. Its share of global production has increased from around 1.5% in 2020 to approximately 15% in 2025.

Cobalt intermediates and cobalt metal prices



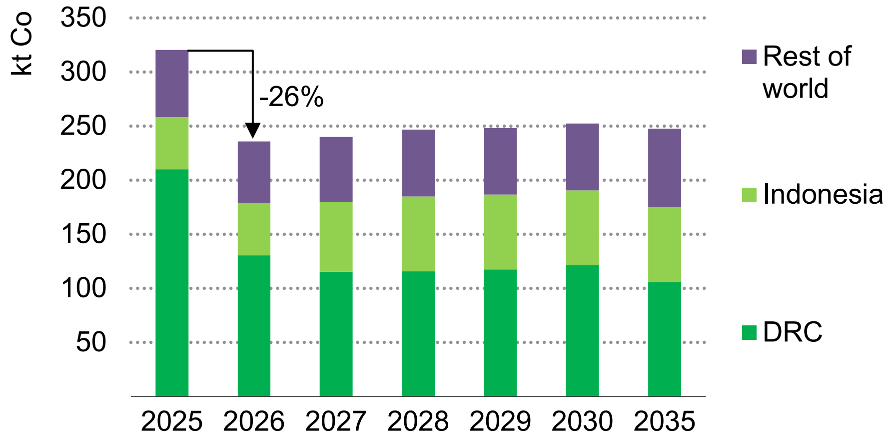
Note: DRC = Democratic Republic of the Congo. The DRC implemented an export ban on cobalt in February 2025 and replaced this with an export quota system in September 2025.
Source: IEA analysis based on data from Benchmark Minerals Intelligence.

Impact of the DRC's policy changes: export restrictions, strategic reserve and mineral partnerships

The DRC remains the world's largest cobalt producer, accounting for two-thirds of global mined output. However, its supply profile has been fundamentally altered by successive policy interventions since late 2024. The [quota system](#) introduced by the Regulatory and Control Authority for Strategic Mineral Substances (ARECOMS) in September 2025 took effect in October 2025 to bring up cobalt prices and incentivise value addition. Under this system, ARECOMS will distribute quotas pro rata based on historical export volumes, with exceptions granted to the state-owned entity Entreprise Générale du Cobalt and Société pour le Traitement du Terril de Lubumbashi. Companies are excluded from the quota system if they exported less than 100 tonnes in 2024, operate refineries without mining activity or possess depleted cobalt reserves.

A strategic quota was also allocated to ARECOMS and will be used for projects of national strategic importance, with the right to buy back excess cobalt stocks and withdraw quotas from companies that process third-party or artisanal cobalt.The system increased supply uncertainty, with no clear allocation framework provided beyond 2027. Meanwhile, inventories of cobalt hydroxide in the DRC continue to build, forcing mining operations to manage excess materials through stockpiling in warehouses, storage in tailings facilities or production curtailments.

Marketed global mined cobalt supply by region



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Notes: DRC = Democratic Republic of the Congo. The supply numbers for 2025-2026 consider sold supply volumes, instead of production volumes, in the DRC. Following 2026, the export quota is assumed to remain in place at the current level.

In April 2026, the DRC established a strategic reserve of critical minerals, administered by ARECOMS. The mechanism enables the state to withhold or release volumes in response to prevailing price conditions. As such, downstream buyers will need to factor in discretionary state interventions by ARECOMS, which could increase medium-term price uncertainty.

The Strategic Partnership Agreement between the United States and the DRC has also led to early-stage deals aimed at enabling value addition within the DRC while diversifying ownership of supply. In January 2026, the DRC offered US investors access to state-owned mineral assets not committed under existing farm-outs or joint venture arrangements, including Gecamines' Mutoshi copper-cobalt project, Sakima's coltan and gold assets and Cominiere's lithium licences. Through the partnership, Glencore announced a non-binding (MoU) with the Orion Critical Minerals Consortium (backed by the US International Development Finance Corporation) for a potential 40% stake acquisition in Glencore's DRC assets in February 2026. Also with support from the Orion Critical Minerals Consortium, Virtus Minerals announced the acquisition of Chemaf in April, one of the largest producers of high-grade copper and cobalt, with a potential capacity of at least 20 kt of cobalt hydroxide annually. Shortly after, Virtus Minerals signed an MoU with US Strategic Metals to supply cobalt and copper directly to US Strategic Metals' hydrometallurgical plant. While these initiatives may help attract non-Chinese capital into the sector, they are unlikely to translate into significant new volumes in the near term.

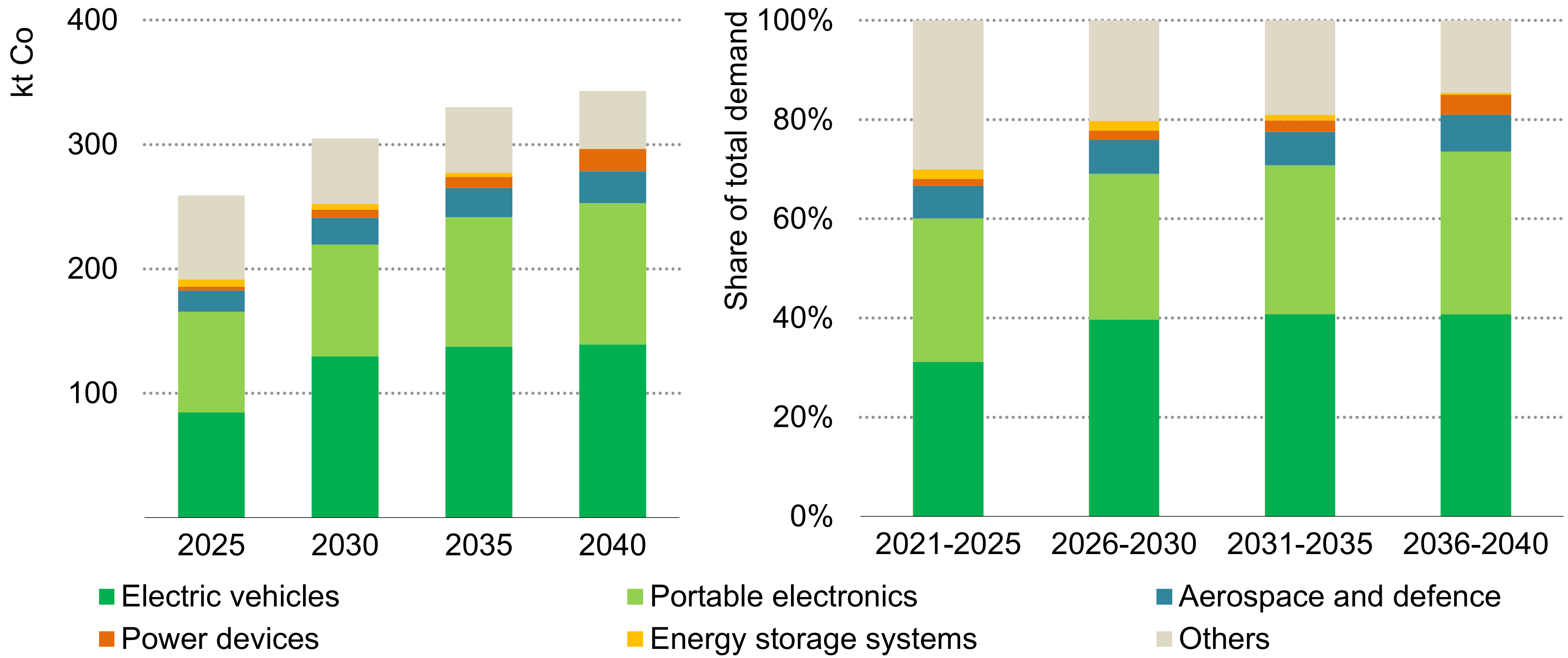
Indonesia's rise as an alternative supplier amid emerging cost and input constraints

Indonesia is the second-largest and fastest-growing cobalt producer. By 2035, mined cobalt production in the country is set to almost double in the base case, supported by the expansion of the Pomalaa and Morowali processing hubs. However, structural challenges remain. In Indonesia, cobalt is produced as a by-product of nickel processing via the High Pressure Acid Leach (HPAL) route, which treats limonite ore – a lateritic nickel ore type that also contains recoverable cobalt. Production of MHP from HPAL operations is slowing down due to tight availability of sulphuric acid, a constraint that is being reinforced by rising sulphur import costs and supply disruptions, given Indonesia's heavy reliance on imported inputs for acid-intensive processing. While copper-cobalt SxEw operations in the DRC are also highly dependent on sulphuric acid inputs, the near-term impact on cobalt supply is expected to be more contained due to elevated inventory levels and more established acid sourcing channels, including regional suppliers such as Zambia, reducing exposure to disruptions affecting Middle East sulphur trade routes. Larger, integrated producers in particular benefit from access to domestic or contracted supply, although smaller operations remain exposed to rising reagent costs and procurement risks.

At the same time, in April 2026, Indonesia revised its mineral benchmark ore price (HPM) formula for nickel ore, for the first time explicitly valuing cobalt content as a priced component of the nickel ore HPM, rather than treating it as an free-of-charge by-product. Associated cobalt is also now subject to a 2% royalty tax rate. With cobalt content factored into the price and tax base of nickel ore, offtake contracts for mixed hydroxide precipitate (MHP) or other intermediates sourced from HPM-referenced ore must account for cobalt's contribution to the benchmark price. This further increases processing costs for MHP and battery-grade intermediates containing cobalt. Any increase in cobalt production also requires a considerable increase in nickel production in the country at a time when nickel prices are low.

Electric vehicles maintain the largest share of demand, while aerospace and defence see steady growth through to 2040

Cobalt demand by sector in the STEPS (left) and sectoral demand composition (right)



Note: STEPS = Stated Policies Scenario.

The cobalt market transitions to deficit from 2026 under persistent DRC export constraints, with adequate supply contingent on responses from Indonesia and other producers

Cobalt demand growth continues to be led by EVs, with cobalt use for EV batteries rising by nearly two-thirds through 2040 in the STEPS, even though cobalt demand for EV batteries has been revised down compared with last year's *Outlook* due to shifts in battery chemistry choices.

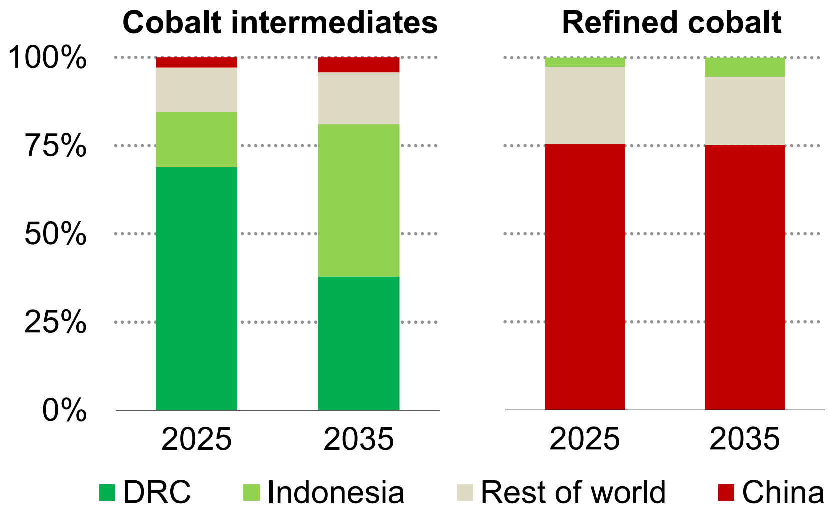
The rapid rise of LFP batteries continues to weigh on cobalt demand growth. However, this effect is partially offset by changes within nickel-cobalt-manganese (NCM) chemistries compared with previous expectations. In particular, NCM 622 and NCM 532, both more cobalt-intensive than higher-nickel chemistries such as NCM 811, are maintaining stronger market shares in premium EV segments, especially in Europe and North America, where energy density requirements, vehicle performance considerations and original equipment manufacturer product cycles continue to support cobalt-bearing cathodes. As a result, battery chemistry developments have a mixed impact on cobalt demand, with the growth of LFP reducing demand while the persistence of cobalt-intensive NCM chemistries provides an important source of support.

Beyond EVs, non-EV sources make growing contributions to cobalt demand. Devices and wearables enabled with artificial intelligence (AI) functions are driving energy density requirements that favour lithium cobalt oxide cathodes, and smartphone replacement cycles have exceeded prior projections. The share of portable electronics is set to grow from over 15% to almost 30% in the medium term and by up to 40% to 2040 from the base year. Cobalt superalloys, used primarily in high-temperature aerospace engine components where demand is not substitutable, account for approximately 7% of global cobalt consumption. Aerospace and defence are exhibiting structural demand growth: commercial aircraft order backlogs are extending delivery timelines, sustaining superalloy demand beyond military applications. Should planned increases in defence spending materialise across major economies, incremental demand for cobalt in superalloys and lithium-cobalt battery applications could provide additional upside to projections. Total demand for cobalt is growing, with an increasing regional share from North America and Europe.

Mined supply of cobalt is increasingly shaped by policy developments in the top suppliers

Near-term mined supply is driven by DRC policy implementation and Indonesian ramp-up, but intermediate markets are expected to be tight while export controls remain in place. In 2025, large-scale miners in the DRC posted strong production results. CMOC produced 117 kt from Tenke Fungurume and KFM, while Glencore's production from KCC and Mutanda totalled 36 kt. However, export quotas limited the material reaching the market: KCC and Mutanda did not export cobalt in Q4 2025, and while CMOC's cobalt production was up 0.3% year-on-year, sales were down 92% year-on-year. For 2026, CMOC received 31 200 tonnes of the total quota of 96 000 tonnes, including the DRC's strategic quota to be distributed by ARECOMS to projects of national strategic importance, while Glencore received 22 800 tonnes. The currently published 2026 quota levels are insufficient to meet projected intermediate supply requirements, which may be further constrained by administrative delays in physical exports.

Concentration in battery-grade cobalt material production



IEA. CC BY 4.0.

Note: DRC = Democratic Republic of the Congo. Cobalt intermediates include cobalt hydroxide and mixed hydroxide precipitate.

This has tightened hydroxide availability and increased competition for intermediate feedstocks, limiting the ability of refining capacity to respond to growing demand. While Indonesia is expected to provide incremental supply, its contribution is subject to constraints. Indonesia's 2026 RKAB quota tightening and rising sulphur costs have disrupted HPAL feedstock availability and increased cost pressures. At the same time, quota-driven tightness on nickel supply supports nickel prices, which in turn underpins the economics of cobalt produced as a by-product. As Indonesian nickel production drives cobalt supply expansion over the long term, cobalt markets become increasingly linked to nickel markets, with almost 50% of global cobalt projected to be produced as a by-product of nickel by 2035 in the base case.

From around 2030, production in the DRC starts to decline by around 5% per year to 2040, driven by diminishing ore quality. Meanwhile, Indonesia already accounts for over 15% of total mined cobalt supply and is projected to expand output by almost 40% to 2040 in the base case. Diversification of mined supply beyond the DRC and Indonesia remains limited in the near term. Australia and Canada together accounted for 3.5% (around 11 kt) of global cobalt production in 2025, a share projected to reach 4% by 2040, supported by by-product extraction from nickel and copper operations and government support programmes. Moreover, many projects in alternative jurisdictions projects remain pre-production, with no material volume contribution expected before 2027. For example, Cobalt Blue's Broken Hill Cobalt Project in Australia may provide supply outside of the top two producing countries by 2027, with around 0.6 kt of cobalt per annum. It is in the process of submitting its environmental permits for 2026. Possible projects in Canada include Nickel Creek Platinum's Nickel Shaw and Giga Metals' Turnagain, which may add around 3 kt to global supply by 2027, though both are in pre-feasibility.

China's lead in refining persists as diversification prospects remain limited

China remains the leading cobalt refiner, accounting for more than 75% of the market in 2025, a share that remains broadly unchanged through the projection period. Limited new refining projects in geographically diverse regions are in sight, keeping China's refining dominance intact in the near to medium term. Chinese refineries have dealt with shortages in cobalt intermediates due to administrative delays in DRC quota allocation, though the impact has been contained given that quota allocations have been directed primarily to Chinese-invested DRC operations.

For cobalt sulphate, a key precursor for EV batteries, the market is set to grow by almost 60% by 2035, with few operations outside China and Indonesia. In January 2026, Morocco's Managem planned to switch its cobalt metal production in Bou Azzer to sulphate, with a capacity estimated at 6 kt per annum, of which 1.2 kt is contained cobalt. In the long term, operations such as Umicore's Kokkola cobalt refinery in Finland will continue to contribute almost 2.5 kt per annum.

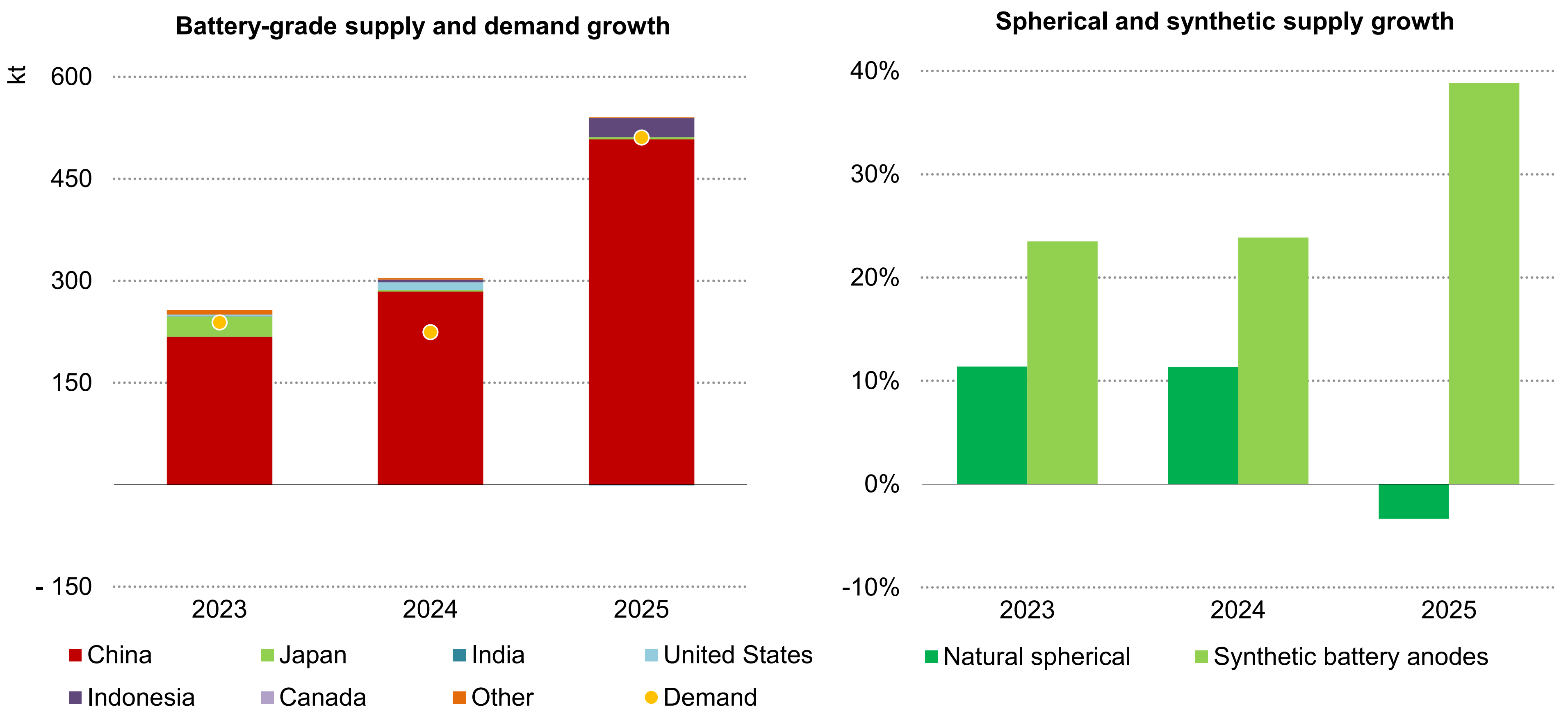
Secondary cobalt supply is projected to over double by 2035 to almost 45 kt, though volumes remain insufficient to close the demand gap from primary sources. China lifted its ten-year ban on black mass imports on 1 August 2025, redirecting secondary feedstock to Chinese refiners and reinforcing its downstream position. A combination of policy actions incentivising higher recycling of consumer and EV batteries is projected to raise the secondary share of total supply to 15% by 2035 in the STEPS.

Overall, the market remains constrained by uncertainty around exports of DRC-mined material, with limited ability to offset these restrictions through increased production elsewhere. In 2025, supply was sufficient to meet demand, with only a marginal surplus, although this outcome was supported by the extension of Q4 2025 export quotas into the first quarter of 2026, allowing delayed shipments to be completed as the DRC's quota system was being implemented. This masked underlying tightness in intermediate markets. If existing export quotas persist at current levels, the market will move into deficit from 2026 onwards, with these imbalances expected to persist into the longer term. This reflects the continued reliance on DRC supply, limiting the ability of the market to respond to growing demand despite expansion projects in other regions.

Outlook for graphite

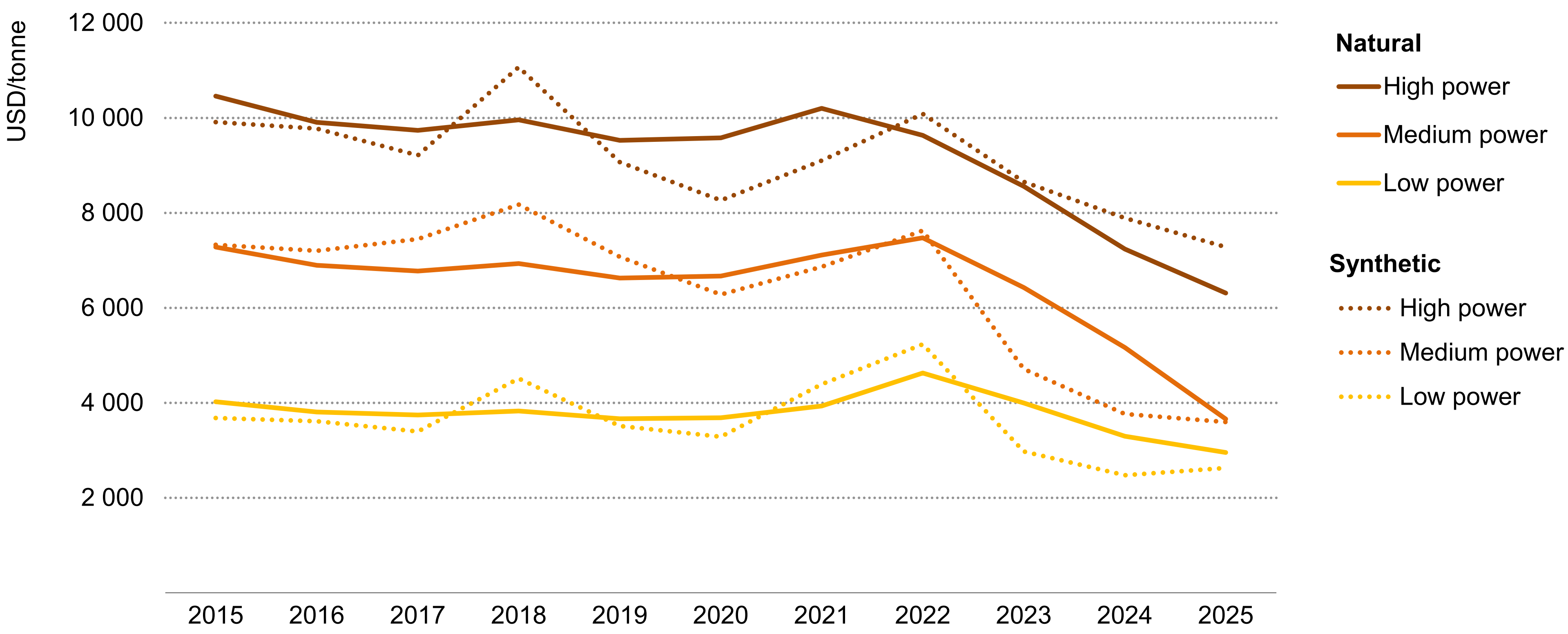
New synthetic graphite production in China drives supply growth…

Growth of natural and synthetic graphite supply and demand, 2023-2025



…consolidating a downward trend in prices

Price of China's synthetic and natural anode active materials



Notes: Free on board China prices. High power: >340 mAh/g; medium power: 320-340 mAh/g; low power: <320 mAh/g.
Source: IEA analysis based on data from Wood Mackenzie.

Graphite demand grows strongly, while overcapacity drives a persistent low-price environment

In 2025, global graphite demand increased by around 6% year-on-year, driven almost entirely by the battery sector, where demand rose by over 14%, reflecting continued growth in EV and stationary storage deployment. By contrast, demand from non-battery applications remained broadly stable. Despite the strong demand growth, the graphite market remained oversupplied across all major segments of the supply chain, with sustained downward pressure on prices. New supply was mainly driven by the growth of synthetic graphite, which increased by 22% in 2025, while natural spherical graphite supply decreased by 3%.

Natural graphite

In the natural graphite segment, additional supply entered the market in 2025 following the restart of the Balama mine in Mozambique and some output from the Lindi Jumbo project in Tanzania, although operations there remained constrained after entering administration. These developments contributed to a modest diversification of upstream supply, reducing the share of the top supplier in mined graphite output to around 80% in 2025, from 84% in 2023.

In 2025 and early 2026, some spheroidisation and coating projects, in which mined graphite is converted into battery-grade anode material, announced significant developments. These included the Vittangi anode project in Sweden, the Tangier anode plant in Morocco, and the Bécancour plant in Canada, which together are expected to produce around 20 kt of battery-grade coated spherical graphite by 2030.

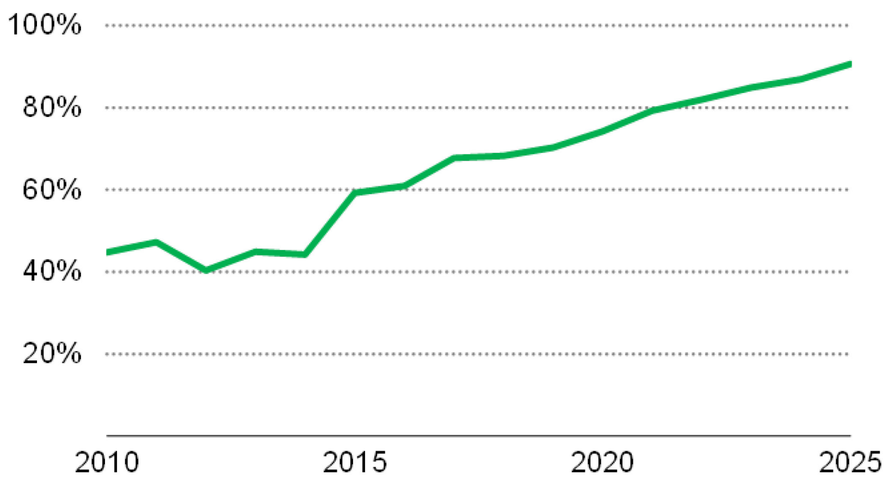
Synthetic graphite

The synthetic graphite market remains highly concentrated, with the vast majority of production capacity located in China and only a limited number of projects producing at scale elsewhere. From 2022 to 2025, synthetic graphite supply increased at an average rate of 15% per year, outpacing the growth of natural graphite. With growing competitive pressures in a prolonged low-price environment, consolidation and vertical integration are becoming more visible along the anode supply chain, including moves by established Chinese producers, such as China Baoan Group's participation in the restructuring of Shanshan Group through its subsidiary BTR.

Some projects outside China have revised or scaled back their planned capacity expansions in response to weaker project economics. Recent examples include SGL's graphite facilities in Poland and Tokai COBEX's project in France, both of which have adjusted their ambitions amid sustained price pressure, high operating costs and strong competition from the dominant supplier.

As production costs become an increasingly critical factor for battery manufacturers, the synthetic graphite industry is shifting away from an exclusive reliance on high-quality needle coke towards a multi-feedstock model in which low-sulphur petroleum coke accounts for a growing share of inputs. In addition to lowering costs, this transition reduces exposure to needle coke supply constraints. China remains a net importer of needle coke, despite recent investments to expand domestic production capacity.

Global share of synthetic graphite in battery anodes, 2010-2025



Source: IEA analysis based on data from Wood Mackenzie.

Anode material

The supply and demand dynamics described above led prices of synthetic graphite anodes for medium- and low-power applications to roughly halve from 2022 to 2025, while prices of spherical natural graphite anodes fell less sharply, with those for low-power applications decreasing by one-third. Synthetic anodes used to be more expensive than those made of natural graphite, reflecting higher production costs. However, more recently, the use of lower-cost feedstocks has contributed to a sharper decline in synthetic battery anode prices. These dynamics have reinforced a structural shift in anode composition: anode active material production in China is now almost entirely based on synthetic graphite, while natural spherical graphite retains a higher share outside China. Prices of anode material are now set at historic lows, making further reductions challenging.

Needle coke

Contrasting with this trend, needle coke prices increased in 2025, with calcined petroleum needle coke up around 4% year-on-year, reflecting persistent supply deficits in China and rising production costs. In early 2026, shipping disruptions in the Strait of Hormuz pushed up oil prices, with knock-on effects on needle coke markets: prices rose by more than 20% since the start of the conflict, and uncalcined needle coke reached USD 928 per tonne in April. These increases could materially affect the cost base of synthetic graphite anode production.

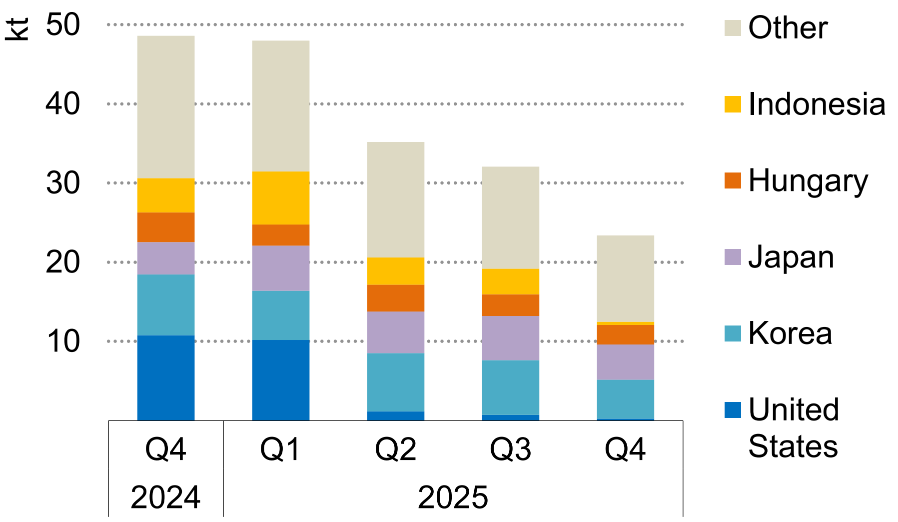
Graphite electrodes for electric arc furnaces

The graphite electrodes market remained subdued in 2025, as delays in electric arc furnace project expansions weighed on demand. Prices edged up slightly in 2025 but remained below historical averages amid ample supply and slower steel sector activity. However, in early 2026, several producers announced price increases, citing rising input costs.

Trade and industrial policies add to market uncertainty

Trade policy developments are adding a further layer of uncertainty to already concentrated graphite and battery supply chains.

China's exports of battery-grade natural spherical graphite



Source: IEA analysis based on China Customs statistics, commodity codes 25041091 and 38019010.

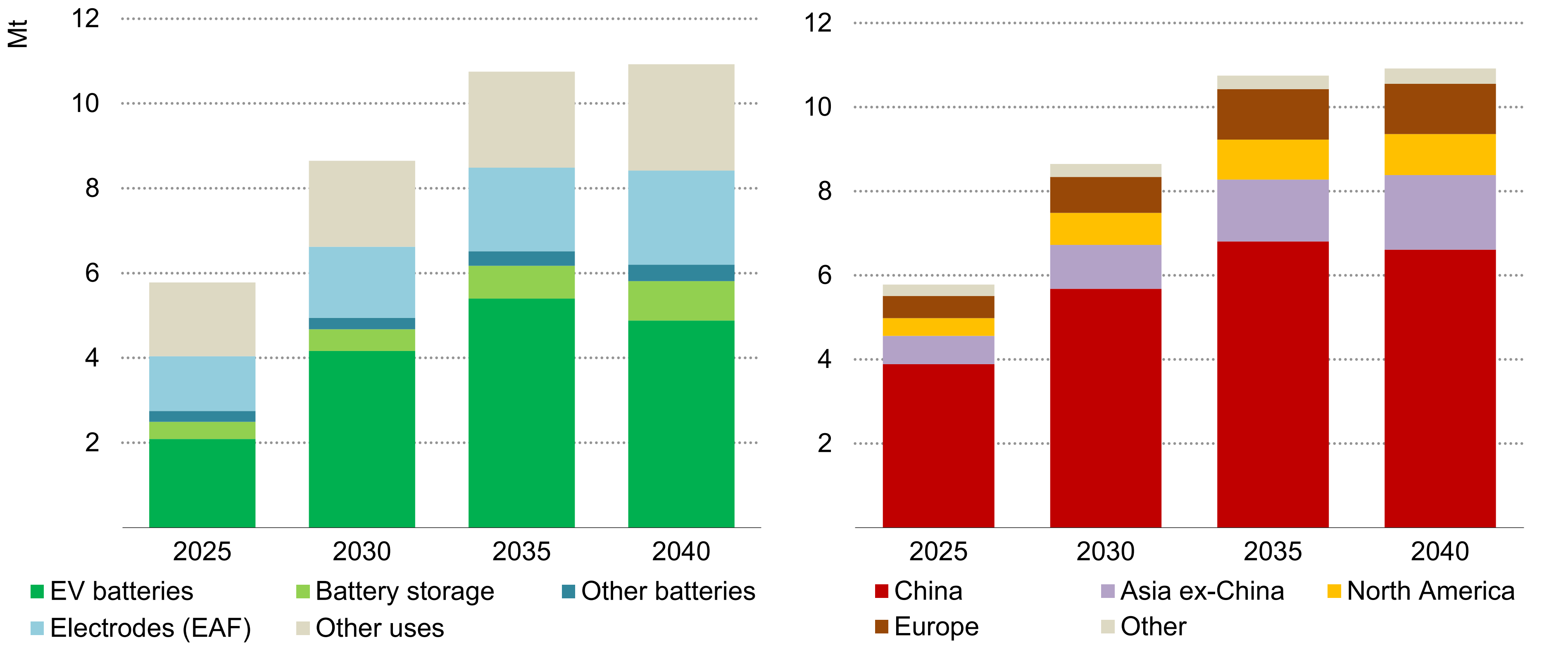
Following the introduction of export controls on natural and synthetic graphite in 2023 and 2024, China announced new export controls covering batteries in October 2025, including graphite anode materials and anode production equipment. One month later, in November 2025, China's Ministry of Commerce and Customs suspended these measures for one year. While the suspension has alleviated immediate supply disruptions, risks remain elevated. Any re-imposition or expansion of restrictions would significantly constrain efforts to establish competitive anode supply chains outside China, which already face challenges related to financing, cost competitiveness and access to advanced processing technologies.

Trade in battery-grade graphite from China has been affected by the controls announced in 2024, with total exports of spherical graphite decreasing by 16% in 2025. The issuance of export licences has in some cases been targeted to specific countries, with exports of spherical graphite to the United States halted since April 2025. In June 2026, Mozambique also introduced restrictions on the export of unprocessed materials, mandated local value addition and required 10% of mining revenues to be directed to local communities.

Regulatory changes in importing countries are also reshaping incentives for local production. In the United States, total tariffs on graphite imported from China fell sharply from over 200% in February 2026 to about 35% by late March, following rulings by the Supreme Court and the United States International Trade Commission. At the same time, in May 2026 the International Trade Commission determined that graphite electrodes imported from China and India were sold at less than fair value, highlighting the continued use of trade measures to address perceived market distortions.

EV and storage batteries drive graphite demand growth through 2040, with China playing a leading role

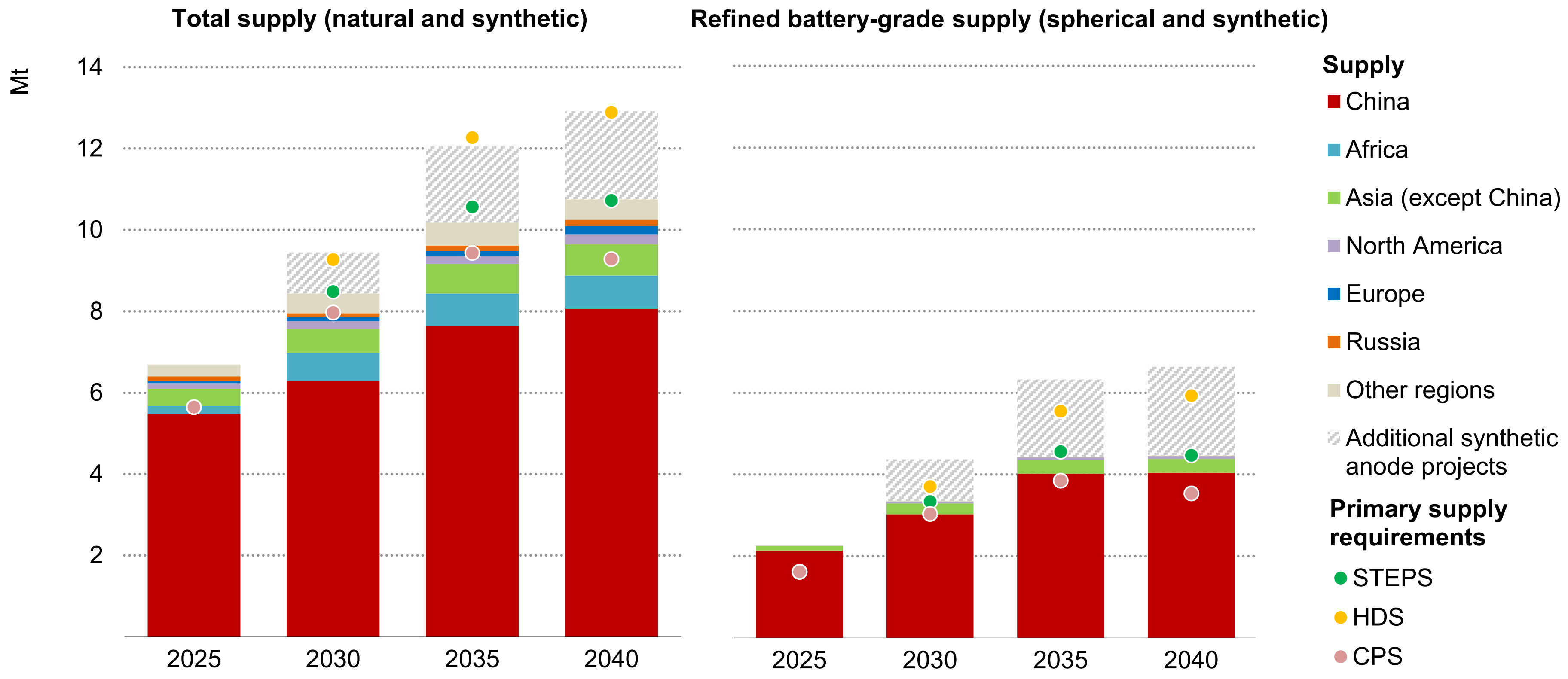
Global graphite demand outlook by sector and region in the STEPS



Note: EAF = electric arc furnace; STEPS = Stated Policies Scenario.

Supply is also expected to grow strongly, with significant idle synthetic graphite production capacity available

Total and battery-grade graphite supply from existing and announced projects in the base case, additional supply from synthetic anode projects, and demand in the CPS, STEPS and HDS, 2025-2040



Note: CPS = Current Policies Scenario; HDS = High Demand Scenario; STEPS = Stated Policies Scenario.

Concentration risks call for strong action and policy support for diversification

The global graphite market remains broadly well supplied through 2030, with ample idle synthetic production capacity that could be mobilised in China in response to market signals. However, new demand comes not only from batteries but increasingly from non-battery applications, notably electrodes for electric arc furnaces, as well as graphite use in other industrial and strategic sectors. Several of these applications require specific graphite grades that are not readily interchangeable with battery-grade material, underscoring the emerging risks of grade-specific tightness.

Demand

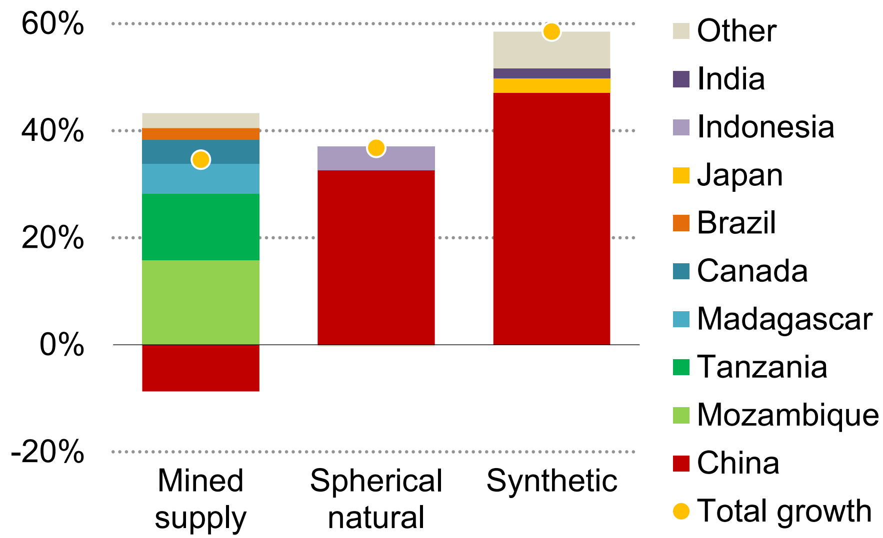
Graphite demand is set to almost double from 2025 to 2035 in the STEPS, mainly driven by strong growth in demand for EV and storage batteries. In the long term, material choice and technology substitution will play a role in shaping demand for battery-grade graphite, as silicon, lithium metal and hard carbon are set to progressively increase their market shares and substitute graphite.

Demand is expected to remain concentrated in China, which accounted for two-thirds of demand in 2025. Outside China, new graphite demand is expected to come mainly from new battery projects in Asia, North America and Europe.

Electrification of steel is driving demand growth for graphite electrodes, set to increase by around 50% from 2025 to 2035, though surplus production capacity is expected to persist into the 2030s, while other uses such as refractories, foundries and recarburising are expected to overall increase by 30%.

Supply

Graphite supply growth by country, 2025-2035



From 2025 to 2035, total graphite supply is expected to grow by over 50% in the base case, driven by new battery-grade supply (both natural spherical and synthetic) from China. Mined supply, however, is expected to decrease in China, offset by new flake mine developments in other regions, mainly Africa, Canada and Brazil. In Canada, Nouveau Monde Graphite confirmed the final investment decision for its Matawinie Mine project, which is expected to produce around 100 kt per year of graphite starting before 2030. New graphite mine developments are expected to deliver significant progress in mined supply diversification, decreasing China's share from 80% in 2025 to 53% in 2035. However, the country is expected to retain a strong hold on refined graphite markets, with its share of battery-grade graphite supply decreasing only from 94% to 91% in the next decade.

Box 2.1 Strategic importance of specialised graphite beyond batteries

Graphite plays a strategic role across defence, aerospace, nuclear and other high-technology sectors where performance requirements combine extreme temperatures, mechanical stress, electrical conductivity and chemical or nuclear stability. In many of these applications, graphite and carbon-based materials are effectively non-substitutable.

High-purity graphite for these specialised applications, with carbon content higher than 99.9%, is obtained through isostatic pressing, which requires ultra-fine controlled powders, and is always produced from synthetic feedstocks. However, there is growing interest among producers in high-purity natural graphite as demand from these sectors grows.

In defence and aerospace, graphite and carbon-carbon composites are essential inputs for missile and rocket nozzles, hypersonic and re-entry structures, aircraft braking systems, seals and bearings. These applications require high-density materials that retain strength and dimensional stability at very high temperatures while remaining lightweight.

In nuclear energy systems, nuclear-grade graphite is a critical component in graphite-moderated reactors, serving both as a neutron moderator and a structural material.

The safety and performance requirements of nuclear applications impose exceptionally tight specifications, including ultra-high purity (up to 99.999% carbon content), controlled isotropic microstructure, high density and resistance to radiation-induced degradation.

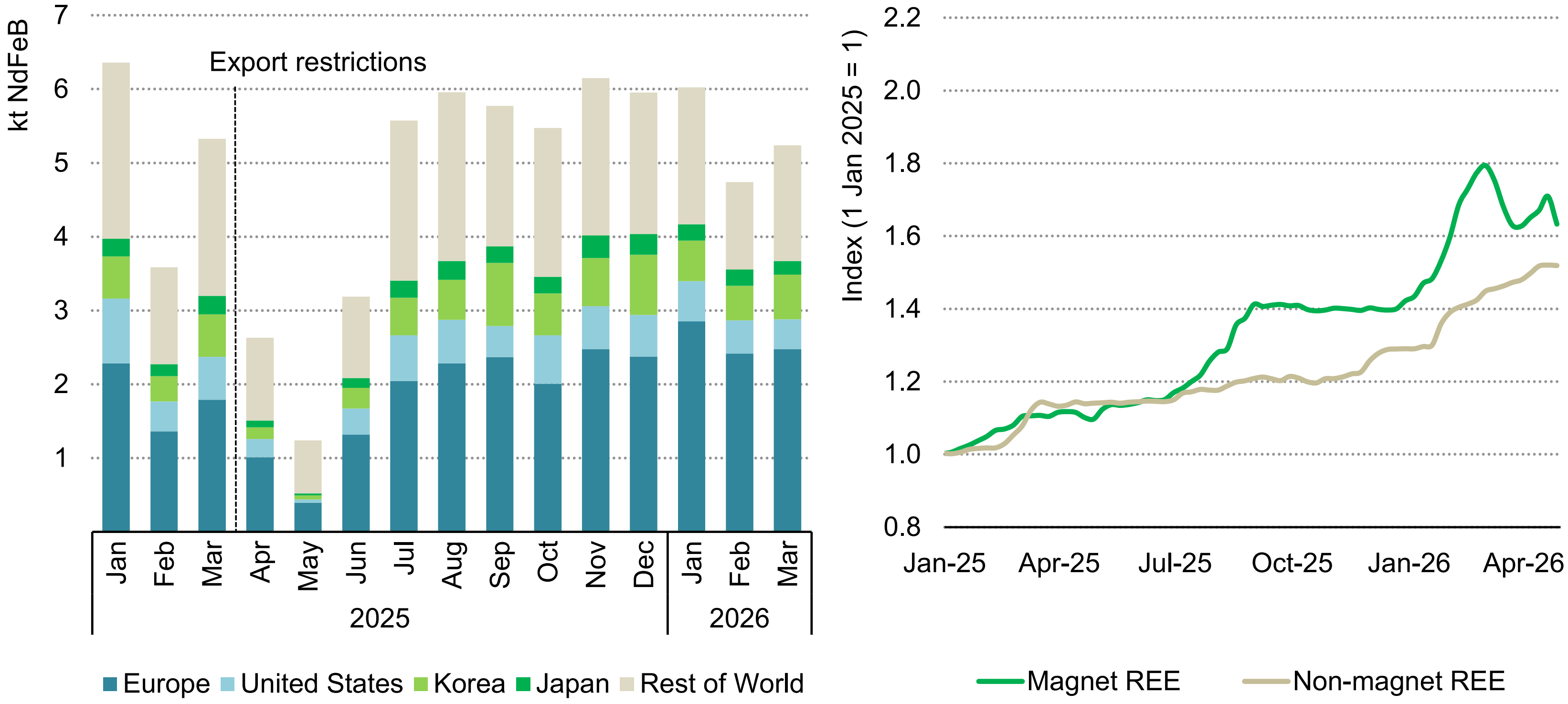
Other strategically important industries, such as semiconductors, solar PV, fuel cells and hydrogen technologies, depend on very high-purity graphite with tightly controlled grain size, porosity and thermal properties. Materials for these applications are required to operate in ultra-clean, high-temperature environments where contamination or microstructural variability can lead to system failure.

While these non-battery applications account for a relatively small share of total graphite volumes, they are highly specification-sensitive and mission-critical. Demand for specialised graphite is expected to increase steadily over the next decade, driven by rising defence expenditure, expansion of aerospace and space systems, expansion of nuclear capacity, and the scaling-up of semiconductor manufacturing. This creates strategic exposure, as supply chains for high-grade graphite remain highly concentrated, and capacity for specialised grades is significantly more difficult to substitute or scale than bulk battery materials.

Outlook for rare earth elements

With export controls, rising prices and supply uncertainty, 2025 was one of the most turbulent years for rare earth element markets since the 2010s

Evolution of rare earth magnet export volumes from China (left) and price of selected rare earth elements (right) since January 2025



Notes: kt = thousand tonnes; NdFeB = neodymium-iron-boron permanent magnet; REE = rare earth elements. Magnet REE = neodymium, praseodymium, dysprosium and terbium. Non-magnet REE = yttrium, samarium, gadolinium, holmium, erbium and lutetium. The assessment is based on neodymium, praseodymium, dysprosium, terbium, yttrium, samarium, cerium, erbium and lanthanum rare earth oxide 99.5% min free on board China spot prices, and scandium, gadolinium, holmium and europium rare earth oxide 99% min Ex Works China prices. Indexed values were calculated relative to January 2025.

Sources: IEA analysis based on statistics from China's General Administration of Customs, accessed 13 May 2026 and KOMIS (2026), accessed 29 April 2026.

Against the backdrop of supply uncertainty triggered by geopolitical events, unprecedented momentum emerged to support projects in geographically diverse regions

Export controls, trade and prices

In 2010, China implemented rare earth controls using quotas and licensing, causing a global supply shock and rare earth prices to spike temporarily by as much as ten times. These controls were eventually ruled non-compliant with the World Trade Organization (WTO), leading to their removal. In 2025, significantly strengthened and expanded rare earth export controls from China re-emerged.

The April 2025 export controls on seven heavy rare earths (including dysprosium, terbium and samarium, which have applications in permanent magnets) and their related products led export volumes from China to drop sharply in April and May, leaving many automakers in the United States, Europe and beyond struggling to source permanent magnets. Exports of dysprosium and terbium oxides and metals were also affected by the restriction, dropping in May before slowly recovering in the following months, impacting the supply of feedstocks for magnet manufacturing outside China. Even after trade volumes recovered, a significant premium for magnets produced outside China remained.

Expanded export controls announced in October 2025 not only added five additional rare earth elements, notably holmium, which was used as a substitute by magnet makers in the aftermath of the April controls, but also broadened the scope to include “internationally made” products containing Chinese-sourced “parts, components and assemblies” or manufactured using Chinese technologies. In November 2025, China announced a one-year suspension of the export restrictions introduced in October 2025, providing relief to the market. However, the underlying risks and potential for future implementation remain (see Chapter 1).

Notably, prices for neodymium-praseodymium (NdPr) oxide nearly doubled over the seven months from October 2025, reaching around USD 125 per kilogramme in February 2026, their highest level since mid-2022. The elevated prices are likely to be temporary, with a marginal downward correction already being observed.

New landscape for policy support and partnerships

Governments have rapidly deployed a range of policy instruments to reduce vulnerabilities across rare earth supply chains, spanning trade, project financing, research and development, and international partnerships. These efforts were accelerated by the announcement of export controls and growing recognition of the importance of fostering long-term supply chain resilience.

Financing has been the most widely utilised policy response, with governments stepping in where private capital is lacking. Australia's AUD 1.65 billion (Australian dollar) loan to Iluka Resources for the Eneabba rare earths refinery is one example, alongside the United States' USD 150 million loan to MP Materials for its plan to expand heavy rare earth separation capabilities. Additional actions from the Australian government are expected, partly linked to the country's Critical Minerals Strategic Reserve initiative. The US International Development Finance Corporation has also been active, including through the Critical Minerals Consortium, which is backed by USD 600 million in funding. Export credit agencies have started to finance projects as well, including Export Development Canada's letter of interest to support a Viridis mining project in Brazil with CAD 100 million (Canadian dollars) in debt financing. In November 2025, the Indian government approved an INR 72.8 billion (Indian rupee) (approx. EUR 780 million) scheme to develop integrated permanent magnet manufacturing capacity of , covering the full value chain from rare earth oxides to finished magnets.

Research, development and innovation along the supply chain have also received significant funding, including the US Department of Energy's National Energy Technology Laboratory's letter of intent with USA Rare Earth to develop digital twin technology for heavy rare earth separation at the company's Wheat Ridge laboratory and Round Top deposit.

Geological exploration has been a way for countries to expand their domestic resource base. India's Atomic Minerals Directorate, for example, has been conducting systematic rare earths exploration and targeting monazite and xenotime deposits. Between 2021 and 2024, the Geological Survey of India launched 368 critical mineral exploration projects, which include rare earths, with a further 195 projects initiated from 2024 to 2025. These efforts were complemented by the 2026 Union Budget, which introduced dedicated rare earth industrial corridors in Andhra Pradesh, Kerala and Odisha, designed to bundle extraction, processing and value-added manufacturing into a coherent development strategy for electronics and defence supply chains.

Recycling is also a parallel priority for many countries. The European Union's Critical Raw Materials Act introduced a suite of measures aimed at strengthening rare earth recycling across the region, including requirements for rare earth content labelling and minimum recycled content obligations, with implementation scheduled between 2028 and 2032. In parallel, under the RESourceEU Action Plan, the European Commission is expected to put forward a proposal to restrict exports of permanent magnet scrap and waste from EU countries. India's incentive scheme to promote critical minerals recycling sets aside INR 1 500 crore (approx. EUR 145 million) to provide financial incentives for the development of recycling capacity for the separation and production of critical minerals from secondary sources.

International partnerships have increasingly become a cornerstone of many countries' efforts to secure rare earth supply chains. For example, the United States has signed many bilateral agreements since 2025, including a framework with Australia specifically focused on securing supply in the mining and processing of critical minerals and rare earths, and more recently a with Saudi Arabia. Last December, Malaysia signed a memorandum of co-operation to strengthen technical collaboration on rare earth exploration and resource evaluation to support geological surveys, technology exchange and capacity building, and to position Malaysia as a hub for an integrated rare earth supply chain. In February 2026, Brazil and India signed a non-binding MoU on rare earths and critical minerals, establishing a framework for cooperation on reciprocal investment, exploration, mining and technology applications, including AI. In April 2026, France and Japan agreed to strengthen their existing co-operation on rare earth supply chains, building on their co-operation on the Caremag project for rare earth processing and recycling. The IEA Critical Minerals Security Programme was reinforced in February 2026 to serve as an avenue for partnerships on strategic projects and policy instruments. In addition, a growing number of governments are making collaborative efforts to develop supply chains from mining to magnet manufacturing, from joint ventures between state-backed entities and mining companies to government-facilitated offtake agreements and equity investments by national resource agencies in foreign operations. In June 2026, Group of Seven (G7) member countries agreed to reduce dependencies on rare earths and permanent magnets from a single supplier to under 60% by 2030 in the G7 leaders' declaration on securing supply chains for critical minerals. These examples point to an emerging approach in which governments are extending more direct support to the supply chain, in addition to creating enabling policy environments.

Private sector engagement sees a step change

For decades, investment levels in rare earth companies in geographically diverse regions remained low due to a combination of low prices, small market sizes, price-sensitive end-use industries, lack of market transparency and policy uncertainty. However, developments in 2025 highlighted the strategic importance of rare earths, particularly magnet rare earths (neodymium [Nd], praseodymium [Pr], dysprosium [Dy], terbium [Tb]), across a wide range of sectors from energy and transport to electronics, high-tech manufacturing for AI and data centres, aerospace and defence. Unprecedented billion-dollar investment agreements in the rare earths industry have come from both the public and private sectors in the last 12 months, with companies playing an increasingly active role in efforts to build diversified supply chains. The agreements have often been cross-border, leveraging strengths in different regions, with many companies aiming to create "mine-to-magnet" value chains.

In July 2025, MP Materials, which operates one of the only integrated rare earth facilities outside China, announced a landmark partnership with the US Department of War to expand domestic permanent magnet production, including support for its existing Independence magnet manufacturing facility and the development of the new large-scale 10X magnet manufacturing campus. The US Department of

War committed to a floor price of USD 110 per kg for neodymium-praseodymium products. The company also signed a USD 500 million agreement with Apple, under which Apple will purchase magnets produced at the Independence facility using recycled feedstock. The two companies also agreed to establish a recycling line at Mountain Pass to recover and reprocess materials from end-of-life products and scrap.

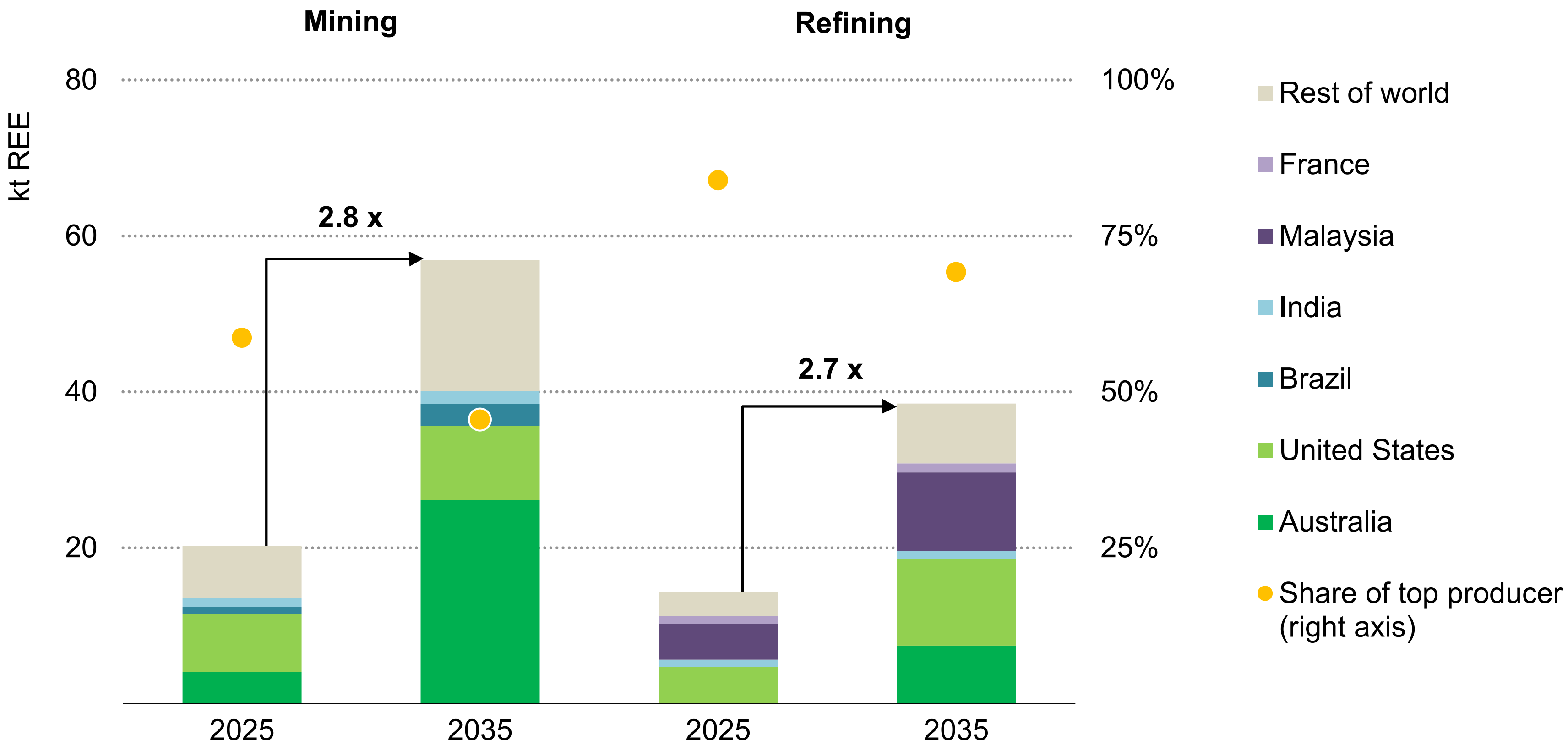
USA Rare Earth has signed multiple agreements in less than a year, including its acquisition of United Kingdom-based metallisation company Less Common Metals with an equity investment of USD 125 million and Brazil's rare earth mining company Serra Verde for . The company has also planned an all-stock purchase of Texas Mineral Resources Corporation and announced a 12.5% equity stake in the French metal and alloy production facility operated by Carester. In addition to an estimated USD 1.6 billion in financing and equity support from the US government, USA Rare Earths has also raised around USD 2 billion from private sources to help finance these deals.

Lynas Rare Earths has signed a binding letter of intent with the US Department of War to finalise a four-year supply agreement for light and heavy rare earth oxides, under which approximately USD 96 million will be allocated for purchases, including a floor price of USD 110 per kg for NdPr oxide. The company has also agreed to a 12-year supply arrangement with Japan for the same floor price. Both deals match the minimum level established last year in the support agreement with MP Materials. The deal also allocates to Japan around half of Lynas's future heavy rare earth oxide production, supported through the Japan Australia Rare Earths partnership involving Sojitz and the Japan Organization for Metals and Energy Security (JOGMEC). In March 2026, Lynas signed a co-operation deal with Korean company LS Eco Energy, with plans to build a metal processing facility in Viet Nam. Last October, the company also partnered with United States-based magnet manufacturer Noveon Magnetics in an agreement that includes both light and heavy rare earth materials.

Private companies also boosted efforts to scale up recycling. Neo Performance Materials and Cyclic Materials signed a non-binding MoU to develop a circular and traceable rare earth supply chain, centred on recycling magnet-production scrap and end-of-life magnet-bearing materials into mixed rare earth oxides that can be reintegrated into Neo's alloy and magnet-manufacturing operations in Europe. Korea Zinc and Alta Resource Technologies formed a joint venture to build a rare earth recycling facility in the United States by 2027, aiming to reach a production capacity of 100 tonnes of oxides per year. ReElement Technologies will receive USD 80 million in federal loans to expand recycling and refining capabilities, supporting closed-loop production of neodymium-iron-boron magnets. Ionic Rare Earths signed an MoU with US Strategic Metals to develop a recycling plant in Missouri that will produce high-purity rare earth oxides.

Timely realisation of all announced projects would nearly triple today's volumes of mined and refined production for magnet rare earths from diversified sources by 2035

Mined and refined rare earth production outside the top producer in the high production case and share of top producer



Notes: REE = rare earth elements. For mining, the figures exclude China and Myanmar. The figures are for magnet rare earths (neodymium, praseodymium, dysprosium and terbium) only.

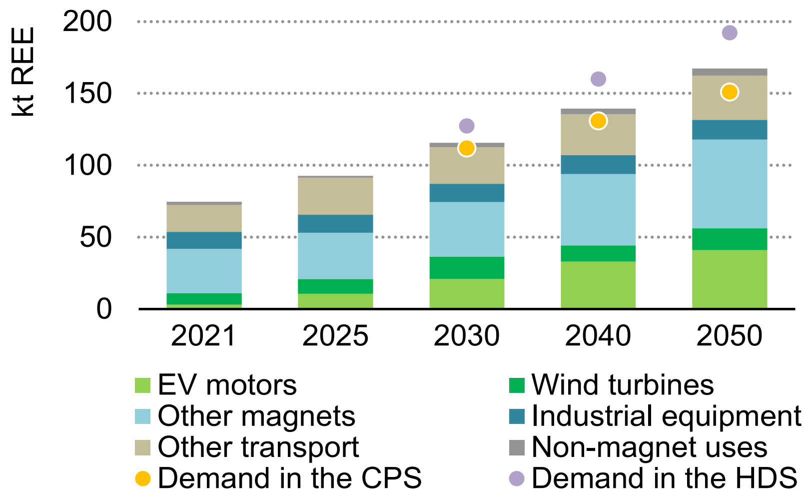
While demand continues to grow steadily and supply remains sufficient at the global level, supply from diversified sources remains well below demand outside the top producer

Demand

As described in the IEA's Rare Earth Elements special report, demand for magnet rare earths – neodymium, praseodymium, dysprosium and terbium – continues to grow steadily. It has doubled since 2015, driven by rapid growth in the electrification of end uses and industrial processes, as well as the deployment of new energy technologies such as EV and wind turbines, whose powerful motors rely heavily on permanent magnets. The two heavy magnet rare earth elements, dysprosium and terbium, continue to play small but significant roles in phosphors, displays, medical equipment, nuclear reactors and metallurgy, but the strongest driver of their demand growth has been their use as additives to enhance the performance of modern permanent magnets.

In the STEPS, global demand for magnet rare earths is set to expand by a quarter between 2025 and 2030, approaching 120 kilotonnes of rare earth elements (kt REE), and by over 80% to 2050, reaching 170 kt REE. Driven by sustained growth in the deployment of EVs, wind generation, industrial motors and automation, and other applications in transport, appliances and electronics, permanent magnets, though of various sizes and performance specifications, account for the majority of magnet rare earth demand throughout the projection period. Demand from wind turbines, though still rising throughout the period, is lower by over 10% in 2030 and 15% in 2050 compared with the projections in the Global Critical Minerals Outlook two years ago. Emerging growth in automation, robotics and digital technologies plays a larger role in driving total demand beyond 2030, as permanent magnets enable precision motion control, miniaturisation (through small motors with high power) and energy efficiency for these applications.

Magnet rare earth demand by sector in the STEPS, 2021-2050



Notes: CPS = Current Policies Scenario; STEPS = Stated Policies Scenario; HDS = High Demand Scenario; EV = electric vehicle; REE = rare earth elements. The figures are for magnet rare earths only.

Demand for magnet rare earths outside China also rises steadily in all scenarios, driven primarily by the rapid expansion of electrification, energy and automation technologies. The largest contribution comes from EV deployment in both advanced economies and emerging markets and developing economies. Major original equipment manufacturers expanding production across Japan, Korea, North America, Europe and India rely on magnet rare earths most prominently for EV traction motors, but also for many smaller magnetic components, such as actuators, speakers and sensors, in conventional cars and other types of vehicles. Asia, excluding China, remains the dominant centre of demand, accounting for roughly half of global consumption outside China throughout the outlook period, supported by large manufacturing bases in Japan and Korea. Europe and North America register notable increases, reflecting strong policy support for electrification and renewed ambitions to scale up domestic manufacturing for high-tech supply chains. Nevertheless, the global share of demand outside China expands only gradually, indicating that China continues to play a central role in magnet rare earth consumption throughout the projection period.

Although magnet uses account for over half of total rare earth element demand, demand for non-magnet rare earths is also notable: gadolinium (used in medical devices and nuclear control rods and as a substitute for dysprosium in magnets) and holmium (used in phosphors, displays and ceramics) grow at an average rate of around 4% per year, while yttrium (used in medical devices, optic fibres, high-frequency applications and coatings in aviation parts) grows at 2.5% per year to 2030.

Supply

From today's levels, mined supply for magnet rare earths rises by 30% to reach 104 kt REE in 2035 in the base case, and an additional 21 kt REE is added in the high-production case, which includes projects at earlier stages of development. Refined supply also increases similarly, reaching 125 kt REE in the high-production case in 2035.

In response to export controls and heightened supply risks, many projects have been announced in geographically diverse regions in recent years. In the high-production case, production outside the dominant supplier triples for both mining and refining, reaching 57 kt REE and 38 kt REE, respectively, by 2035. While China remains the dominant supplier throughout the projection period, it is worth noting that the steady build-out of a diversified pipeline leads to its share in mined supply of magnet rare earths declining from around 60% in 2025 to 55% in 2035 in the base case and further to 45% in the high production case – falling below half of global mined supply for the first time in recent decades if all announced geographically diverse projects are delivered on time. Increase in diversified mined supply is led by Australia and the United States, with additional contributions from Brazil, Lao People's Democratic Republic (PDR), Tanzania, India and other smaller producers. For refining, China's share dropped from 90% to 85% between 2024 and 2025, with the majority of the lost share being claimed by the United States and the rest by Malaysia, and is projected to decline to 73% in 2035 in the base case and further to 70% in the high-production case. Diversified refining activity is concentrated in Malaysia and the United States, followed by Australia, Viet Nam, Japan, the United Kingdom, France and Estonia.

Despite this progress, cumulative planned production of metals, alloys and finished magnets from projects announced as of early 2026 amounts to around 57 kt of neodymium-iron-boron (NdFeB) in 2035, equivalent to 18 kt of magnet rare earth content, significantly less than diversified rare earth mining and refining capacities. This reflects a modest pipeline led by the United States, with notable contributions from Europe, Japan, Korea and Viet Nam. This pronounced tapering of diversified projects from upstream mining to downstream magnet manufacturing highlights the difficulty of establishing entire supply chains outside China. While resource development is advancing in several regions, the comparatively slower build-out of refining and magnet production suggests that critical midstream and downstream stages could remain bottlenecks. Without accelerated investment in these parts of the value chain, many regions may continue to depend on external processing and manufacturing, even as domestic extraction capacity expands.

Supply-demand balances

Global rare earth markets have been well supplied over the last decade, as supply, predominantly from the top supplier, has continued to outpace demand growth, despite a slowdown in China's production quota growth in 2024. Projected supply remains broadly sufficient through to 2040. Global mined supply from announced and planned projects in the base case grows faster than demand in the STEPS and CPS, but satisfying demand after 2030 in the HDS requires at least half of the projected supply from less advanced projects in the high-production case to come online as planned.

Despite this global picture of well-supplied markets, the announcement of export controls from China and sustained social and governance challenges in Myanmar have emerged as tangible risks to the reliable supply of these minerals for strategic industries in the rest of the world. Demand for magnet rare earth elements in regions outside the dominant supplier is set to grow by 50% over the next decade. Production from current capacities and their planned expansions in regions outside China, and outside Myanmar for mining, accounts for about 50% of the ex-China demand for mining, 25% for refining and well below 20% for magnets in 2035. Many new projects have been announced across geographically diverse regions, but even if these come online as scheduled, their sustained operations will depend on consumer motivation to buy materials from diversified suppliers. Nurturing strategic manufacturing industries, including EVs, energy technologies, electronics, data centres, robotics, aerospace and defence, can provide a solid demand base for diversified mined, refined and magnet supply sources.

Innovation throughout the rare earths value chain is vital to closing existing gaps in geographically diverse projects and mitigating supply pressures

Innovation to build diversified ecosystems

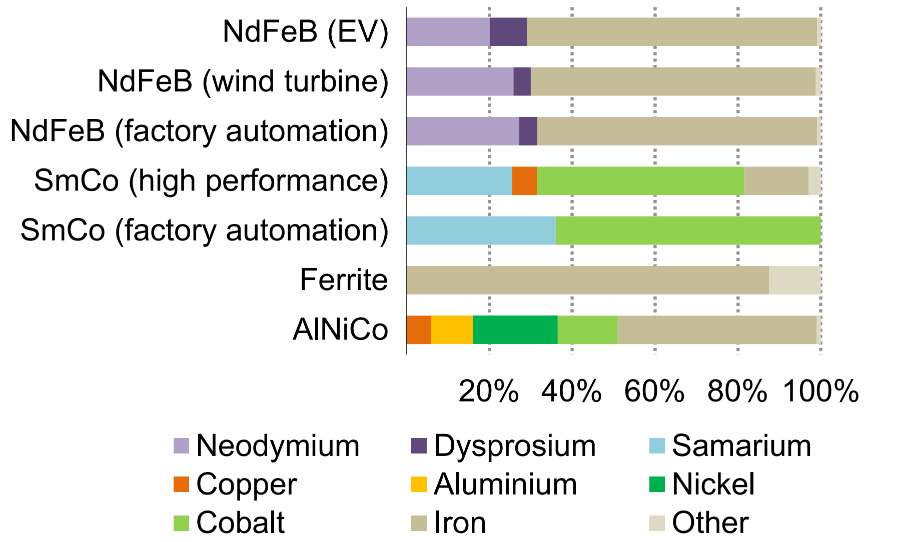
Rare earth separation and processing and permanent magnet manufacturing are complex and technically demanding processes that have been improved and perfected by the dominant supplier over a few decades. Diversification is therefore not simply a question of planning new projects. Technology, equipment and skills gaps need to be addressed in parallel in order to nurture an entire-ecosystem approach. Chapter 3 discusses these issues in more detail.

Innovation in magnet composition and design

Demand-side innovation represents a powerful complement to supply-side efforts, providing a pathway to alleviate supply constraints. It can take three distinct forms: reducing the amount of heavy rare earth elements (HREEs) required within existing magnet chemistries, substituting one HREE for another that is less supply-constrained, and developing entirely new technologies that drastically minimise or eliminate rare earth use altogether.

The performance of NdFeB permanent magnets can be enhanced through the addition of HREEs, notably dysprosium and terbium, which improve coercivity and high-temperature stability. However, HREE production remains overwhelmingly concentrated in China and Myanmar. This over-reliance heightens vulnerability to supply disruptions and export restrictions. One major avenue of innovation therefore focuses on reducing HREE intensity within NdFeB magnets without sacrificing performance.

Indicative elemental composition of different types of magnets



Note: NdFeB = neodymium-iron-boron magnet; EV = electric vehicle; SmCo = samarium-cobalt magnet; AlNiCo = aluminium-nickel-cobalt alloy magnet.

The HREE content of magnets varies significantly by application: high-performance EV traction motors contain around 8.5-11% of HREEs by weight (although the latest designs could have much lower content of around 2%, but with performance trade-offs), while magnets used in industrial motors and wind turbines typically have slightly lower ratios of heavy to light rare earths. Manufacturers are improving grain boundary engineering, motor cooling and system design to achieve equivalent functionality with less dysprosium or terbium.

Together with continued improvement in materials science and engineering, co-ordinated action across the value chain can accelerate both reduction and substitution strategies. Collaboration among motor manufacturers, magnet producers and public authorities is particularly effective in overcoming technical barriers and scaling innovation. Following the rare earth supply shock of 2010, for example, Japan implemented government-supported programmes to redesign motors for vehicles, industrial equipment and hard disk drives. Even though demand has risen again in recent years due to growing magnet applications, overall rare earth demand in Japan has fallen significantly since the implementation of these measures. Total rare earth demand in Japan, including heavy rare earths, is currently nearly 30% below 2010 levels.

A more transformative pathway is the development of technologies that substitute rare earth-based magnets entirely. Mature alternatives such as ferrite and aluminium-nickel-cobalt (AlNiCo) magnets contain little or no rare earth content and are already widely used where performance requirements are lower. These materials, based on abundant iron alloys or ceramic oxides, can replace NdFeB magnets in applications such as speakers, sensors and lower-power motors, thereby reducing overall rare earth demand and material costs.

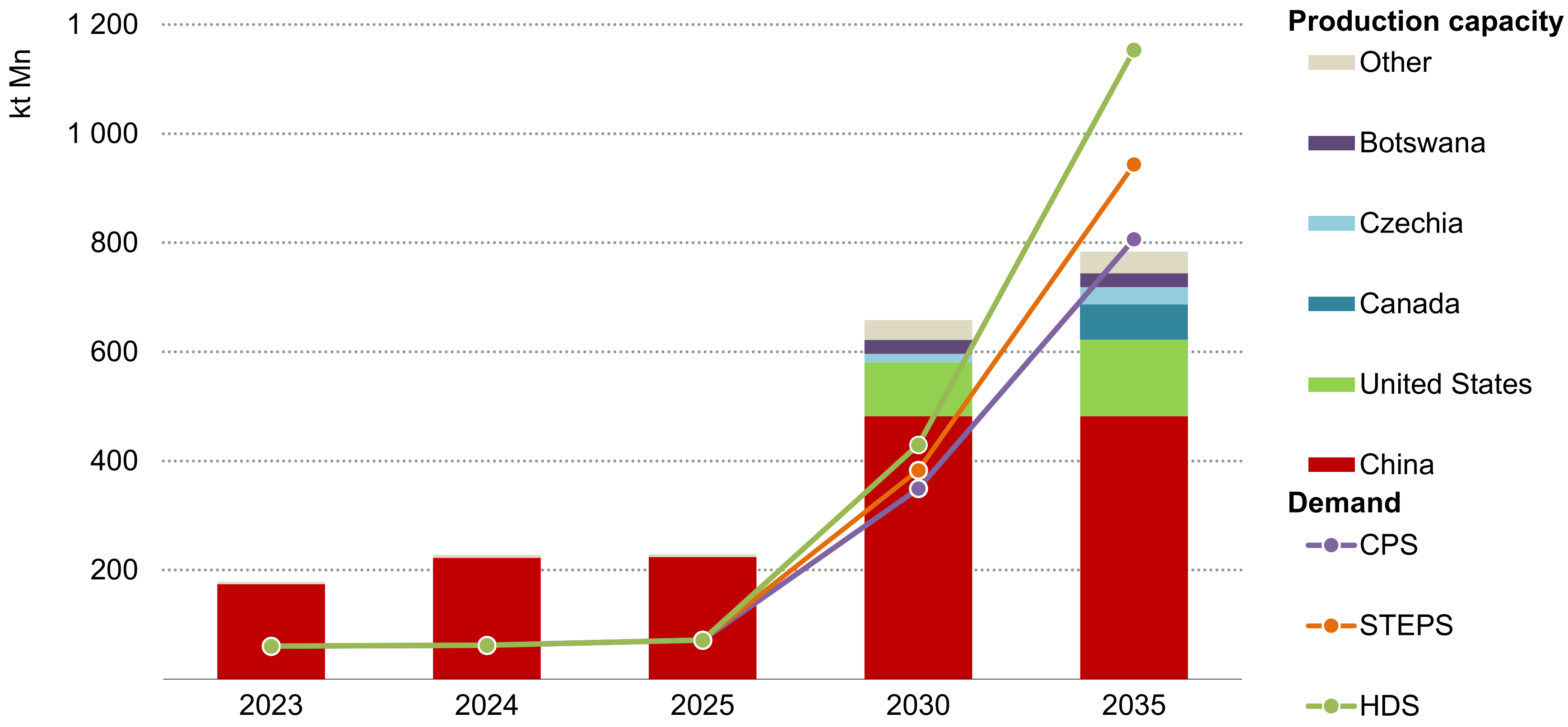
Emerging rare earth-free technologies are also progressing towards commercialisation. In the United States, Niron Magnetics has begun construction of a permanent magnet manufacturing facility in Minnesota based on iron nitride (FeN) technology with no rare earth elements, aiming to serve the automotive and electronics sectors. In parallel, research programmes are developing electric motors that avoid permanent magnets altogether by using alternative electromagnetic designs based on widely available materials such as iron and aluminium. Although many of these technologies remain at demonstration or early commercial stages, they illustrate a growing strategic shift towards reducing dependence on critical minerals.

For new solutions to achieve widespread adoption, they must offer a competitive combination of performance, cost and manufacturability without introducing new supply constraints elsewhere in the value chain. Innovations that merely shift dependency from rare earths to other scarce or geopolitically concentrated materials would provide limited systemic benefit. Priority should therefore be given to technologies based on abundant inputs, scalable production processes and compatibility with existing industrial systems.

Other key materials

Manganese: Battery-grade manganese sulphate remains a major potential chokepoint for battery supply chains, but the project pipeline is diversifying

Battery-grade manganese sulphate production capacity and demand, 2023-2035



Notes: CPS = Current Policies Scenario; STEPS = Stated Policies Scenario; HDS = High Demand Scenario. Production capacity is the nameplate capacity.
Source: IEA analysis based on data from Benchmark Mineral Intelligence.

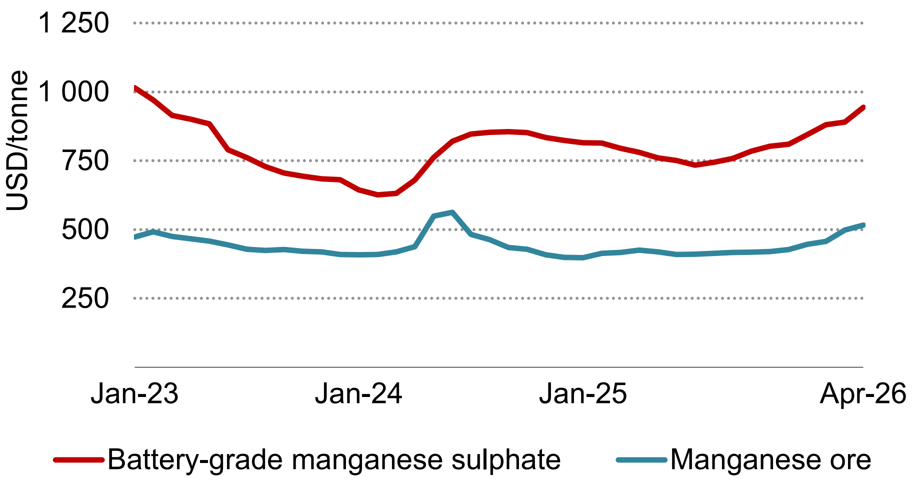
Manganese: The United States and Canada are leading diversified battery-grade manganese sulphate project announcements, but challenges remain in bringing these projects to reality

While manganese demand remains dominated by steel, its growing importance in battery chemistries is making it an increasingly strategic mineral. Conventional nickel-based and emerging battery chemistries, namely manganese-rich and sodium-ion, require battery-grade manganese sulphate, which is emerging as a potential chokepoint for battery supply chains. Production of battery-grade manganese sulphate is exceptionally concentrated, with China producing over 95% of global supplies in 2025, making it highly vulnerable to potential future supply disruptions.

Despite China dominating current production, a number of projects are being announced and developed in geographically diverse regions, particularly the United States, Canada and Czechia. Despite having no operating capacity in 2025, the United States is expected to have over 140 kt of manganese sulphate production capacity (kt manganese contained) by 2035, amounting to almost 20% of global capacity if planned projects come online as scheduled. Canada also plans for significant growth in production capacity, with almost 10% of capacity in 2035, while Czechia accounts for 5%. However, reliable production of battery-grade manganese sulphate at scale is technically challenging, so new players may face considerable challenges in ramping up capacity. There may also be competitiveness challenges relative to established Chinese players in terms of limited economies of scale, limited production expertise and stricter environmental requirements for handling by-products and waste. At present, there are only two operating refineries producing battery-grade manganese sulphate outside China, in Japan and Belgium. Partnerships between existing and new players could help accelerate learning and project development.

The projected supply gap for manganese sulphate has narrowed to a deficit of almost 20% in 2035 compared with 45% in last year's *Outlook*. While still significant, the demand outlook has moderated slightly due to the strong growth of LFP batteries over nickel-based chemistries. The uptake of lithium manganese iron phosphate (LMFP) batteries has also been slower than expected due to the continued innovation and improved performance of the latest LFP chemistries. A potential source of demand upside in the medium term is the emergence of high-energy-density lithium-manganese-rich (LMR) chemistries, though large-scale deployment is not expected until the 2030s. Given these developments, battery-grade manganese sulphate demand is projected to reach almost 1 Mt in 2035 under today's policy settings, amounting to 5% of total manganese demand, up from less than 1% today. However, between 2035 and 2040, battery manganese demand is set to almost double to close to 10% of total demand, reflecting the growing deployment of manganese-rich chemistries.

Manganese prices, 2023-2026



Note: Mn sulphate 32%, Ex Works China. Manganese Ore Mn32% Fe20%,Tianjin-SA.
Source: IEA analysis based on data from Bloomberg.

Following a period of price volatility in 2024 from major supply disruptions, manganese ore prices eased in 2025. However, in 2026, prices have started rising again. With the increase in oil prices from the conflict in the Middle East raising costs across the mining sector, manganese producers are among the most affected. Manganese mining operations, primarily open-pit, typically have a strong dependence on diesel for extraction, ore transport and the generation of backup power. Leading production in South Africa and Gabon is located deep inland, requiring significant diesel-dependent rail and road transport. Given the surge in diesel prices, manganese margins are being compressed, adding pressure on manganese prices. Moreover, a major weather-related supply disruption in Australia in March 2026 added further pressure to prices. Prices for battery-grade manganese sulphate have broadly followed changes in manganese ore prices, but in early 2024, prices fell to historic lows, leading several Chinese operations to halt production. These cuts flipped the market from oversupply into deficit, leading to price recoveries throughout 2024. Prices fell slightly in the first part of 2025 but have been increasing steadily due to increases in sulphuric acid prices in the latter half of 2025 and particularly in 2026 from the Middle East conflict, with reports of manganese sulphate contracts recently being settled at over USD 1 000/tonne. Increased sulphuric acid costs, as well as higher ore prices, are key drivers.

South Africa still dominates mined manganese supply, with almost 40% of global production in 2025. Gabon is the second-largest supplier, with a quarter of global supply in 2025. Ghana and Australia are the other major suppliers, with 10% and 8% of global production in 2025, respectively. Supply disruptions have remained a major source of volatility in manganese markets. For example, the major disruption at South32's GEMCO mine, the second-largest manganese mine in the world, in Australia from cyclone damage in 2024 led to major manganese ore and sulphate price increases. Despite resuming production in 2026, operations were paused again in March 2026 due to a new cyclone, highlighting the risks to major manganese assets from weather incidents.

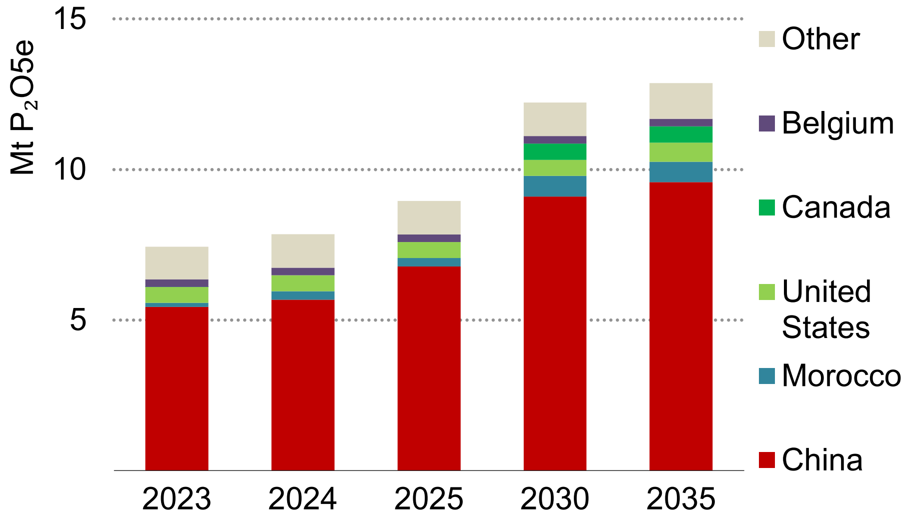
Phosphoric acid: Battery-grade purified phosphoric acid is a major chokepoint for battery supply chains, with little diversification on the horizon

LFP batteries have rapidly become the leading battery chemistry, accounting for 55% of the global electric car market and 90% of the battery storage market in 2025, up from 15% and 30%, respectively, in 2020. LFP battery production requires battery-grade purified phosphoric acid (PPA), which is produced from phosphate rock and sulphuric acid. China currently dominates global PPA supply, with 70% of production in 2025. The rapidly growing deployment of LFP batteries, particularly in battery storage, and the high level of PPA supply concentration make PPA an increasingly important chokepoint for global battery supply chains.

Unlike manganese sulphate, there is limited diversification in the project pipeline for PPA. Based on current project announcements and developments, China is projected to maintain 75% of global production capacity in 2035, almost the same as today. Despite having the world's largest phosphate rock reserves and plans to expand phosphate mining, Morocco is set to hold only 5% of global PPA production capacity by 2035. The United States is set to have the third-largest capacity, with almost 5% by 2035, followed by Canada. Together, Morocco, the United States and Canada account for over 55% of planned ex-China PPA capacity by 2035.

Development of PPA production capacity outside China faces similar challenges to those facing battery-grade manganese sulphate. Key challenges include cost competitiveness stemming from economies of scale and established phosphate production advantages in China, as well as limited production expertise and equipment availability. There are also additional challenges related to waste and by-product disposal.

Purified phosphoric acid (PPA) production capacity, 2023-2035

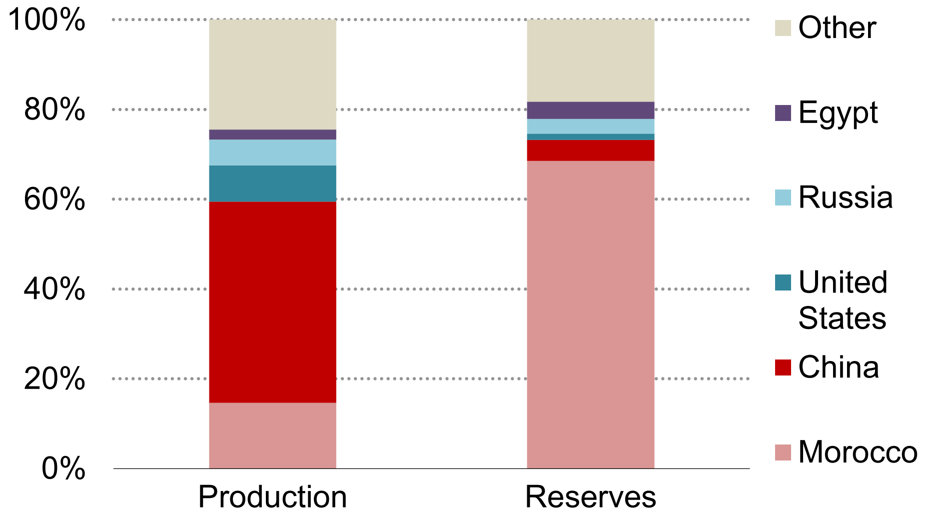


Note: P_2O_5e = phosphorus pentoxide equivalent.
Source: IEA analysis based on data from Benchmark Mineral Intelligence.

Prices for phosphoric acid have been increasing due to rising input costs, increasing by almost 4% to over USD 1 500 per tonne in the first quarter of 2026. PPA generally trades at a premium to phosphoric acid and faces the same cost pressures. As sulphuric acid is a key input for PPA production, rising prices for sulphur and sulphuric acid from the conflict in the Middle East are providing upward pressure on PPA prices. This is being compounded by higher prices for phosphate rock, which also increased due to the disruption to phosphate exports from Jordan following the closure of the Strait of Hormuz. Phosphate rock prices have also increased on the back of the announcement by Egypt's Ministry of Petroleum and Mineral Resources that it would not sign any new phosphate export contracts, as the government tries to shift from exporting raw materials to producing higher value-added products, such as phosphate fertilisers. Together, these effects are increasing PPA prices, with likely knock-on effects for LFP cathodes and batteries. However, the higher prices may support diversified project development.

Despite having the world's largest reserves of phosphate rock, with 70% of global reserves, Morocco currently accounts for less than 15% of global mined supply. China, on the other hand, leads mined phosphate rock supply, with 45% of global production in 2025, despite holding only 5% of global reserves. The United States is the world's third-largest producer, with almost 10% of global supply in 2025. In recent years, there has been a surge in Chinese battery supply chain investment in Morocco, including from Gotion, BTR, Huayou and CNGR, with its major phosphate reserves a key driver. Morocco's trade agreements with the European Union and its free trade agreement with the United States also provide these Chinese-backed battery supply chain projects with preferential access to EU and US markets compared with direct exports from China.

Phosphate rock mining and reserves, 2025

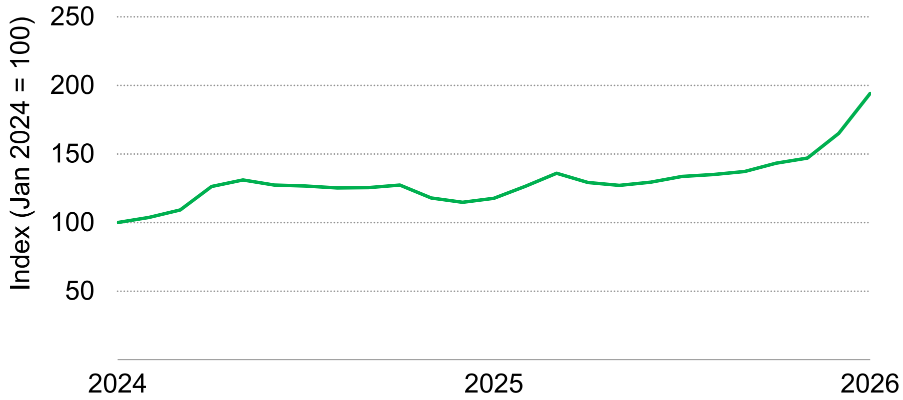


Source: IEA analysis based on data from US Geological Survey (2026).

Tin: Strong demand growth driven by high-tech and energy applications has met constrained supply, although supply conditions have begun to ease in recent months

Over the past few years, tin prices have continued to rise as strong demand growth, fuelled by the AI investment boom and related semiconductor demand, has coincided with supply constraints in major producing countries such as Indonesia and Myanmar, stemming from mining permit issues and crackdowns on illegal mining.

Tin prices, 2024-2026



Note: LME tin 99.85% cash prices.
Source: IEA analysis based on data from Bloomberg.

The largest tin mining country is China (24%), followed by Indonesia (21%) and Peru (11%). China is also the largest tin refining country, accounting for about 50% of global supply. Recent data indicate that refined tin supply is recovering from the supply disruptions in 2025, as reflected in rising inventory levels. While this is helping to ease market tightness, strong underlying demand is expected to keep prices above historical norms.

More than half of global tin consumption is used as solder for bonding circuit boards. Beyond traditional uses in consumer electronics, demand for tin is expanding in strategic applications such as AI and EVs. Tin also plays a crucial role in solar PV through soldering and electrical interconnections.

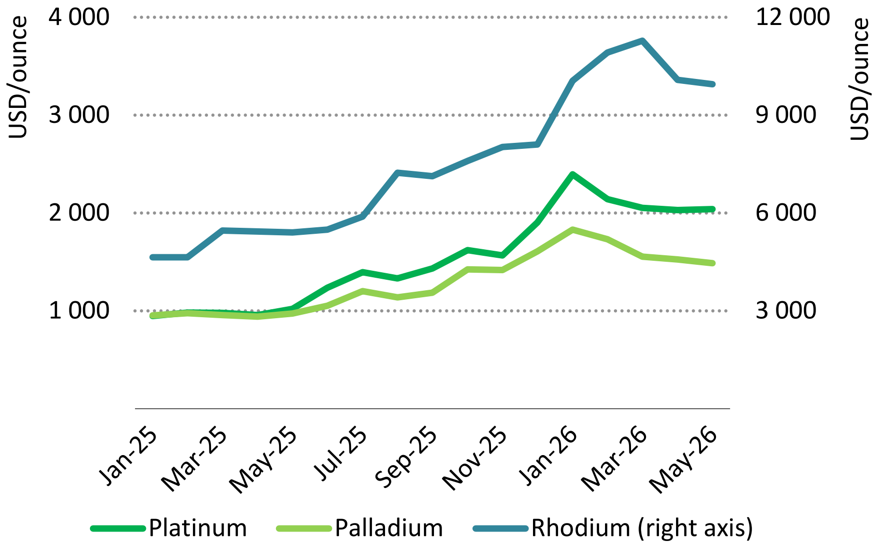
Historically, tin-lead solder was widely used, but lead-free solders are now more common due to environmental regulations such as the EU Restriction of Hazardous Substances Directive. Currently, tin-silver-copper solder is the most prevalent type, where tin provides strong wettability, conductivity and reliable connections.

Tin is not easy to substitute, although epoxy resins could partially replace it in certain applications. Like copper, tin is a highly recyclable material that can be reused without loss of quality. In 2023, recycled tin accounted for about one-third of total tin supply.

Platinum group metals: Prices have strengthened again due to constrained mine supply and improving demand prospects

The six platinum group metals (PGMs) – platinum, palladium, rhodium, ruthenium, iridium and osmium – are highly geographically concentrated in production. South Africa accounted for around 70% of global mined platinum supply in 2025, followed by Russia at 12%. For palladium, Russia is the leading mined output supplier at around 45%, followed by South Africa. Zimbabwe and North America also produce PGMs, but at smaller shares.

Price trend for key platinum group metals (monthly average)



Sources: IEA analysis based on data from Bloomberg and Johnson Matthey.

PGM markets experienced renewed price strength in 2025 and early 2026. Platinum prices doubled throughout 2025 and reached an all-time high in January 2026. Palladium prices rose by around 90% year-on-year in January 2026. Rhodium prices also soared, reaching USD 11 000 per ounce in March 2026, their highest level since 2023. These price developments were driven by a combination of constrained mine supply and improving demand prospects.

Mined PGM output declined in 2025 across key producing regions, reflecting persistent structural challenges. In South Africa, production was affected by rising production costs and electricity supply constraints. For example, ore mining and milling operations at the Bokoni platinum mine were suspended in June 2025 due to cost pressures. PGM output in Russia also edged lower compared with 2024, reflecting declining ore grades, equipment replacement and maintenance at Norilsk Nickel facilities. Secondary supply from recycling registered strong growth in 2025, increasing by about 17% year-on-year. In China, continued incentive schemes to encourage the scrappage of older vehicles have increased volumes of end-of-life autocatalyst scrap, contributing to recycling growth. However, this growth only partially offset primary supply constraints.

At the same time, continued demand growth from the automotive sector supported consumption. Broader macroeconomic uncertainty and geopolitical tensions also boosted investor interest in precious metals, contributing to increased price volatility.

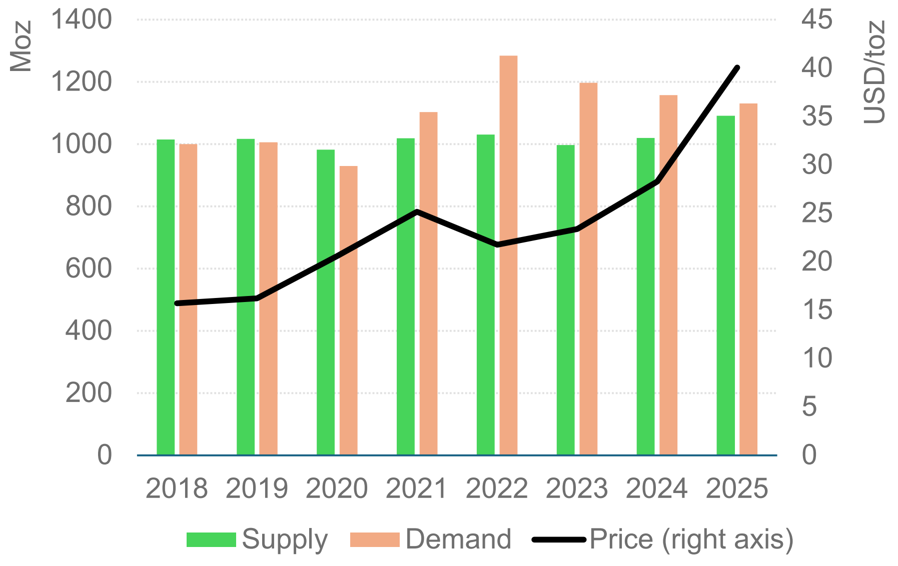
In the near term, PGM markets are expected to remain relatively tight. Mine supply is expected to decline, reflecting persistent cost pressures, operational challenges and limited new production growth. The expansion of commercial operations at Ivanhoe’s Platreef mine and stable supply from Implats’ PGM operations are expected to support production volumes, while Russia is projected to see a slight decline in output due to changes in the metal composition of processed feedstocks. While recycling supply is expected to continue increasing, it is unlikely to fully offset constraints in primary production. Demand from autocatalysts is expected come under pressure from the growth of EVs, although continued sales of internal combustion engine and hybrid vehicles, are expected to support PGM consumption in the near term.

Silver: Strong industrial demand and persistent supply constraints are set to support elevated prices despite a narrowing supply deficit

Silver prices increased sharply in 2025, rising from around USD 29 per troy ounce (toz) to approximately USD 72/toz, an annual increase of about 150%. Prices continued to rise into 2026, with spot prices briefly surpassing USD 100/toz for the first time in January 2026. These price increases were driven by accumulated multi-year supply deficits and a strong industrial demand outlook. In particular, expectations of rising industrial silver demand from the expansion of solar PV, growing investment in AI and data centres, and power grid upgrades provided support to prices. The pace of supply growth also remained limited, reflecting the nature of silver production as a by-product of copper, gold, lead and zinc mining, as well as declining ore grades, delays in new project development and tighter environmental and permitting regulations. Uncertainty surrounding US tariff reviews and expectations for Federal Reserve policy also contributed to heightened market volatility.

Silver supply increased to around 1.1 billion toz in 2025, supported by recovering production in South America and growth in recycled supply. Global mine production rose by 3% year-on-year. Higher by-product output from Peru's Antamina mine and expanded production at Russia's Prognoz mine contributed to supply growth. By contrast, production in Mexico, the world's largest silver producer, declined partly due to lower ore grades at the Peñasquito mine, while Indonesia experienced production disruptions at the Grasberg mine. Recycled silver supply also increased strongly, reaching around 200 million ounces, its highest level in more than a decade, supported by increased scrap recovery amid higher silver prices.

Silver market balance and price trends, 2018-2025



Notes: Moz = million ounces; toz = troy ounce.
Source: IEA analysis based on data from the Silver Institute (2026).

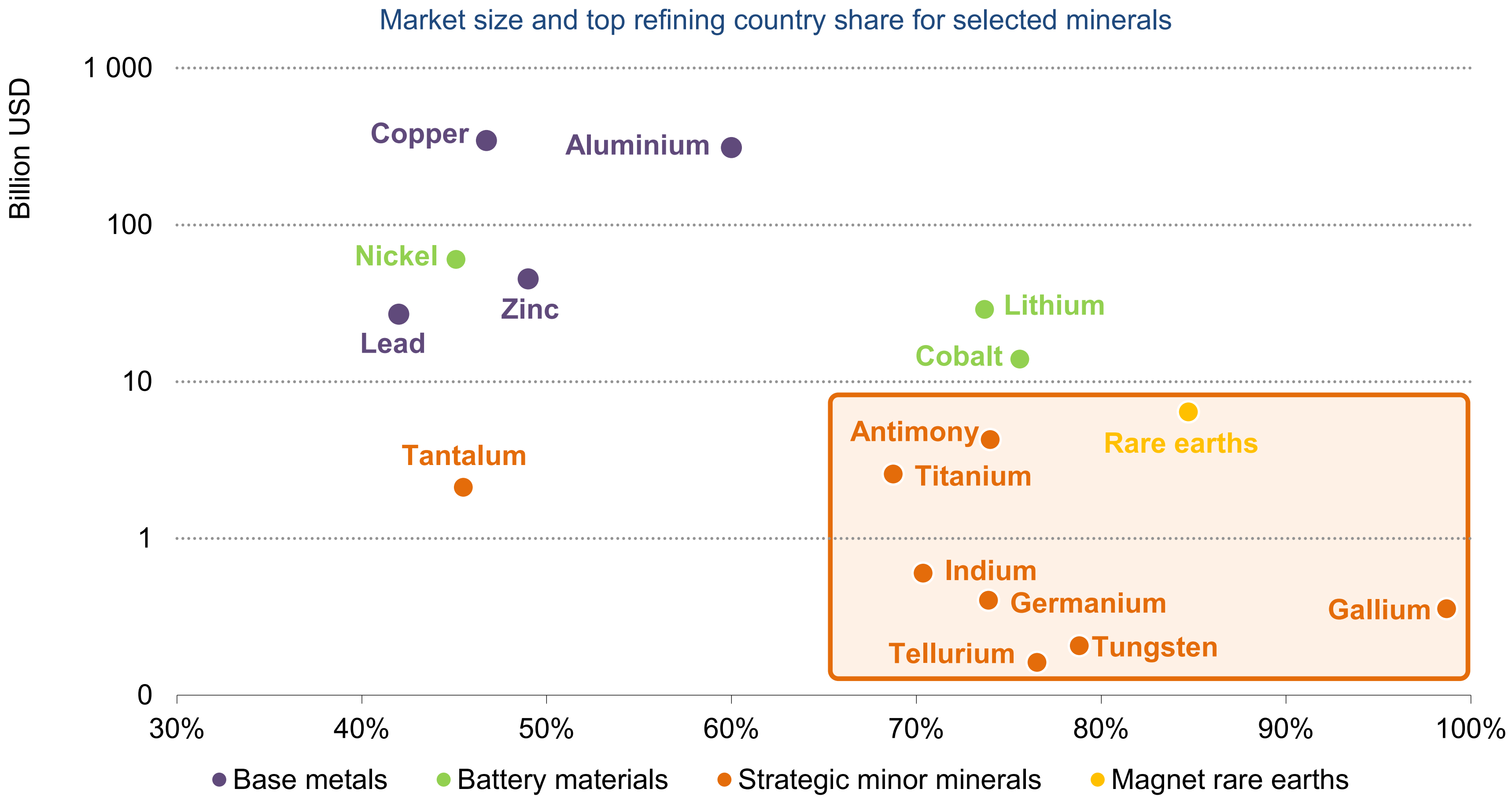
Meanwhile, silver demand fell by 2% in 2025, marking its lowest level since 2021. Industrial demand declined for the first time after four consecutive years of growth. In particular, weaker demand from the solar PV sector was a key factor behind the broader slowdown in silver demand growth. Although global solar installations continued to expand, reductions in silver usage per cell partially offset the impact of installation growth. This reflected manufacturers' efforts to reduce silver usage (thrifting) and adopt alternative materials in response to higher silver prices.

However, expanding investment in AI and data centres, together with the expansion of EVs, charging infrastructure and power grid upgrades, is set to support resilient silver demand in the coming years. Owing to its high electrical conductivity and durability, silver is widely used in semiconductors, servers, power electronics, EVs and energy infrastructure. By contrast, supply constraints are likely to persist, keeping market conditions relatively tight in the near term.

2. Outlook for key minerals Part 2

Strategic minor minerals

Strategic minor minerals: small market sizes, high supply concentration, outsized economic impacts



Notes: Titanium refers to titanium metal. Rare earths refer to magnet rare earths only.

Despite their high supply concentration, strategic minor minerals offer an area where targeted policy measures can deliver rapid improvements in supply security

Beyond key energy minerals, there is a strong case for greater policy attention on a broader group of materials that play a vital role across strategic sectors such as high-tech, aerospace and defence. These materials, referred to here as "strategic minor minerals", typically have small market sizes but face extremely high levels of supply concentration compared with other minerals. They also carry disproportionate economic consequences in the event of a disruption.

Rare earths are a prominent example, but the list extends beyond them to include antimony, gallium, germanium, indium, titanium and tungsten, among others. The market size for many of these minerals is often below USD 10 billion. Like rare earths, China is the leading supplier of almost all these minerals, and a growing number are becoming subject to export controls or other trade restrictions. Given their limited substitutability and vital role in advanced manufacturing, disruptions could have significant economic consequences across the automotive, high-tech, defence and energy sectors.

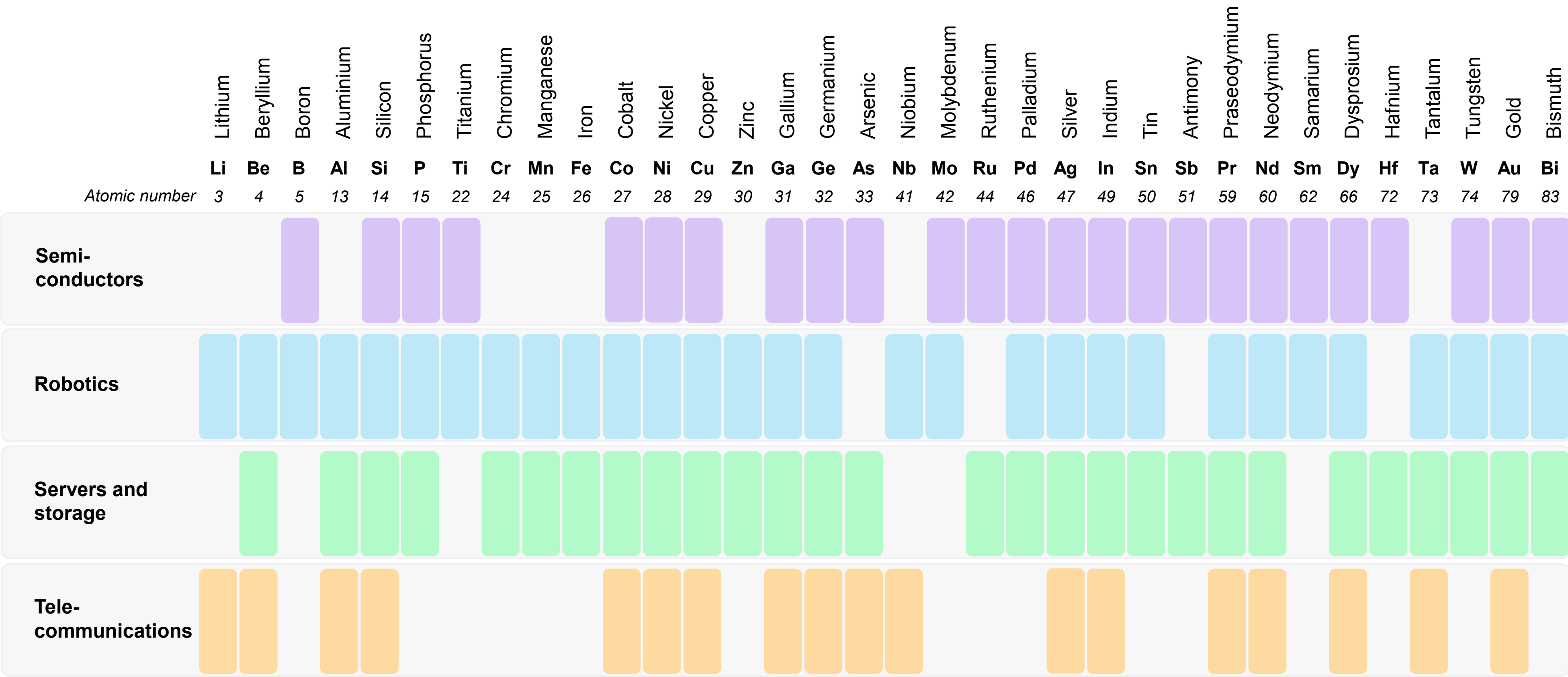
However, counter-intuitively, these minerals offer one of the most promising opportunities to deliver visible improvements in supply security at a reasonable cost, if accompanied by strong policy support. Many strategic minor minerals do not require the massive scale of investment typically needed for bulk commodities. In some cases, bringing a small number of key projects online could materially strengthen supply security and improve diversification. For example, the planned refinery by Korea Zinc, with annual production capacity of 54 tonnes of germanium and 44 tonnes of gallium, has the potential to double diversified germanium supply and increase diversified gallium supply fivefold.

In many instances, this can be achieved without developing new mines. A large share of these minerals are produced as co-products, recovered as secondary outputs during the extraction or processing of primary commodities such as aluminium, copper, zinc and lead. Gallium, for example, is contained in small quantities in bauxite and zinc ores. Typically, less than 10% of the gallium contained in mined ores is recovered. Substantially higher global supply outside the dominant refiner would be possible if gallium were recovered more systematically. This creates a clear opportunity for governments to improve supply security at relatively modest cost through targeted support for recovery, refining and processing capacity.

In this section, we explore the broad landscape of strategic minor minerals, focusing on the key materials used in the high-tech, aerospace and defence sectors and assessing their risk profiles. The IEA plans to publish deeper analysis on these minerals in the coming months, examining their market dynamics, risk exposure and diversification potential.

A wide range of critical metals and minerals form the backbone of many strategic high-tech industries, such as semiconductors, robotics, servers and telecommunications

Indicative list of strategic minerals used across selected high-tech industries



Note: Materials only serving secondary or tertiary applications in one sector were excluded from the chart: semiconductors (cadmium, cerium, chlorine, europium, fluorine, gadolinium, helium, krypton, lanthanum, neon, nitrogen, tellurium, xenon and yttrium); robotics (terbium); and servers and storage (barium and platinum).

As semiconductors, robotics and artificial intelligence chart new frontiers in innovation, supply security for the minerals that underpin them is becoming increasingly important

Modern economies are increasingly moving towards electrified, digitalised and automated systems, and the industries that underpin this transformation are mineral-intensive. This section explores some strategic high-tech industries and assesses which minerals are most critical for them.

Semiconductors

The semiconductor industry relies on a wide range of metals and minerals. The main materials that form the semiconducting layers include silicon, gallium, germanium, indium, arsenic, phosphorus and boron, while other materials such as antimony, tantalum, tungsten, copper, gold, silver, aluminium, nickel, cobalt, palladium, platinum, hafnium, titanium, certain rare earth elements, tin and zinc play important roles in soldering, electrical contact formation, coating and packaging. Among these, silicon is by far the most important, forming the substrate of most integrated circuits. Compound semiconductors such as gallium arsenide (GaAs) and gallium nitride (GaN) have taken on increasingly important roles for high-frequency, optoelectronic and power applications, where GaN, in particular, enables more efficient operation at high voltages and temperatures, making it a critical material for data centre power management. Germanium improves transistor performance in advanced chips. Copper and aluminium are essential for electrical interconnections, and gold, silver and palladium are widely used in contacts and bonding due to their excellent conductivity and resistance to corrosion. Tantalum and hafnium are critical for capacitors and advanced transistor gate materials, helping to improve device efficiency and miniaturisation.

Robotics

As the robotics industry combines several technologies, including actuators, sensors, motors, batteries and electronic systems, it relies on a very large number of materials. The main materials used include steel, aluminium, copper, nickel, cobalt, lithium, manganese, graphite, magnet rare earths (neodymium, praseodymium, dysprosium and terbium), silicon, gold, silver, tantalum, tungsten, titanium, platinum group metals and tin. Among these, bulk materials such as steel and aluminium are important structural components, providing the strength, durability and weight characteristics required for robotic systems. Copper is essential for motors, wiring and power transmission, while lithium, nickel, cobalt and manganese play key roles in rechargeable batteries for mobile and autonomous robots. Silicon underpins the semiconductors that enable sensing, control and AI functions, while gold, silver and tantalum are widely used in electronic components due to their superior conductivity and reliability. Rare earth-based permanent magnets are particularly important because they enable compact, lightweight and energy-efficient motors with high torque and precision. While some materials can be substituted in specific applications, replacing the most critical materials – particularly rare earth elements in high-performance magnets and copper in electrical systems – often results in lower performance, larger component sizes, reduced energy efficiency or higher costs.

Servers and data storage

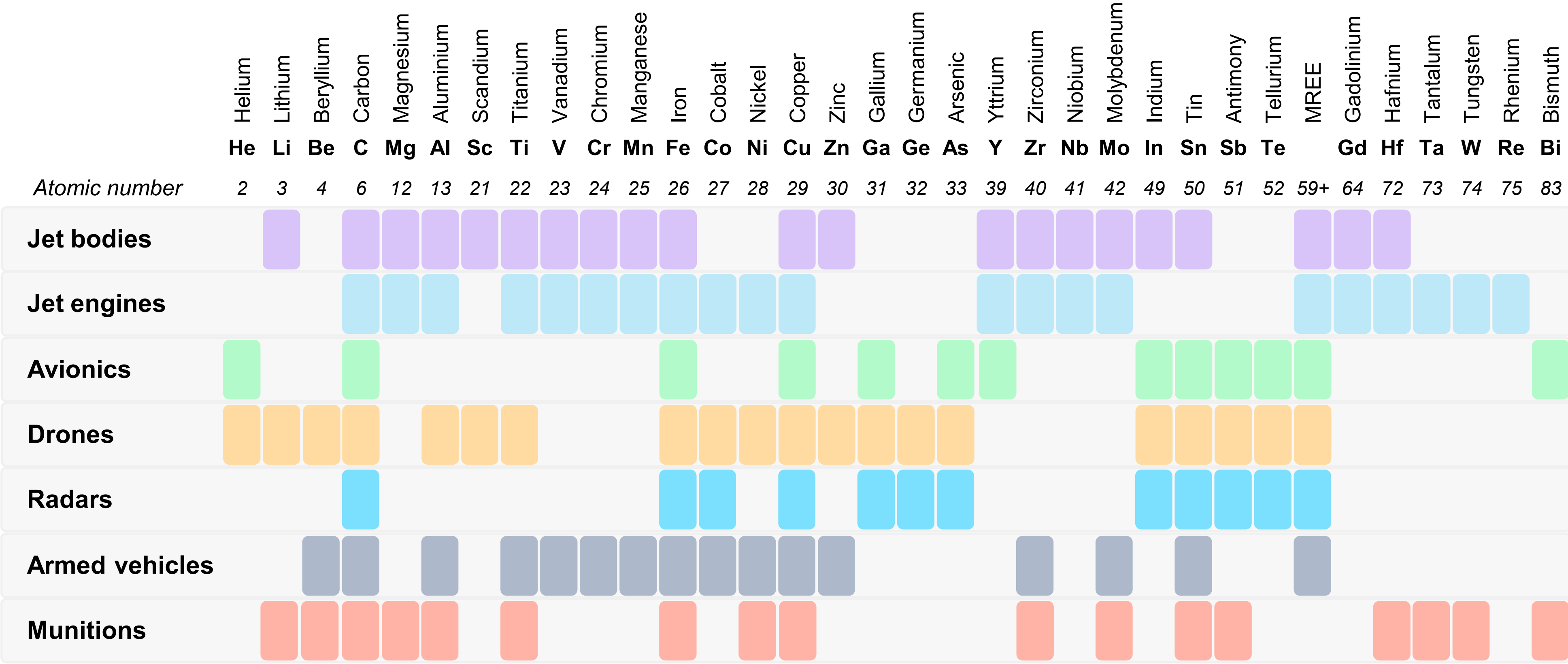
Servers and data storage systems depend on metals and minerals for processors, memory, storage devices, power systems and networking equipment. The main materials include silicon, copper, aluminium, iron and steel, gold, silver, palladium, tantalum, tungsten, nickel, cobalt, tin, gallium, germanium, indium, hafnium, titanium, platinum group metals, graphite and certain rare earth elements such as neodymium, dysprosium and yttrium. Among these, silicon is the most important material, forming the basis of processors, memory chips and other integrated circuits. Copper is essential for electrical interconnections, power distribution and networking infrastructure, while aluminium and steel provide structural support for servers and data centre equipment. Gold, silver and palladium are widely used in connectors and contacts because of their conductivity and resistance to corrosion, and tantalum, tungsten and hafnium are critical for advanced semiconductor components.

Telecommunications

Telecommunications networks, including 5G infrastructure, require materials for semiconductors, antennas, fibre-optic systems, power equipment and network hardware. The main materials include silicon, copper, aluminium, gallium, germanium, indium, arsenic, tantalum, gold, silver, nickel, cobalt and certain rare earth elements such as neodymium, praseodymium and dysprosium. Among these, silicon forms the basis of the semiconductors used in network equipment, base stations and communication devices. Copper is essential for electrical wiring, power distribution and telecommunications cables, while gallium-based compounds, particularly GaN and GaAs, are critical for the high-frequency and high-power performance required by modern 5G networks. Rare earth elements are used in magnets, signal processing equipment and specialised electronic components, while gold and silver provide reliable electrical contacts and connections.

A range of materials are critical to the aerospace and defence sectors, with major applications including aircraft components, jet engines, drones, radars, armed vehicles and munitions

Indicative list of strategic minerals used across aerospace and defence applications



Note: MREE = magnet rare earth elements.

The aerospace and defence sectors rely on critical minerals for specific high-performance requirements

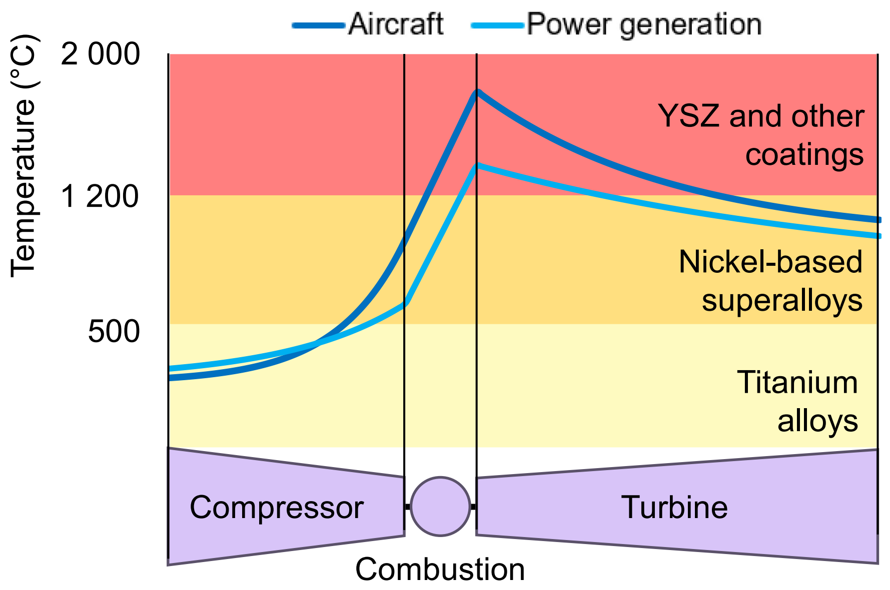
A wide range of materials are critical to the aerospace and defence sectors. These are used typically as high-performance materials with high strength and resistance to high temperatures, in energy applications in the sector, as well as in radars and sensors.

Aerospace

In aerospace and defence, aluminium and titanium alloys are key structural materials, along with steel and composites. For example, aluminium-copper alloys are used in aircraft fuselages and aluminium-zinc alloys in upper-wing skins, stringers and stabilisers, both of which are sometimes replaced by aluminium-lithium alloys to achieve weight reductions. Titanium alloys are used for parts requiring a high strength-to-weight ratio, such as landing gear assemblies, or moderate temperature resistance. These materials also play a key role in gas turbines, which are used both as aircraft engines and to produce electricity in gas-fired power plants.

The main elements of gas turbines are the compressor, the combustion chamber and the turbine. The temperature profile in these sections is key for selecting materials: in the compressor, temperatures increase to around 500 °C, a range that is too high for aluminium but below the range requiring superalloys, and in which titanium-based alloys can be used.

Temperature profile and materials used in turbine engine stages



Note: YSZ = yttria-stabilised zirconia.

In the combustion chamber, however, much higher temperatures are reached, as higher turbine inlet temperatures directly influence the efficiency of the machine, and are typically between 1 250 °C and 1 800 °C. To withstand these extreme temperatures, nickel- and cobalt-based superalloys are used up to around 1 200 °C, after which ceramics and thermal barrier coatings become necessary. Typical coating materials include yttria-stabilised zirconia or other rare earth zirconates such as gadolinium zirconate, nickel-chromium-aluminium-yttrium alloys, advanced multilayer ceramic coating systems and platinum group metals.

Various other elements, such as hafnium, rhenium, tungsten, molybdenum, vanadium and zirconium, are also used to enhance the high-temperature strength, creep resistance, and oxidation resistance of superalloys in aircraft and gas turbines. Rhenium is particularly important for turbine blades operating at high temperatures. Around 80% of global rhenium demand is for superalloys, particularly for turbine blade applications.

Defence

An important set of critical minerals for the defence sector overlaps to some extent with energy applications. Lithium-ion batteries are widely used in aircraft and unmanned aerial and ground vehicles (UAV and UGV), as well as in guided munition systems and onboard equipment for armed vehicles. Magnet rare earth elements are key in defence applications for motors and actuators in aircraft, unmanned systems, missiles and smart munitions, naval propulsion and ground vehicles. Nuclear propulsion also contributes a distinct application, with naval reactors in submarines and aircraft carriers requiring enriched uranium fuel, typically at higher enrichment levels than in the civilian sector and designed for long operational lifetimes.

Military jets use materials similar to those used in civilian aircraft, but in different proportions. Titanium is typically used in higher shares (around one-third of total weight in some advanced military aircraft, compared with around 10-15% in passenger planes), due to its higher tolerance to damage, corrosion resistance and low weight, with lower shares of aluminium (often around 10-20%, compared with higher in commercial aircraft).

Radar-absorbing materials are used in defence to achieve stealth properties. These can be magnetic materials such as nickel-zinc and manganese-zinc ferrites, which are heavy but effective. Lighter carbon-based materials include carbon fibre composites, nanotubes and graphite, making graphite a critical mineral for these applications. Polymers and ceramics are also used where mechanical strength, light weight and thermal resistance are needed.

There is a wide intersection between the minerals used for high-tech applications and defence. In most cases, these minerals, whose demand is mostly driven by their civilian uses, remain critical to defence contexts, in which they are rarely substitutable. Radars, infra-red detectors and night vision equipment rely on high-tech materials. Gallium arsenide is used in high-frequency radio-frequency chips and gallium nitride in high-power radar modules. Indium gallium arsenide is used for short-wave infra-red detectors, while modern-generation night vision uses gallium arsenide in photocathodes. Germanium is key for infra-red optical lens materials and fibre optics. Indium antimonide is typically used for mid-wave infra-red detectors, which capture thermal images for night vision. Tellurium-based semiconductors are also key for infra-red equipment. Electronic equipment relies on silicon as a base semiconductor material and copper for wiring.

Munitions and missiles use critical minerals and materials for structural elements, guidance systems, thermal stability and mechanical strength. Aluminium is used in structures for propellant tanks and casings, where it can be replaced by titanium or carbon fibre when high strength, light weight, thermal resistance or a specific fragmentation pattern is needed, and also as a solid propellant in the form of powdered aluminium. Carbon-based composites derived from graphite are used as heat shields and re-entry systems, thanks to their thermal stability and mechanical strength. Tungsten is fundamental for kinetic energy penetrators and fragmentation applications, primarily because its exceptionally high density and hardness enable effective penetration of hardened targets at high speed. Bismuth is part of the binder in explosive mixtures and is used as a non-toxic substitute for lead in bullets and shot, driven by environmental regulations and the phase-out of lead-based ammunition in several North Atlantic Treaty Organization (NATO) countries.

Minerals are essential enablers of high-tech, aerospace and defence technologies

Key critical minerals in the high-tech, aerospace and defence sectors

High-tech industries	
Semiconductors and telecommunications	Gallium
	Silicon
	Germanium
	Silver
	Arsenic
	Indium
	Tungsten
Robotics and servers	Antimony
	Bismuth
	Magnet rare earths
	Beryllium
	Tin
	Tantalum
	Cobalt

Aerospace and defence	
Superalloys	Cobalt
	Nickel
	Niobium
	Rhenium
	Vanadium
Light weight	Graphite
	Titanium
High-performance	Magnet rare earths
	Molybdenum
	Tungsten
	Yttrium
Sensors	Antimony
	Germanium
	Tellurium

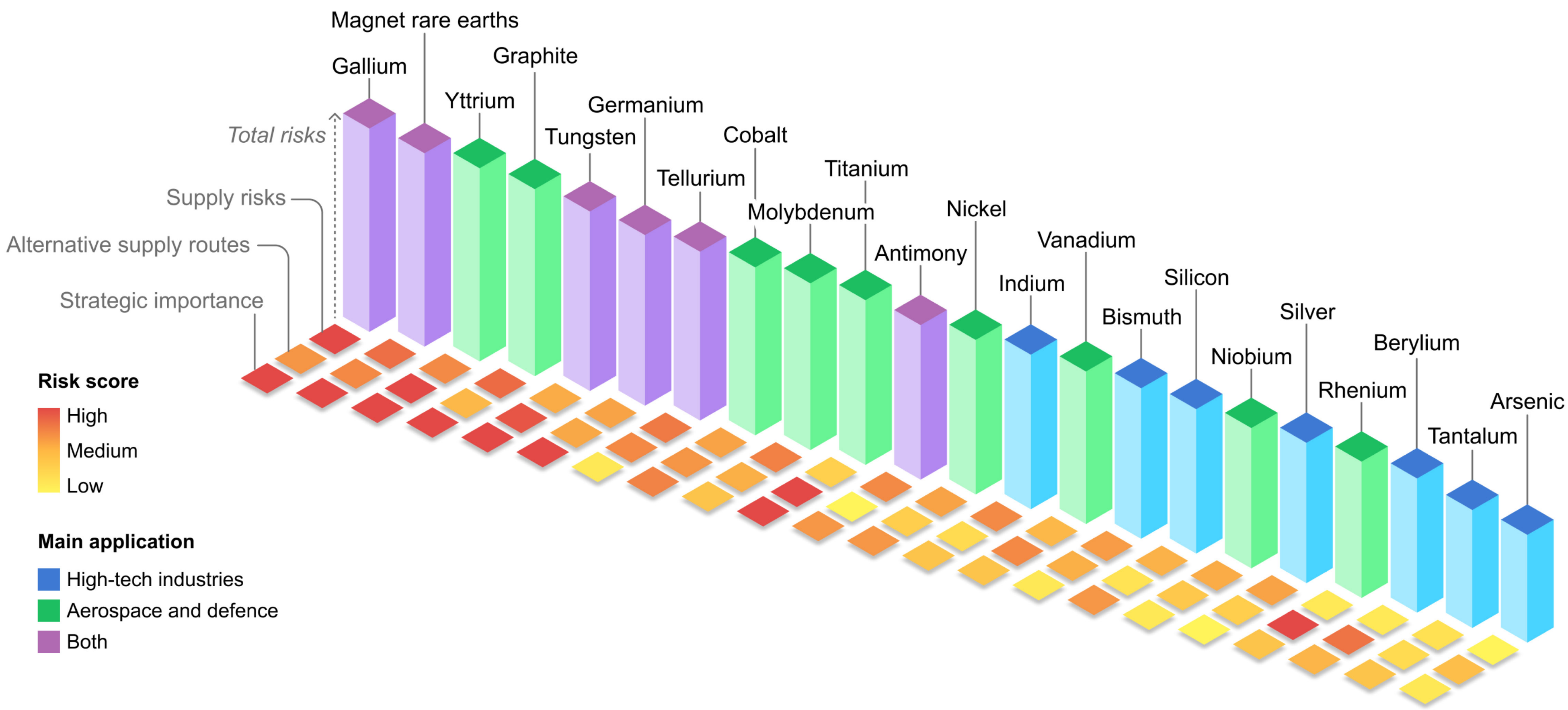
The risk assessment considers a range of factors, including supply risk, the availability of alternative supply sources and strategic importance

Risk assessment framework

Dimension	Indicator	Metric
Supply risk	Concentration (refining)	Share of top 1 supplier
	Concentration (mining)	Share of top 1 supplier
	Price volatility	Price standard deviation since 2014
	Export restriction	Existence of active restriction on any form of the material
	Supply-demand balance	Projected market tightness in 2030
Alternative supply routes	Number of suppliers	Number of producers accounting for at least 5% of supply
	Ease of substitution	Assessment of substitutability in strategic applications
	By-product dependence	Share of production relying on by-products
	Price transparency	Existence of price indexes
Strategic importance	National security	Presence of the material in strategic materials lists
	Strategic applications	Number of strategic applications relying on the material

Many strategic materials essential to high-tech, aerospace and defence applications face elevated supply risks

Risk assessment results



Gallium, magnet rare earths, yttrium, graphite, tungsten, cobalt and germanium exhibit some of the highest levels of supply risk

Risk assessment methodology

To assess the risk exposure of materials essential for high-tech, aerospace and defence applications, we developed a framework based on key criteria, including supply risk, the availability of alternative supply routes and strategic importance. This allows materials to be ranked according to their overall exposure across multiple dimensions of risk.

When evaluating supply risk, the first risk dimension, the level of supply concentration in both mining and refining, is a critical measure. Relying on a few dominant suppliers means that any disruption can quickly push markets into shortfall. For gallium, graphite, manganese and rare earths, the top refiner, China, accounts for over 90% of global supply. High price volatility further complicates the development of new supply: for example, lithium, vanadium, rare earths and cobalt have exhibited significantly higher volatility than oil and gas. Many high-risk minerals are already affected by some form of export restriction, such as rare earths, gallium, and tungsten, straining their supply chains.

The availability of alternative supply routes is the second key risk dimension. For some materials, there are limited options for substitute materials, such as chromium for corrosion-resistant stainless steel, titanium for alloys requiring a high strength-to-weight ratio and germanium for high-performance fibre optics, heightening the risks from supply disruptions. Additionally, many materials are produced as co-products or by-products (see Annex) alongside other minerals, making their supply less responsive to demand or price signals. For example, gallium is mainly recovered as a by-product of zinc and aluminium production, tellurium from copper and lead processing, and germanium from zinc and coal.

The strategic importance of each material depends on the sectors in which it is used. When materials have applications in strategic sectors such as semiconductors or defence, their security of supply becomes a crucial factor for economic and national security. While strategic importance can be assessed at the global level, each country should also consider domestic vulnerabilities and dependencies to assess the potential impact on its overall security and resilience.

Risk assessment results

The results of the risk assessment show that some of the highest-risk materials include gallium, magnet rare earths, yttrium, graphite, tungsten, germanium, tellurium and cobalt. Most of these materials are characterised by high supply concentration, limited availability of substitutes and strategic applications, and many are already subject to some form of export restriction. Several of them, such as gallium, magnet rare earths, graphite, cobalt and germanium, play essential roles across a wide range of strategic applications.

Many high-tech materials are characterised by high exposure to supply risks, including high supply concentration and dependence on by-product supply, as well as limited substitution options. These minerals, such as gallium, magnet rare earths, cobalt, germanium, nickel, indium and silicon, are widely used across multiple technology domains, underscoring their systemic importance and creating strong cross-sector dependencies. Many of these minerals' markets are also relatively small-scale, making their supply more vulnerable to disruption and market volatility. At the same time, the parallel expansion of these sectors, driven by rapid growth in electrification, automation and AI-related technologies, would simultaneously increase competition between sectors, leading to additional pressure on supply chains and an increased risk of market tightness and imbalances.

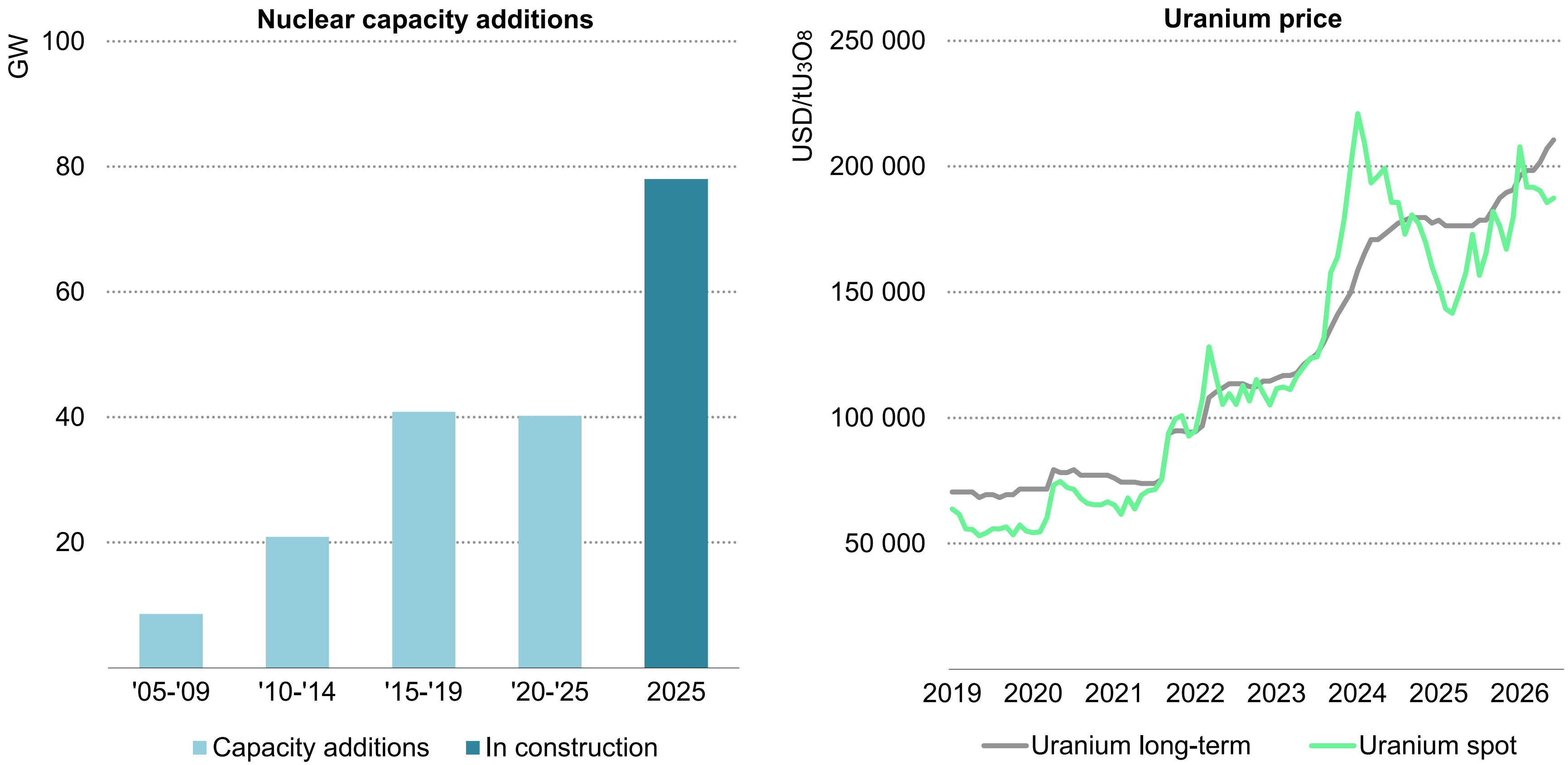
Inherently, most materials critical for the aerospace and defence sectors have high strategic importance given the national security implications. Beyond this, many are already subject to export restrictions targeting military applications through "dual-use" designations, are highly concentrated in supply and are very challenging to substitute, making them high-risk materials. Given the challenging operating temperatures and conditions, the range of materials that are critical for these sectors is wide. The highest-risk materials for the aerospace and defence sector can be split into four broad categories of primary applications: high-performance materials, lightweight materials, superalloys and sensors. Most of the key materials used in high-performance applications are challenging to substitute and already subject to export restrictions, including yttrium, tungsten, magnet rare earths and lithium. Superalloy applications also present high risk, particularly where they are challenging to substitute and have by-product dependencies, such as vanadium and cobalt. Lithium and graphite are critical for defence, as they are used in batteries needed for drones and portable electronics for soldiers' equipment. There are also some materials that have key lightweight applications, in particular titanium, which is highly difficult to substitute. Finally, many high-tech materials are also key for aerospace and defence, including gallium, germanium, tellurium and antimony, which are utilised in radar and sensing applications.

2. Outlook for key minerals Part 3

Nuclear supply chains

Nuclear power is making a strong comeback, with uranium prices rising and reactor capacity additions reaching record highs

Total nuclear capacity additions and capacity under construction (left) and uranium price development (right)



Notes: tU_3O_8 = tonne of triuranium octoxide. Capacity is reported on a gross basis and shown as annual average additions for each period.
Sources: IEA analysis based on data from the International Atomic Energy Agency's PRIS database (2026), and UxC and TradeTech for uranium prices (2026).

Strong growth in nuclear capacity requires a new wave of uranium supply

Nuclear capacity currently under construction, at around 78 GW, is at its highest level in 30 years. Nuclear power has entered a renewed phase of expansion in recent years, marking a clear shift from the stagnation observed in the early 2000s. Global installed nuclear capacity has increased steadily, reaching close to 420 GW by 2025, compared with around 390 GW in the early 2000s. China has been the main driver of this growth, adding close to 35 GW since 2015 and bringing its total fleet to nearly 65 GW by 2025, while India, Korea, Türkiye and the United Kingdom have also continued to expand capacity.

In parallel, tightening uranium market conditions reflect changing demand expectations, renewed contracting activity and dwindling secondary supply. After several years of subdued prices, uranium markets strengthened significantly from 2020 onwards, with spot prices of uranium concentrate rising from around USD 60 per kg of oxide content to peaks above USD 200 per kg of oxide content in 2024, before moderating in 2025.

Looking ahead, in the STEPS, global nuclear generation doubles by 2050 while maintaining a relatively stable share of close to 10% of total electricity generation. Installed capacity rises from close to 420 GW in 2025 to nearly 800 GW by 2050, with even higher levels in the HDS. This expansion reflects sustained policy support across an increasing number of countries, driven by energy security considerations and decarbonisation objectives.

China is set to have the world's largest nuclear fleet in the early 2030s, accounting for roughly one-third of global capacity additions through 2050, with its fleet expanding by more than 2.5 times over the next decade. The United States also sees renewed growth, increasing from around 100 GW in 2025 to about 140 GW in 2040, supported by both reactor life extensions and new builds. Shares of nuclear in power generation also rise in India, Japan, Korea and Russia, while remaining stable in Brazil and the United Arab Emirates. At the same time, deployment is expanding into a broader set of emerging markets beyond traditional markets, including Türkiye, but also Bangladesh, Egypt, Kazakhstan, Poland, Uzbekistan and Viet Nam. This widespread expansion points to sustained growth in nuclear fuel requirements and the need for significant capacity additions across uranium supply chains.

Nuclear fuel types vary depending on the reactor and technology design

Selected nuclear fuel characteristics

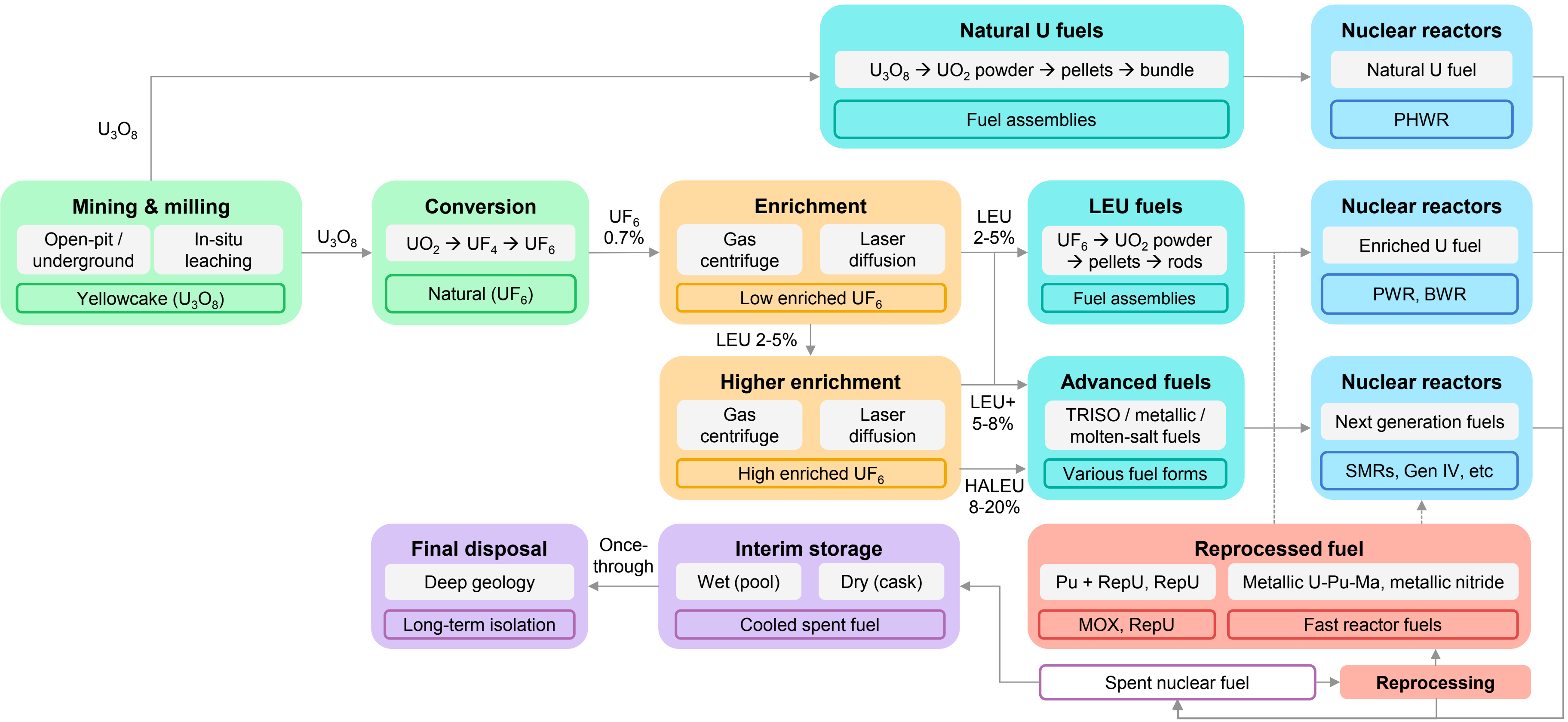
Type	Lattice	Associated reactors	Current reactor share
Existing fuels			
Natural uranium	Cylindrical	Pressurised heavy water reactor (PHWR)	7%
Low-enriched uranium (LEU, 2% to 5%)	Square	Pressurised water reactor (PWR)	62%
		Boiling water reactor (BWR)	13%
		Light water graphite reactor (LWGR)	2%
	Cylindrical	Gas-cooled reactor	1%
	Hexagonal	VVER (ex-Soviet designed PWR)	14%
Emerging fuels			
Low-enriched uranium plus (LEU+, 5% to 8%) or High-assay low-enriched uranium (HALEU, 8% to 20%)	Square or hexagonal	PWR, VVER, BWR	Next-generation
	Pebble or prismatic	Sodium-cooled fast reactor	Next-generation
		Lead-cooled fast reactor	
		High-temperature gas-cooled reactor	
	Circulating liquid molten salt	Molten salt reactor	Next-generation
Secondary fuels			
Mixed oxide fuel (MOX, 2% to 5%) or Reprocessed uranium (RepU, 2% to 5%)		PWR, fast breeder reactor	Marginal
		PWR, LWGR	Marginal

Notes: Natural uranium demand includes reactors with fuel enriched below 2%. MOX combines recycled uranium and plutonium.

Sources: IEA analysis based on data from the International Atomic Energy Agency's PRIS database (2026); World Nuclear Association (2025), World Nuclear Power Reactors and Uranium Requirements.

The emergence of advanced nuclear reactors is diversifying the nuclear fuel cycle

Illustrative nuclear fuel cycle value chain

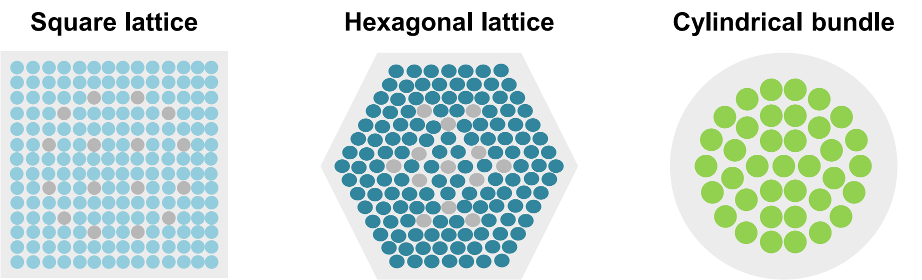


Notes: BWR = boiling water reactor; HALEU = high-assay low-enriched uranium (8-20%); LEU = low-enriched uranium (2-5%); LEU+ = low-enriched uranium plus (5-8%); MOX = mixed oxide fuel; PHWR = pressurised heavy water reactor; Pu = plutonium; PUREX = plutonium uranium reduction extraction; PWR = pressurised water reactor; RepU = reprocessed uranium; SMR = small modular reactor; TRISO = tri-structural isotropic; U = uranium; U_3O_8 = triuranium octoxide; UF_4 = uranium tetrafluoride; UF_6 = uranium hexafluoride; UO_2 = uranium dioxide. This figure illustrates a simplified, generalised flowsheet and does not capture the full complexity of real-world circuits, which frequently require customisation for specific mined ores, enrichment needs, and nuclear fuel requirements.

What types of fuels and uranium requirements are associated with different reactor types?

Nuclear power generation is currently dominated by light water reactors, notably pressurised water reactors and boiling water reactors, which account for close to 90% of global capacity and rely on low-enriched uranium (LEU), typically enriched to 2-5% uranium-235. Some reactor types, such as Russian water-water energetic reactors (VVERs), require specific fuel assembly designs, limiting substitutability across suppliers (see section below on supply concentration).

Lattice structure of selected nuclear fuels



Note: The figure illustrates simplified fuel rod designs used in reactor cores and does not capture the full complexity of customised and real-world fuels.

Pressurised heavy water reactors (PHWRs), deployed in Argentina, Canada, India, and Romania and accounting globally for a 7% market share in 2025, consume specific fuel types containing natural uranium (around 0.7% uranium-235) that do not require enrichment. New advanced PHWRs, such as those under construction in India, can require slightly enriched uranium of up to 1.1% to achieve improved burnup.

Growing role of small modular reactors

Large-scale reactors continue to dominate new nuclear deployment, but momentum behind small modular reactors (SMRs) is building. China already operates a land-based SMR and has an additional 125 MW commercial SMR under construction, while Russia operates a marine-based SMR and is building a further 300 MW unit. Additional SMR projects are planned or being developed in Argentina, Canada, Korea, Sweden, the United Kingdom and the United States, necessitating reactor manufacturing and fuel services. In the STEPS, SMRs grow from the early 2030s, reaching close to 40 GW by 2050, or around 5% of total capacity.

SMRs include both small-scale pressurised water reactors and a range of advanced designs using alternative fuels. Many of the projects under development are expected to rely on low-enriched uranium plus (LEU+), enriched to between 5% and 8%, or high-assay low-enriched uranium (HALEU), enriched up to 20%, enabling higher burnup and longer operating cycles. In some cases, specific fuel geometries may be required, as opposed to the more conventional square lattice pellets used in current light water reactors, such as tri-structural isotropic particles. Enrichment specifications vary accordingly.

Alongside the expanding global nuclear fleet, uranium requirements are set to increase strongly, with new fuel types needed for emerging next-generation fleets

Mining

Annual uranium demand is close to 70 kilotonnes of natural uranium equivalent (ktU) today, and this is set to increase strongly as global nuclear generation expands. While uranium requirements generally increase with nuclear generation, improvements in fuel utilisation and reactor performance may reduce uranium demand per unit of electricity generated.

40% of this growth is concentrated in China and 20% in other emerging markets, including in India, the Middle East and Africa as new programmes mature. Demand in the European Union is expected to grow moderately.

Enrichment

Global enrichment requirements are close to 49 million separative work units (SWU) today and are set to rise significantly. The emergence of LEU+ and HALEU and the broader shift towards higher enrichment levels introduce additional requirements beyond the current supply chain configuration, including industrial facilities and specific cascade technologies. For a given amount of fuel, higher enrichment grades imply greater requirements for mined uranium and enrichment work units, making the front end of the nuclear fuel cycle more resource-intensive and reinforcing pressure on both uranium and enrichment work unit supplies. Greater development of next-generation reactors and stronger demand for HALEU could push overall enrichment requirements higher.

Fuel

The composition of reactor technologies also reshapes fuel requirements. Global uranium oxide fuel fabrication requirements are around 11.5 kilotonnes of heavy metal today and are also set to increase in line with nuclear capacity expansions. Among conventional large-scale reactors, pressurised water reactors and boiling water reactors are set to continue to dominate uranium consumption. VVER designs, which operate with a hexagonal fuel lattice, maintain a significant market share: current global consumption of close to 11 ktU is expected to grow further. PHWRs in Canada and India also currently retain an important regional role, requiring about 3.4 ktU of dedicated fuel supply.

New projects are needed to meet growing demand for nuclear fuels

Mined uranium

The market for mined uranium remains tight. Existing capacity and the project pipeline suggest that the gap between requirements and likely available output is expected to widen over the next decade, making accelerated project development and access to higher-cost or undiscovered resources necessary. While identified uranium resources are generally sufficient to support projected nuclear growth, maintaining adequate supply will require timely investment in new mining projects and fuel-cycle infrastructure. Long-term supply risks are therefore driven primarily by the pace of investment and project development rather than by physical resource availability.

Recent project developments present a mixed picture, highlighting both new sources of supply and emerging structural constraints. The restart of the Langer Heinrich mine in Namibia is expected to contribute additional volumes, but these gains are partly offset by disruptions in traditional supply corridors. In Canada, the restart of Cameco's McArthur River-Key Lake operation has brought significant capacity back into production after suspension, with potential for further expansion to full licensed capacity. New projects are also being developed in Mongolia (France's Orano), Uzbekistan (domestic operator Navoiyuran), Tanzania (Russia's Uranium One) and Mauritania (Australia's Aura Energy).

However, several large legacy mines are progressively approaching depletion, with Canada's Cigar Lake mine, which accounts for close to half of the country's production capacity, facing decline from the mid-2030s and McArthur River about a decade later. Supply additions are also exposed to geopolitical and logistical complications. Production in Kazakhstan, the leading producer of uranium, is increasingly limited by sulphuric acid supply constraints, declining ore grades and rising costs, prompting a pivot towards higher-value contracts. Without new expansion or greenfield developments, the longer-term supply outlook is likely to tighten.

Higher uranium prices in recent years have supported a revival of exploration and development activity, initially focused on restarting idled capacity before extending to new greenfield investment decisions across Central Asia, Africa and North America. However, delivering sufficient new supply remains challenging: mine development timelines typically span 10-15 years, reflecting increasingly stringent regulatory requirements. Producers are also facing rising input costs, supply chain disruptions and increasing operational complexity. In addition, supply remains vulnerable to geopolitical disruptions, as illustrated by the loss of around 1 000 tonnes of production in Niger, which previously supplied about 23% of EU demand. This underscores the continued exposure of uranium markets to concentrated supply risks.

Uranium conversion: new projects needed rapidly

Uranium conversion, the first step that prepares mined concentrate for enrichment, remains structurally fragile. The process involves transforming uranium concentrate into uranium hexafluoride. Global uranium hexafluoride capacity, totalling 62 ktU, leaves little margin to absorb disruptions and volatility. Conversion prices recorded historic highs, with prices increasing by close to 30% over the year. These increases were driven by shifting trade flows and stronger demand expectations, although long-term fuel procurement strategies and the use of commercial inventories provide a buffer against short-term supply disruptions.

Rising demand is expected to require a major expansion of conversion capacity. While new projects and capacity expansions are planned in Canada, France, the United Kingdom and the United States, including by new players, long development timelines may delay their impact. In parallel, recently launched facilities are still ramping up, and it may take time for new projects to make a significant contribution in the near term. In this context, inventory management and long-term contracting practices complement efforts to diversify supply sources, helping to mitigate short-term market tightness.

Enrichment capacity: sufficient today, but additions needed for the future

Enrichment capacity remains sufficient in the near term but may face a bottleneck with rising demand over the medium term. This tightening outlook is already reflected in market signals, with spot and term enrichment prices rising respectively by more than 10% and 6% compared with 2024. Given the long lead times associated with new facilities, additional projects will be needed to prevent emerging constraints, as no major greenfield commercial capacity is expected before 2030.

In China, the ongoing expansion of enrichment capacity is primarily oriented towards strengthening domestic supply security rather than increasing export availability. The recent commissioning of the Emeishan plant has increased national enrichment capacity to 10.8 million SWU. Nevertheless, the current pipeline remains limited in its ability to expand the country’s role as an exporter of enriched uranium.

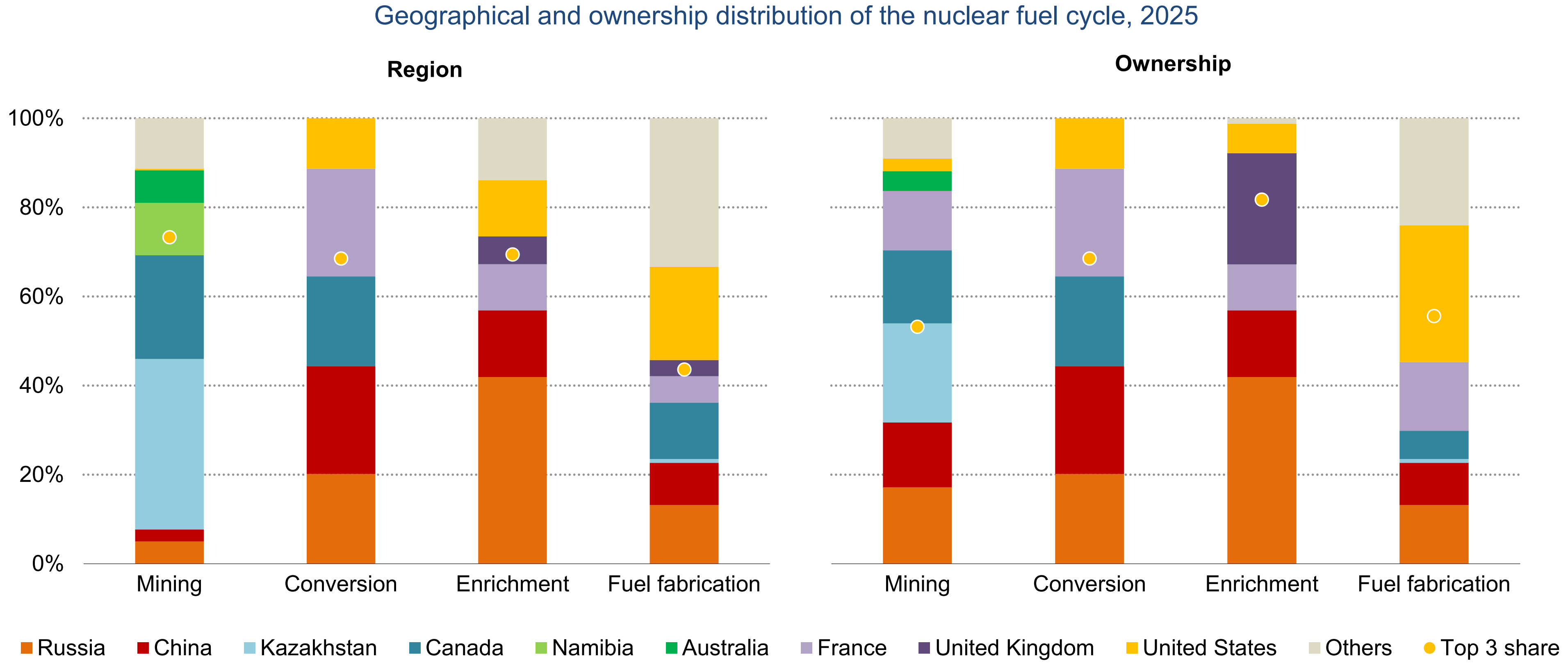
In Europe, enrichment capacity is broadly aligned with domestic demand. However, the region imports enriched uranium from Russia for domestic consumption while exporting its domestically enriched production to other regions, including Japan, Korea and the United States. Planned capacity increases are expected in 2028, including the addition of around 750 000 SWU at Urenco’s Almelo plant and approximately 2.5 million SWU through the expansion of Orano’s Georges Besse II facility. However, these additions are primarily aimed at maintaining supply balance and may offer limited headroom if existing external supply sources are reduced.

In the United States, enrichment capacity is expanding, with the Department of Energy committing USD 2.7 billion to domestic enrichment initiatives, supporting projects led by American Centrifuge Operating, General Matter and Orano Federal Services, including Project IKE. In parallel, Urenco USA announced an expansion of its Eunice enrichment plant by 2036, adding 2.1 million SWU and increasing total capacity to more than 7 million SWU. HALEU projects are also emerging but remain at an early stage of development. Current activities include the operation of Centrus Energy's HALEU pilot facility in Piketon, Ohio, and Global Laser Enrichment's demonstration test loop in Wilmington, North Carolina. Both companies are also advancing plans for larger commercial facilities in Kentucky. Despite this progress, the scale and timing of these projects suggest a gradual build-up of capacity, implying a limited role in serving short-term demand.

Fuel fabrication capacity is sufficient for conventional fuel types, but not for next-generation fuels

Global fuel fabrication capacity remains adequate to meet requirements, supported by utilisation rates below 70%. This provides a buffer to accommodate short-term increases in demand. However, fuel fabrication remains highly reactor-specific, with limited interchangeability across designs, which may create bottlenecks for certain fuel types and reactor technologies. Long-term fuel procurement strategies and commercial inventories provide an additional layer of resilience against short-term disruptions in mining, conversion, enrichment or fuel fabrication services, complementing efforts to diversify supply sources.

Three countries account for almost three-quarters of uranium mining, while 70% of both conversion and enrichment capacity is concentrated in three countries



Notes: Conversion, enrichment and fuel fabrication distributions are calculated based on project capacities. Mining ownership is calculated based on project shares.

Sources: IEA analysis based on Nuclear Energy Agency (2025), Uranium 2024: Resources, Production and Demand; Kazatomprom (2026), Operating and Financial Review for 2025; World Nuclear Association (2024), Conversion and Deconversion; World Nuclear Association (2026), Nuclear Fuel and Its Fabrication; World Nuclear Association (2025), Uranium Enrichment; International Atomic Energy Agency (2026), List of Nuclear Fuel Cycle Facilities; Zang et al. (2015), China's Uranium Enrichment Capacity.

Concentration and new fuel requirements are emerging as key constraints on nuclear fuel supply security

Mining

Three countries, Canada, Kazakhstan and Namibia, currently account for around 70% of global mining output. Concentration is even more pronounced from an ownership perspective, with six companies controlling 88% of global supply. This reflects an industry in which national champions, such as Kazatomprom, Cameco, Orano and China National Nuclear Corporation, coexist with majors operating multinationally, although upstream supply remains more accessible than in subsequent stages of the fuel cycle. This level of concentration reflects muted exploration and development activity during the decade following 2011, when uranium prices were historically low.

The security of mined uranium supply is shaped less by the distribution of resources than by the concentration of transport routes linking production to conversion plants. Kazakhstan and Uzbekistan, two landlocked countries accounting for close to 45% of global mined output, rely entirely on external conversion and enrichment services, making export corridors a potential chokepoint. Historically, uranium flows were oriented towards Russia by land, for transit or conversion, accounting for about 23% of mined uranium transit in 2015. Over time, trade patterns have increasingly shifted towards China, now the largest end market for Kazakh uranium, reflecting both long-term supply contracts and growing Chinese participation in upstream assets in Kazakhstan. Between 2015 and 2025, about half of uranium mined globally transited through Russia or China. This high reliance on a limited number of corridors is compounded by constraints further downstream, highlighting the limited flexibility of alternative primary mined supply under today's market conditions. In parallel, efforts to diversify transport routes have gained momentum since 2022.

One possible export channel is the Trans-Caspian corridor, shipping through the Caspian Sea and the Caucasus to Europe. In addition to providing access to European and North American markets, this corridor is increasingly viewed as a strategic alternative to traditional routes, particularly in the context of shifting geopolitical dynamics. However, this route remains constrained by limited capacity, and the necessary transshipment adds operational complexity and cost.

Adding to these challenges, uranium transport is governed as much by regulatory constraints as by physical logistics, as radioactive materials require country-specific licences that are not mutually recognised. This creates incentives to minimise transit jurisdictions and channel flows through a few specialised routes and ports, a trend reinforced by the declining willingness of some carriers and terminals to handle nuclear cargo.

Looking beyond conventional uranium-based fuels, thorium is attracting renewed interest in some countries, notably India and China, due to their abundant domestic resources and its potential to enhance long-term fuel supply security. However, commercial deployment remains limited to India's Advanced Heavy Water Reactor and China's Molten Salt Reactor programme.

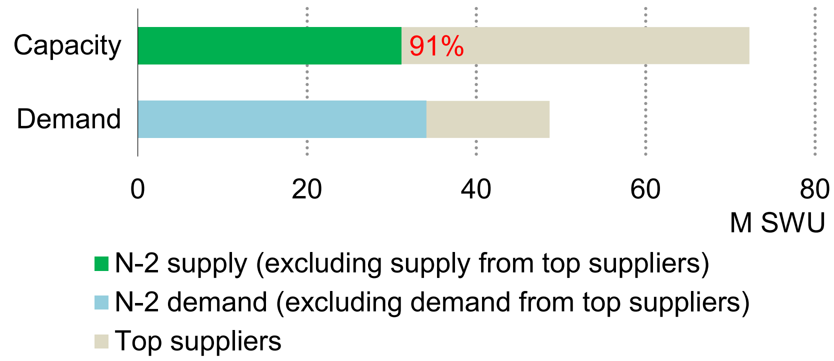
Conversion

Commercial-scale conversion can only be carried out in five major facilities operated and owned by Rosatom, Cameco, Orano, ConverDyn and China National Nuclear Corporation, creating significant exposure to logistical bottlenecks. The top three countries account for around 70% of global output, increasing exposure to potential disruptions while remaining slightly better distributed than enrichment capacity, both by geography and ownership. However, when excluding the two largest suppliers, Russia and China, available conversion capacity is estimated to cover only 80% of requirements, highlighting emerging constraints in supplying diversified markets in an already tight conversion market.

Enrichment

The geographic distribution of enrichment facilities creates significant challenges, with the share of the top three countries reaching close to 70%. Among key producers, Urenco operates across Germany, the Netherlands, the United Kingdom and the United States. Combined with Rosatom (Russia), Orano (France) and China National Nuclear Corporation (China), four companies handle 92% of the enrichment step. While nominal global capacity appears sufficient in 2025, available enrichment capacity outside the two largest suppliers – Russia, whose supplier role to the United States is to be phased out by 2028, and China – is estimated to meet only around 90% of requirements under an N-2 configuration. Effective supply could be even lower given utilisation rates remain below full capacity.

N-2 enrichment requirements and capacity by geography, 2025



Note: The N-2 balance excludes the two largest supplying countries from both demand and capacity.
Sources: IEA analysis based on Nuclear Energy Agency (2025), Uranium 2024: Resources, Production and Demand; World Nuclear Association (2025), World Nuclear Power Reactors and Uranium Requirements; World Nuclear Association (2025), Uranium Enrichment; International Atomic Energy Agency (2026), Nuclear Fuel Cycle Facilities Database (2026); Zang et al. (2015), China's Uranium Enrichment Capacity.

The deployment of SMRs at commercial scale is set to challenge the front end of the nuclear fuel cycle. Depending on the enrichment level, HALEU fuel fabrication can require up to four times more uranium input and five times greater enrichment effort per tonne of fuel. This implies structurally higher demand intensity for both uranium and enrichment services, amplifying pressure on upstream stages.

Commercial-scale HALEU production remains geographically limited, with Russia and China currently the only established commercial suppliers through downblending. The 2024 US ban on Russian uranium imports has reinforced policy efforts to establish alternative supply chains. Outside these suppliers, Centrus Energy's Piketon facility in the United States is the only operating pilot cascade, with cumulative deliveries of less than 1 tonne between late 2023 and mid-2025. Expansion plans target around 12 tonnes per year, supported by recent public funding and private investment. Additional projects are under development, such as Urenco USA's and Orano's enrichment expansions, as well as proposed facilities in Oak Ridge and Paducah. However, most projects are not expected to deliver material volumes before the early 2030s, indicating a potential timing gap between HALEU availability and SMR deployment needs.

In the United States, the Department of Energy's HALEU Availability Program, launched in 2020, is designed as an interim supply mechanism for early advanced reactor projects. Federal stockpiles are projected to reach about 21 tonnes by mid-2026, with approximately 15 tonnes potentially available for temporary allocation. While conditional allocations began in April 2025, government-held inventories under the HALEU Availability Program are expected to play a critical role for first-mover projects, pending the emergence of commercial-scale HALEU production towards the end of the decade.

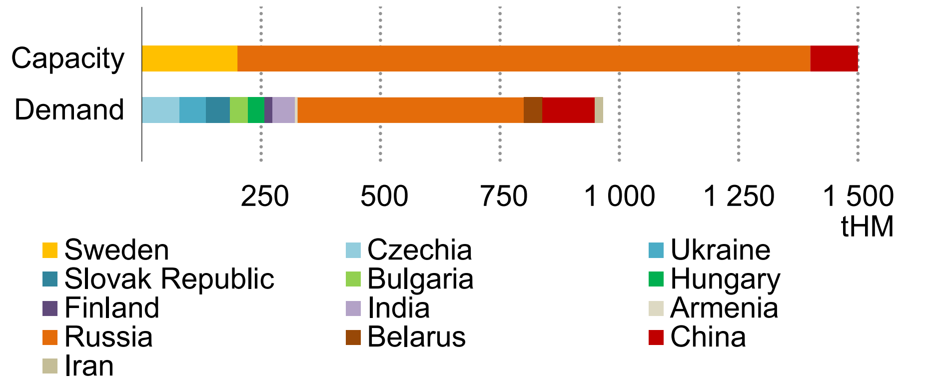
Fuel fabrication

Fuel fabrication capacities are more geographically distributed, with the top three regions accounting for 47%, as dedicated assembly lines are typically located close to reactor fleets. However, while global fabrication capacity generally exceeds demand, effective diversification is constrained by reactor-specific designs and qualification requirements, which limit substitutability between suppliers. As a result, ownership remains relatively concentrated, with Westinghouse (United States), Framatome (France), TVEL (Russia), GNF (United States) and KEPCO (Korea) together holding around 65% of global fabrication capacity.

Recent developments highlight reliability and technological progress as key near-term priorities. In 2025, operational performance and innovation remained areas of attention at key facilities. Following technical difficulties, some plants are currently planning works before resuming production. Framatome advanced the qualification of accident-tolerant fuels for European reactors, including at facilities in France and Germany. At the same time, investment is increasingly directed towards advanced fuel types rather than expanding conventional output, with projects such as X-energy's TRISO-X facility and BWXT's expansion in Lynchburg in the United States.

Reactor-specific and fuel-lattice design requirements are particularly binding for VVER reactors, which account for around 14% of the global nuclear fleet and rely on a limited pool of qualified fuel designs. Historically, Russia's TVEL, which remains outside EU sanctions, has been the primary supplier. Since the early 2020s, Westinghouse has secured offtake agreements for its new VVER-440-compatible fuels, in addition to existing VVER-1000 supply contracts. Framatome, supported by the APIS initiative, is also advancing plans in France and Germany for a new VVER fuel fabrication facility, alongside Westinghouse-linked projects in Spain and Ukraine. While most European VVER operators have taken steps to diversify procurement, only a limited share of fuel requirements is currently covered by alternative suppliers. Westinghouse's Västerås 200-tHM plant has the capacity to supply about half of the demand outside China and Russia. Although diversification efforts are progressing, fuel qualification, licensing and reactor-specific certification requirements remain binding constraints, with available fabrication capacity not immediately translating into usable supply. The pace of diversification is therefore likely to vary across operators and reactor types.

Geographical distribution of VVER fuel demand and supply, 2025



Source: Westinghouse (2026), Press release; International Atomic Energy Agency (2026), Nuclear Fuel Cycle Facilities Database.

For VVER-1200 reactors, there are currently no alternative fuel options, with continued reliance on TVEL representing a particular challenge for countries such as Bangladesh, Hungary and Türkiye. As a result, replacement capacity is expanding but is not yet sufficient to provide meaningful alternatives in the near term. Near-term security of supply therefore continues to rely on a combination of existing inventories, legacy supply chains and ongoing efforts to advance diversification.

Shifting contracting dynamics and prospects for secondary supply

Contracting dynamics

In recent years, contracting dynamics have increasingly shifted in favour of producers, reinforcing sustained price tightness. During the decade following 2011, characterised by persistently low uranium prices, contracts were predominantly structured as fixed-price or base-escalated agreements, often including volume flexibility at the discretion of utilities. Demand-side utilities previously relied on low-priced fixed or base-escalated contracts, leaving producers exposed to prolonged market weakness.

Since 2020, however, a combination of reduced secondary supply and recovering demand has led to a marked tightening of market conditions. Contracts are now market-indexed, often incorporating higher floor prices and, in some cases, more flexible or uncapped pricing structures, with producers seeking to benefit from rising market prices. Utilities have limited bargaining power under today's market conditions, and producers' willingness to lock in volumes several years ahead at prices well above current levels signals strong expectations of continued tightness. Concurrently, these utilities are increasingly turning to longer-term contracting strategies and building inventories to hedge against market and geopolitical uncertainty. The February 2026 long-term agreement between Kazakhstan and India's Department of Atomic Energy, securing a significant share of future production volumes, underscores the shift towards secured state-backed demand.

The evolving market structure is also reflected in the growing presence of financial actors. Physical uranium investment vehicles, such as exchange-traded funds, are accumulating uranium concentrate for storage purposes, effectively removing material from the market and contributing to tighter supply conditions.

The evolving role of alternative and secondary supply

Secondary supply can partially offset primary uranium requirements, supplementing freshly mined material with existing inventories and recycled fuels. This includes (i) drawdowns of stockpiles, (ii) recycling, (iii) enrichment underfeeding practices that reduce primary uranium demand by extracting more value from available material at the cost of additional enrichment effort, (iv) re-enrichment of tails, and (v) the downblending of secondary materials. These supplies have historically played a significant role, at times meeting more than one-quarter of global uranium demand, but their contribution has declined to around one-tenth in recent years. As inventories tighten and underfeeding opportunities diminish, the role of secondary supply is expected to decline further, increasing reliance on mining.

Used fuel remains a stable but limited contributor to fuel supply in the form of mixed oxide fuel, a blend of uranium and plutonium, the latter generated during reactor operation. In France, recycled fuel accounts for around 10% of nuclear feed today, with a target for recycled plutonium to contribute roughly 25% alongside enriched reprocessed uranium, before rising towards 40%. Orano's Melox plant is ramping back up and undergoing modernisation, while longer-term projects at the La Hague nuclear waste treatment plant aim to replace ageing facilities and increase recycling flexibility beyond 2040. Elsewhere, progress remains uneven. Despite advances such as Russia's REMIX pilot completion in 2026, delays at key facilities such as Japan's Rokkasho plant continue to constrain expansion. In parallel, discussions on the potential revival of reprocessing in the United States, including for future SMR applications relying on specific plutonium streams, illustrate renewed policy interest, although concrete deployment pathways remain uncertain. As a result, near-term trends point to consolidation rather than a structural increase in the global role of recycled fuel.

Looking ahead, while current recycling activity remains centred on mixed oxide fuel and reprocessed uranium, alternative reprocessing approaches capable of recovering a broader range of actinides are under consideration for fast-spectrum reactors, such as sodium- and lead-cooled designs. These could expand the role of recycled materials over the longer term, although commercial deployment remains uncertain. Future deployment of fast reactors and advanced closed fuel-cycle technologies could expand the role of recycled materials beyond current commercial applications, potentially affecting long-term uranium requirements.

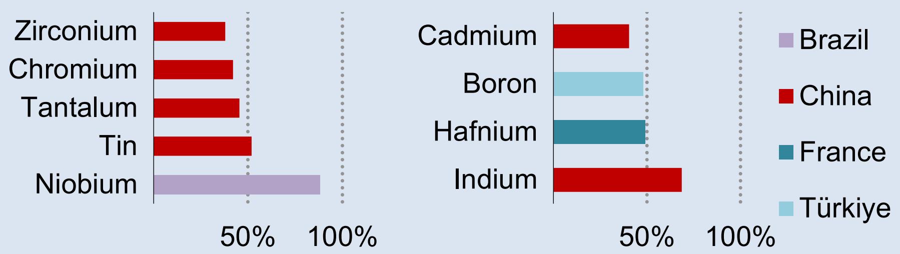
Box 2.2 Nuclear supply chains require more than uranium

Even though nuclear power plants consume relatively marginal volumes of non-uranium minerals compared with other energy technologies, they nonetheless rely on a range of specialised minerals, including zirconium, niobium and hafnium, whose supply chains are often highly concentrated and offer limited alternatives. Fuel cladding tubes, which encase uranium fuel pellets inside reactor cores, depend almost exclusively on nuclear-grade zirconium alloyed with small additions of niobium, tin, chromium and nickel. These materials are subject to single-country supply reliance, creating supply chain risks. Australia and South Africa account for roughly 60% of global zircon mining, while China controls about 38% of global zirconium refining. Niobium is even more concentrated, with three Brazilian mines providing around 90% of global output, one of which accounts for 80% on its own. Brazil exports niobium primarily as an alloy that is not directly usable in fuel cladding, but the transformation of niobium into nuclear-grade material is less concentrated and closer to demand centres.

Reactor control rods rely on boron carbide, hafnium and silver-indium-cadmium alloys, while gadolinium is used as a burnable poison in nuclear fuel. These minerals face highly concentrated supply and co-production constraints, posing vulnerabilities in nuclear-related mineral supply chains.

Hafnium is obtained only as a co-product of zirconium refining, with China being the leading refiner, while France, India, Russia and the United States also produce nuclear-grade zirconium. Indium, a by-product of zinc refining, is similarly dominated by China, which accounts for close to 70% of refined output. VVER fuel rods are also reliant on refined rare earths supplied by China. In addition, the deployment of advanced reactor designs and next-generation fuel systems may increase the importance of other specialised inputs, including nuclear-grade graphite, yttrium and beryllium, whose supply chains may also present structural concentration risks.

Share of the top producer of refined nuclear-related minerals, 2025



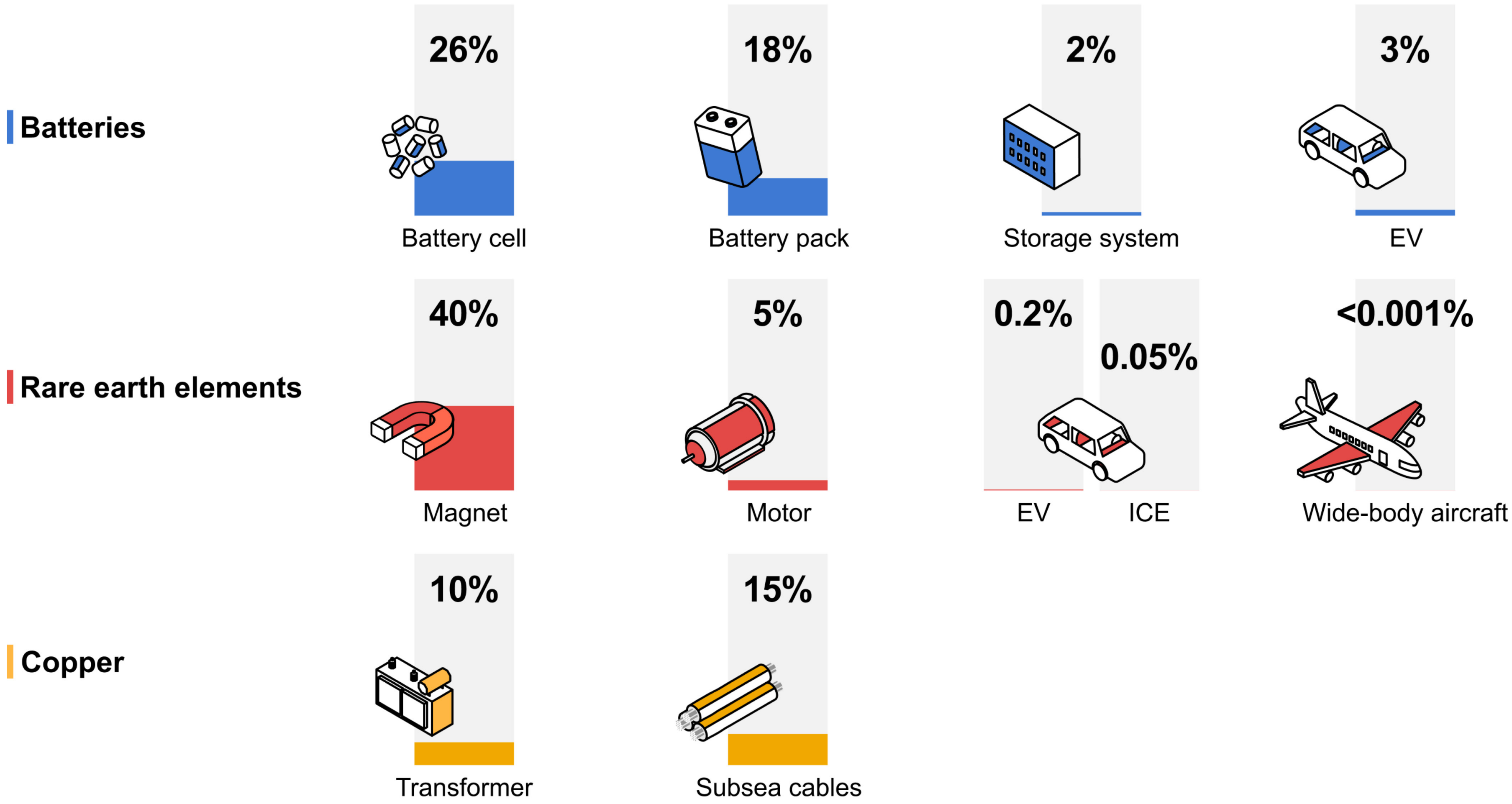
Source: IEA analysis based on USGS (2026), Mineral Commodity Summaries; European Commission (2025), RMIS - Raw Materials' Profiles; Institute for International and Strategic Affairs (2022), Critical Minerals in the Nuclear Industry.

3. Pathways to resilient and diversified supply chains

Emergency preparedness

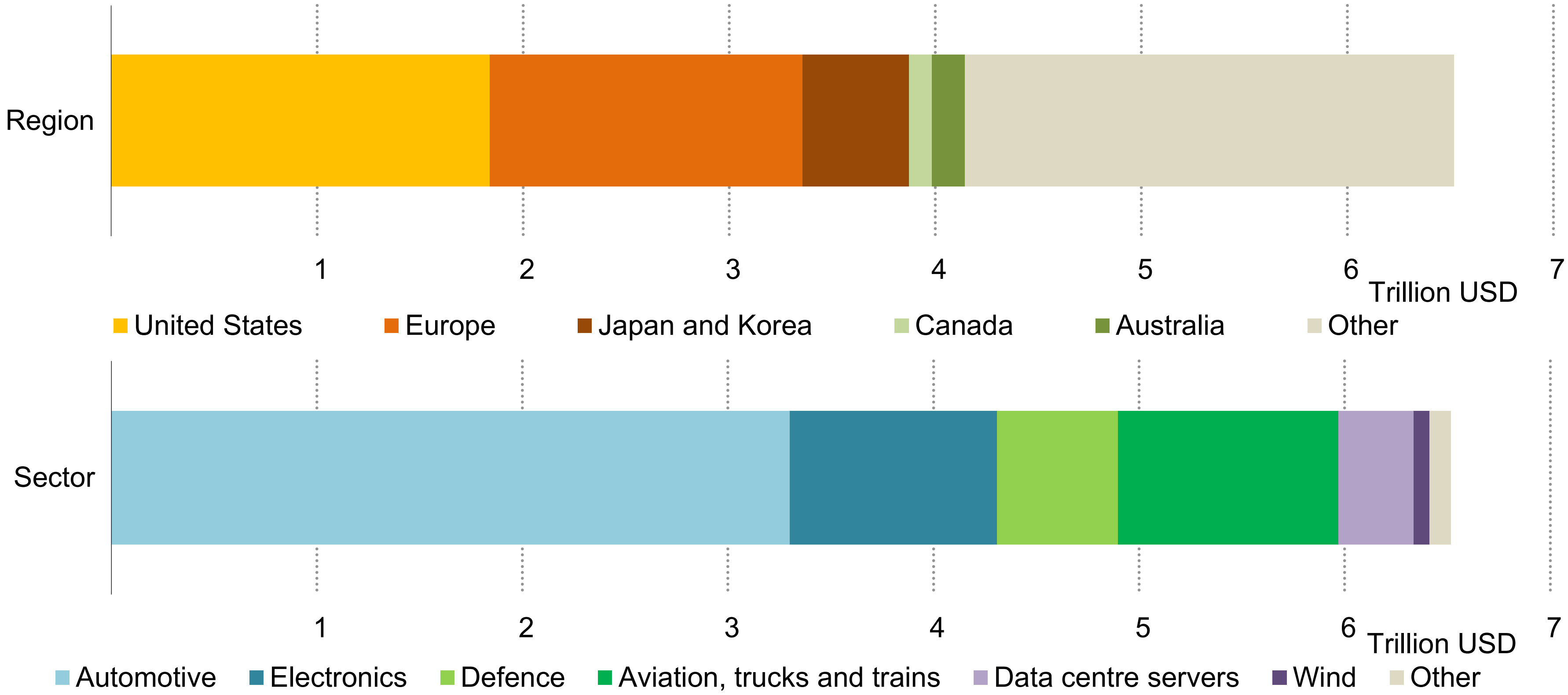
Significant increases in critical mineral prices have a limited impact on the prices of final downstream products

Share of critical minerals in the final price of battery, rare earth and copper products



Effective emergency preparedness starts with understanding the economic impact of supply disruptions; rare earth export controls put USD 6.5 trillion of downstream production at risk…

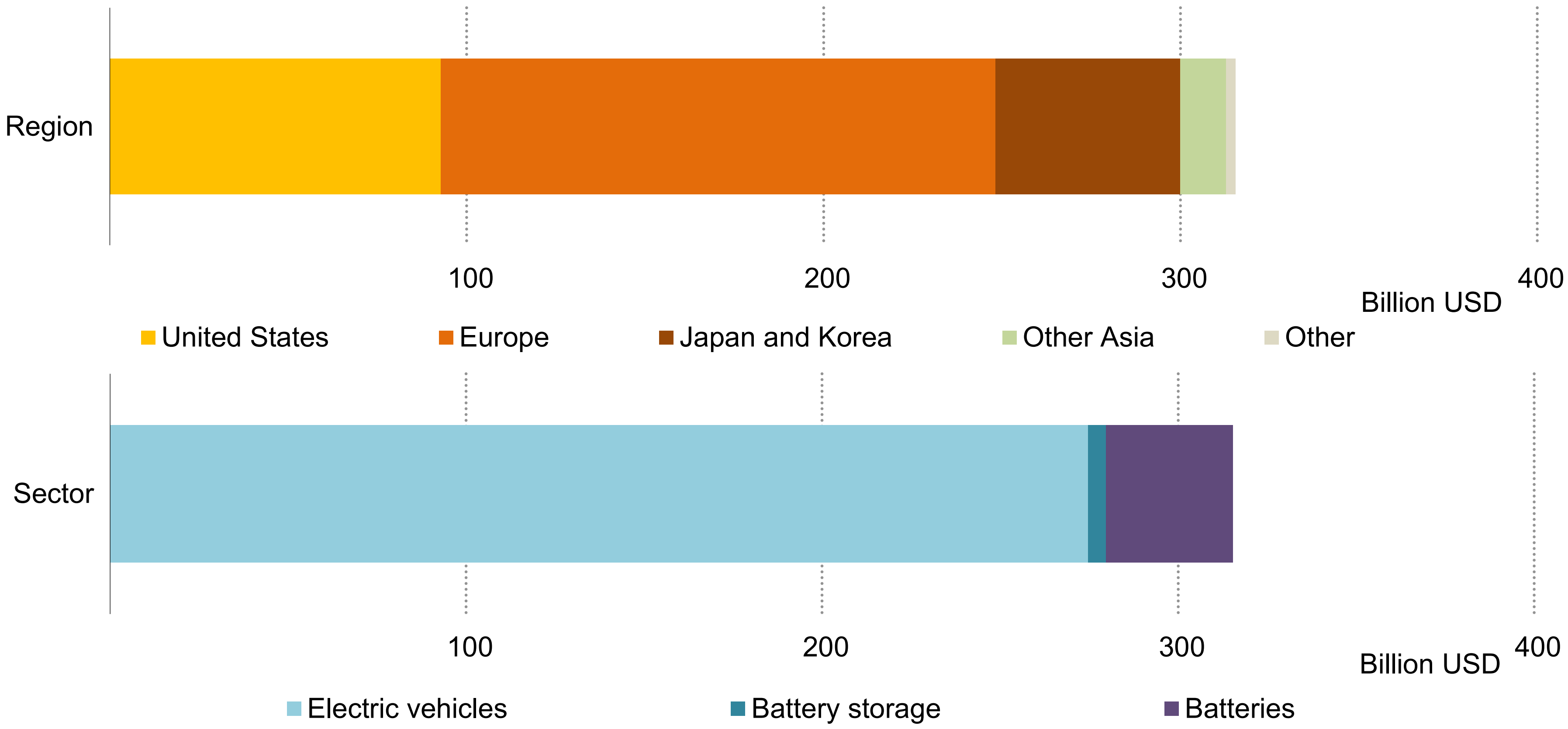
Economic value of downstream production at risk from full export controls of rare earths by region and sector, 2025



Notes: Economic value of downstream production at risk outside China. The full methodology is detailed in the next section.

… and over USD 300 billion of downstream production at risk from graphite export controls

Economic value of downstream production at risk from full export controls of battery-grade graphite by region and sector, 2025



Notes: Economic value of downstream production at risk outside China. Electric vehicles production includes both battery electric vehicles and plug-in hybrid electric vehicles. Battery storage includes all battery storage systems. Batteries include both batteries produced for electric vehicles and storage applications. The full methodology is detailed in the next section.

Understanding strategic risk exposure and the potential economic impact of disruption

In recent years, there has been a surge in both announced and implemented critical mineral export controls. Understanding a country's strategic vulnerabilities and economic exposure has never been more important. Assessing the potential economic impact of existing, announced or possible future export controls, as well as other supply disruptions, is a crucial first step in strengthening emergency preparedness. Identifying the most vulnerable sectors helps countries develop effective response strategies and build the capacity to mitigate impacts quickly in the event of a disruption.

Economic impact of disruption assessment methodology

Estimating the economic value of downstream production at risk from a major critical mineral supply disruption involves several steps.

- First, it requires an understanding of the import volumes of the disrupted material, together with as much information as possible on how it is consumed across sectors.
- Second, it is necessary to identify the products in each sector that depend on the disrupted material and lack immediate substitutes, along with their material intensities.
- Third, imported material volumes and product intensity data are combined to validate the estimated number of downstream products reliant on the exposed material.
- Fourth, product price and independent product sales data are used to calculate the economic value at risk by multiplying the product prices by the number of material-dependent products sold. Sales data provide an additional layer of validation.
- Finally, the results can be aggregated by sector or region, depending on the focus of the analysis.

Using this approach, we assess the economic impact of two major export controls announced by China – on rare earth elements and battery-grade graphite – under a scenario in which trade flows are fully disrupted.

Rare earth element export controls

For magnet rare earths, the economic value of downstream production at risk was estimated based on the export controls announced by China in October 2025 (suspended until November 2026), as if they were implemented in full. If implemented, companies would need to obtain a licence from China to export any domestic or internationally made "parts, components and assemblies" containing China-sourced rare earth materials or produced using Chinese technologies. In a scenario in which the relevant licences are not granted, the production and trade of final end-use products containing Chinese rare earth elements would be severely constrained. As a result, downstream manufacturers would face economic losses stemming from their inability to produce, sell and export the affected products.

To estimate the economic value of downstream production at risk outside China from full export controls, the assessment first utilises data on rare earth magnet demand in end-use products across the economies, covering both neodymium-iron-boron (NdFeB) and samarium-cobalt magnets. These data are combined with data from the IEA database of rare earth intensities for downstream products in each sector to determine the number of magnet-dependent products. These sales numbers are then combined with product price information to calculate the exposed revenue if licences are not granted, thereby quantifying the economic value of downstream production at risk from the loss of sales. Twenty-four specific product categories were analysed. Independent product sales data are also used to validate the estimates derived from rare earth intensities. The resulting economic value of downstream production at risk by product is then aggregated by region and by sector.

Economic impact results – rare earths

If the rare earth export controls are implemented in full, the economic value of downstream production at risk would reach USD 6.5 trillion per year for countries outside China. For context, this economic exposure amounts to around 7% of the combined annual gross domestic product of these countries. The United States and Europe face the largest potential economic value at risk, with over USD 1.5 trillion in direct economic losses each. Japan and Korea together face over USD 500 billion in potential economic losses, underlining the severity of the impact these controls could have on major economies if fully implemented.

In terms of sectoral exposure, the automotive sector accounts for the greatest economic value of downstream production at risk, with over USD 3 trillion in direct losses for countries outside China, followed by electronics and other transport sectors (aviation, trucks and trains), with over USD 1 trillion in losses each. These three sectors together are responsible for almost 85% of the economic value of downstream production at risk, demonstrating their economic importance and vulnerability. The defence sector also faces losses of almost USD 600 billion, while losses in the data centre sector exceed USD 350 billion.

Across all major economies, the automotive sector accounts for the largest economic losses, representing over 40% of losses in the United States and over 50% in other economies. However, vulnerabilities in other sectors vary considerably by region. In the United States, data centre servers and defence applications are more exposed, accounting for 15% of losses each, while Europe, Japan and Korea have high exposure to electronics, at around 20% of losses. Data centres currently represent a smaller source of economic exposure for countries outside the United States, but their significance could increase over time as new facilities are deployed more widely across other economies.

Graphite export controls

The same analysis was conducted for battery-grade graphite, based on the battery supply chain export controls also announced by China in October 2025, which were also suspended until November 2026. This analysis builds on previous battery-grade graphite export controls from 2023. Previously limited to natural flake graphite and synthetic graphite with properties above a set threshold, the newly announced export controls extended controls to all graphite anode materials, both natural and synthetic. Given the central role of graphite anode materials in global battery supply chains, if fully implemented, this control would severely affect battery production outside China, with major constraints on the production of dependent high-value electric vehicles (EVs) and storage systems.

To estimate the economic value of downstream production at risk, the economic value of battery production outside China was first calculated by combining 2025 battery production data by country with the corresponding battery prices. To calculate the impact on EVs, the number of battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) that could not be produced due to the inability to produce batteries outside China was calculated. Using our data on average battery sizes by country and powertrain, together with BEV and PHEV sales shares by country, the number of affected vehicles was estimated. This was then multiplied by average vehicle sales prices in each country to derive the associated economic value. The same was calculated for battery storage systems that could not be produced due to the inability to produce batteries outside China.

Economic impact results – battery-grade graphite

If the battery-grade graphite export controls are implemented in full and trade flows are disrupted, the economic value of downstream production at risk would be over USD 300 billion per year for countries outside China. This is over 20 times smaller than for rare earths, demonstrating the criticality of rare earths for a multitude of major economic sectors. Nevertheless, as demand for batteries, storage systems and EVs continues to expand rapidly, the economic value at risk is set to rise considerably over time.

Europe faces the largest potential economic losses from the export controls, accounting for over half of global losses, with more than USD 150 billion exposed. The United States faces the second-largest exposure with over USD 90 billion in potential losses, while Japan and Korea together are exposed to over USD 50 billion in potential losses. The economic impacts of battery-grade graphite supply disruptions are almost entirely concentrated in these four major markets, amounting to over 95% of economic exposure, compared with just 60% for rare earths. This demonstrates the concentration of EV and battery production in these regions.

By sector, over 85% of exposure comes from EV production with USD 275 billion at risk. BEVs comprise almost 70% of EV economic exposure compared with PHEVs, given their significantly larger share of sales, at 65-80% in all major markets outside China. Only USD 5 billion is exposed for battery storage systems as the vast majority of battery storage deployment outside of China relies on LFP batteries produced in China. However, almost USD 40 billion of battery production is exposed outside of China due to the significant battery production capacity in the United States, Europe, Japan and Korea. One important nuance regarding the economic impact of the graphite restrictions is that the graphite controls do not include the same restrictions on "parts, components, and assemblies" as the rare earth controls. Therefore, affected automakers could potentially mitigate the loss of diversified battery supply by purchasing additional batteries from Chinese suppliers. However, this would further increase the concentration of global battery supply, increasing exposure to future supply risks. One example is the broader battery supply chain export controls announced in 2025, which covered multiple battery supply chain chokepoints. These measures were suspended for one year in November 2025.

Indirect economic impacts

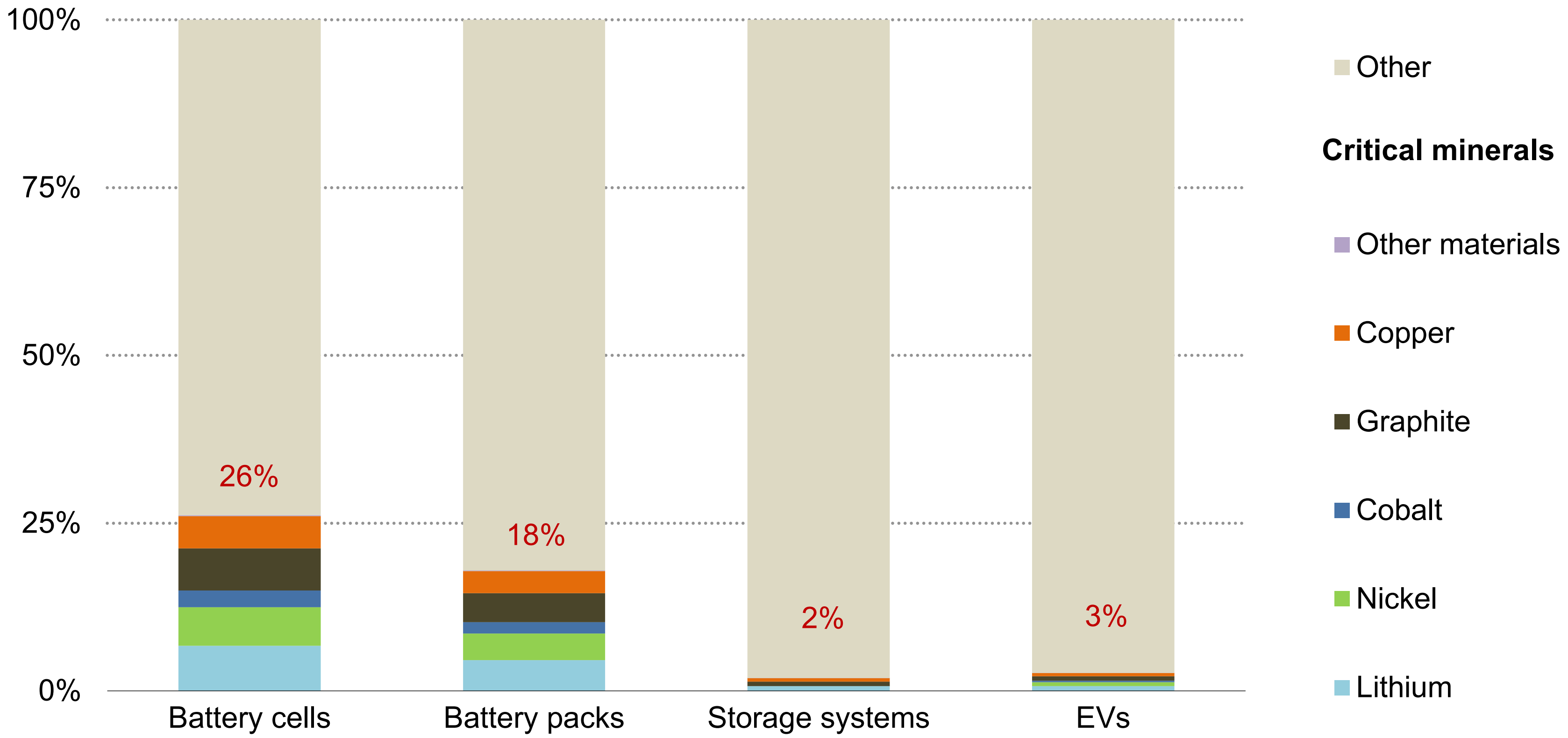
In practice, the impacts of a disruption extend far beyond the loss of direct product sales. A wide range of high-value services depend on sales of critical mineral-dependent products. For example, many high-value services, such as artificial intelligence (AI), e-commerce, fintech and cloud computing, rely on data centre servers, which depend on rare earths. If data centre servers cannot be sold for the installation of new data centres due to rare earth export controls, there could be a major economic multiplier effect beyond the loss from data centre sales. The same is true for the plethora of high-value operations that depend on industrial motors containing rare earths, such as automated and advanced manufacturing, robotics, and applications in energy, mining, and oil and gas production. There is a cascading economic effect from the inability to trade critical mineral-dependent products. These economic losses could be several times larger than the direct economic losses estimated in this analysis.

Strategic impacts

Some sectors may have lower economic impacts in some regions but still pose major strategic vulnerabilities, such as defence or medical applications that rely heavily on rare earths or batteries. Future economic and strategic value is also a key consideration, even where current exposure appears modest today. For example, data centre servers, which are critical for AI development, underpin a sector widely regarded as one of the most strategically and economically significant for the future.

Critical minerals comprise just 3% of the price of an average electric vehicle but almost 20% of the battery pack price

Share of critical minerals in the price of battery cells, battery packs, storage systems and EVs

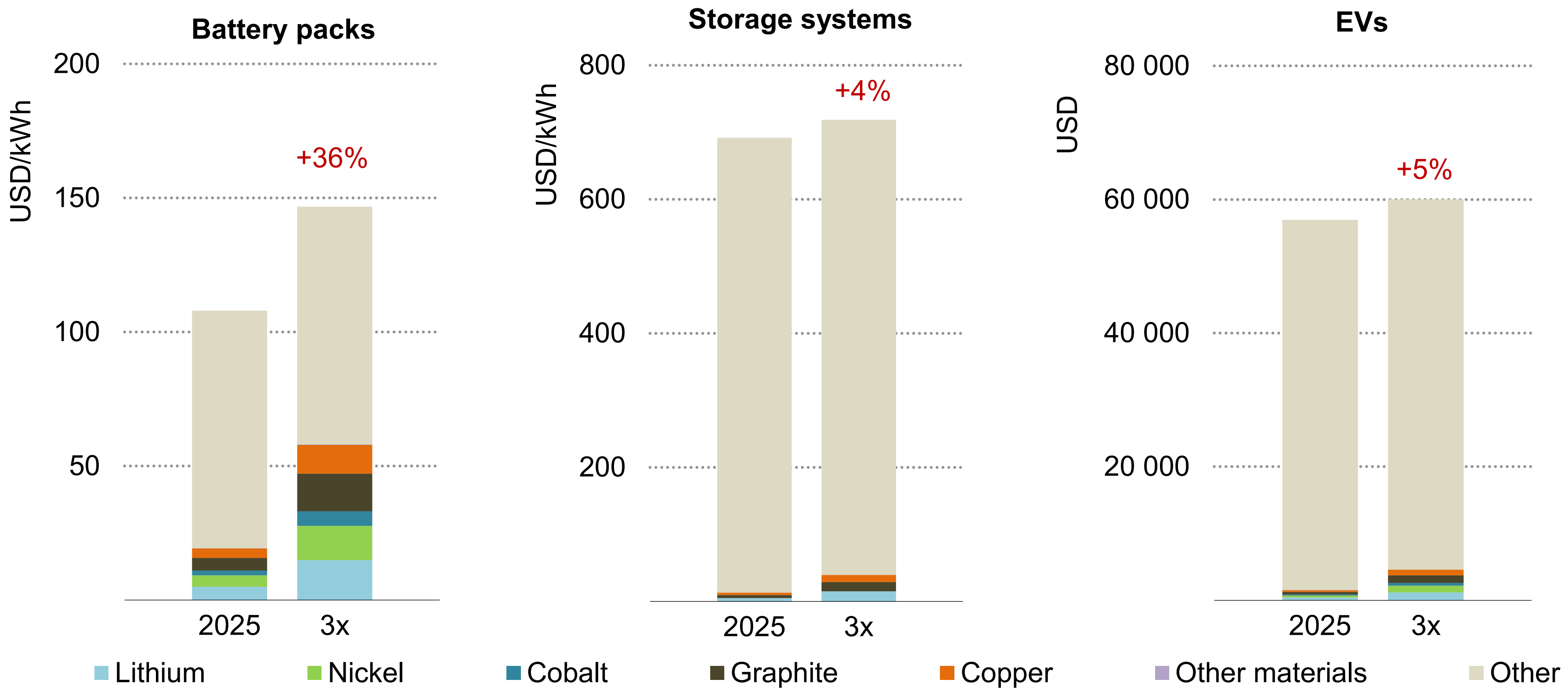


Notes: Other materials include manganese sulphate. Lithium refers to lithium carbonate and lithium hydroxide, graphite to battery-grade graphite, nickel to nickel sulphate and cobalt to cobalt sulphate. Prices utilised are the 2025 global average material prices. Storage systems refer to the global average price for two-hour utility-scale storage. The EV price refers to the average of the European and United States BEV prices in 2025.

Sources: IEA analysis based on BloombergNEF and Global EV Outlook 2026.

A tripling of critical mineral prices would increase battery pack prices by over 35%, but electric vehicle and storage system prices would only increase by 5%

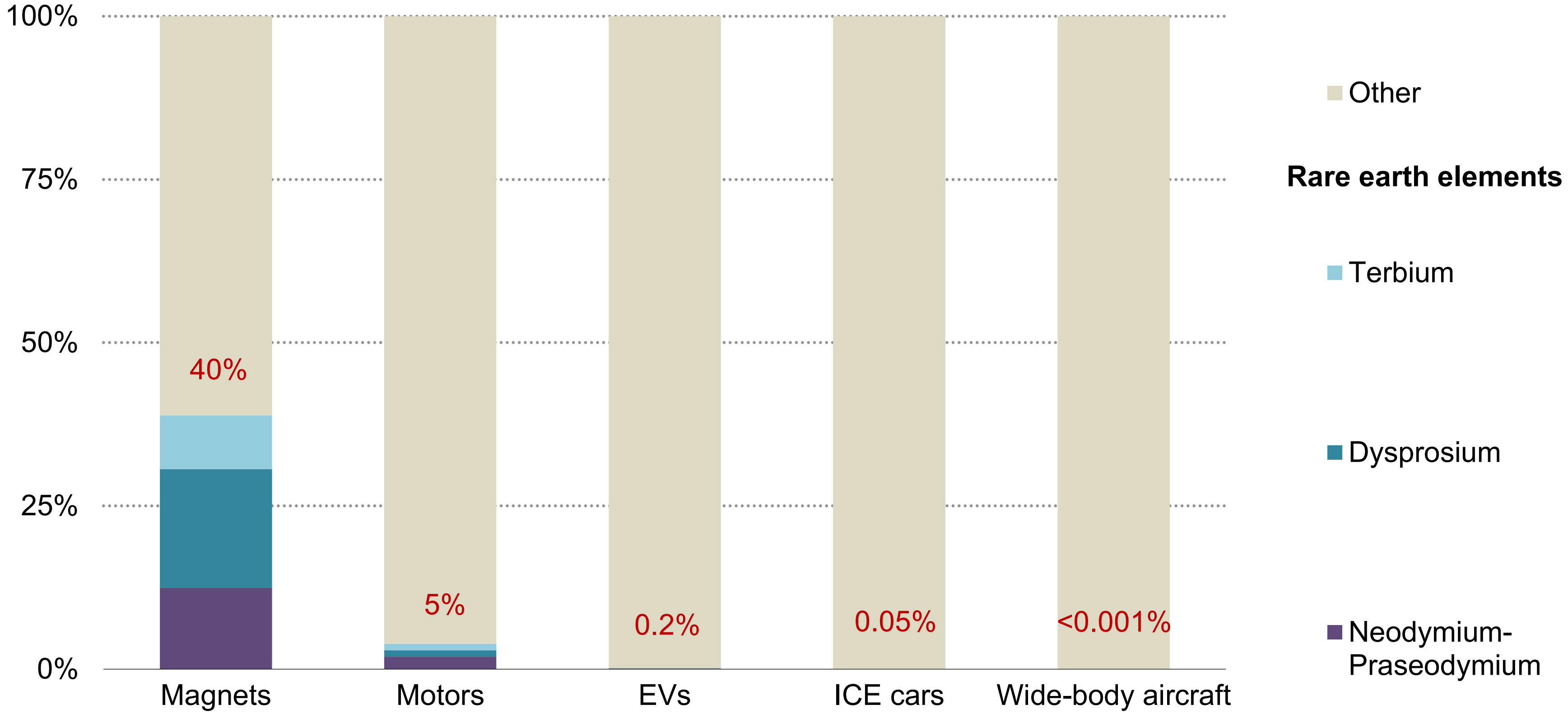
Battery pack, storage and EV price impact of tripling the prices of critical minerals



Notes: 3x refers to the product price impact from tripling the price of all critical minerals. Other materials include manganese sulphate. Lithium refers to lithium carbonate and lithium hydroxide, graphite to battery-grade graphite, nickel to nickel sulphate and cobalt to cobalt sulphate. Storage systems refer to the global average price for two-hour utility-scale storage. Prices used are the 2025 global weighted average material prices. The EV price refers to the average of the European and United States BEV prices in 2025.
Sources: IEA analysis based on Bloomberg, BloombergNEF and Global EV Outlook 2026.

Rare earth elements make up 40% of the value of permanent magnets but less than 1% of the value of electric vehicles and conventional cars

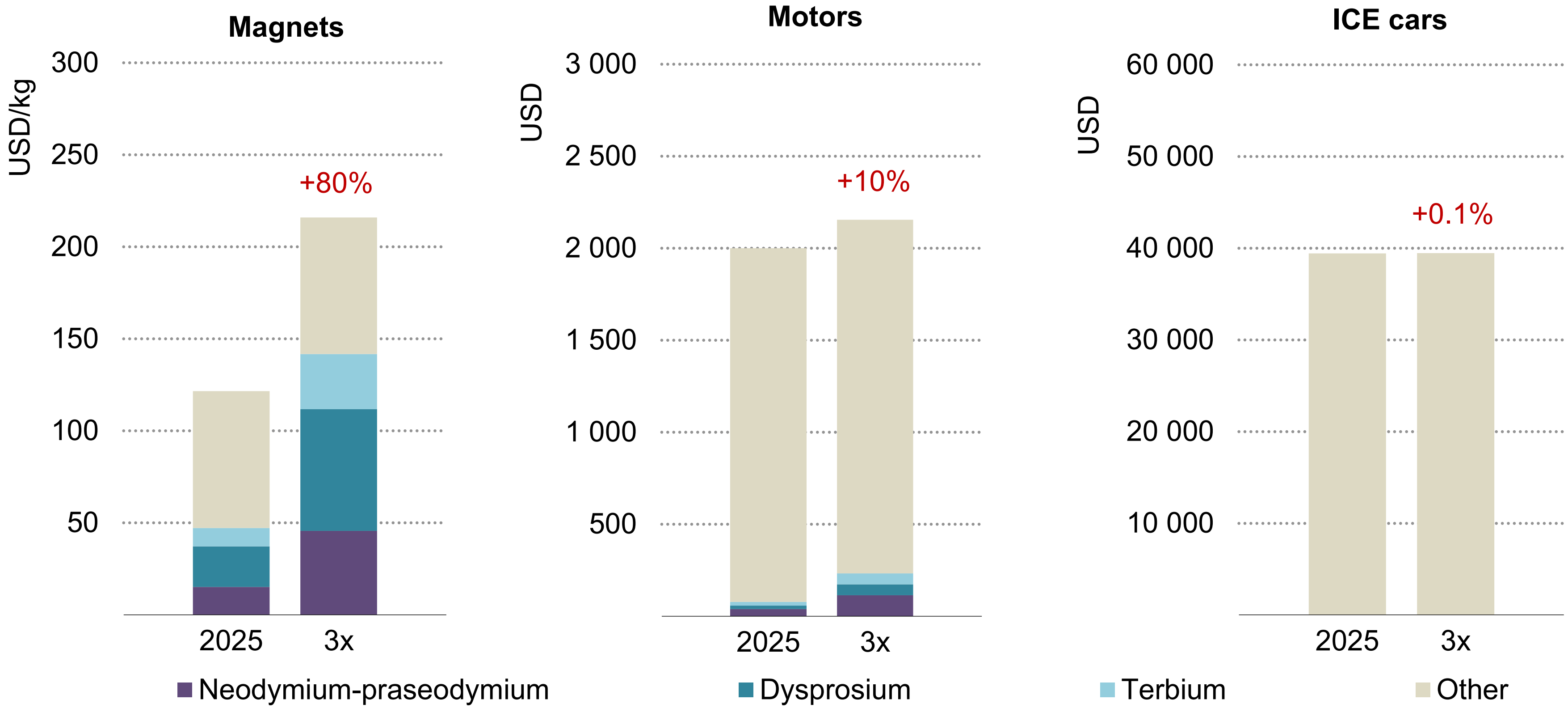
Share of rare earth elements in the final price of magnets, motors, EVs, ICE cars and aircraft



Notes: EV = electric vehicle; ICE = internal combustion engine. Magnet refers to a rare earth element permanent magnet for a midsize BEV, motor refers to a 100 kW EV motor, EV refers to an average BEV, ICE refers to an average internal combustion engine vehicle. Utilises the 2025 average material and product prices.
Sources: IEA analysis based on Bloomberg and Argus.

A tripling of rare earth element prices would almost double the price of permanent magnets but increase the price of a car by just 0.1%

Product price impact of a tripling of rare earth element prices

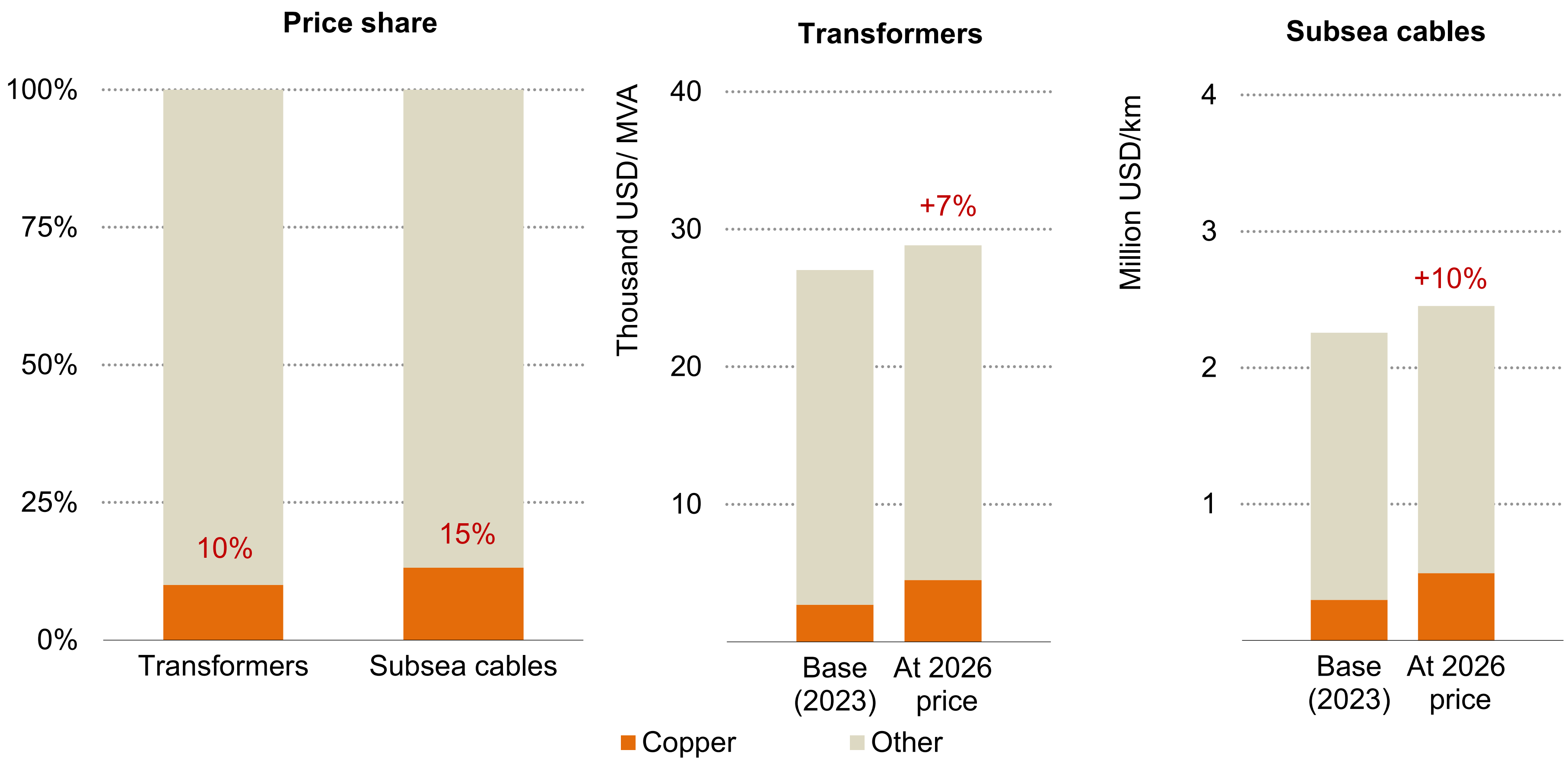


Notes: 3x refers to the final product price impact from tripling the price of rare earth elements. ICE = internal combustion engine. Magnets refer to rare earth element permanent magnets for a midsize BEV, motors to 100 kW EV motors, EVs to average BEVs and ICE cars to average ICE cars. Prices are the 2025 average material and product prices.

Sources: IEA analysis based on Bloomberg and Argus.

Copper comprises 10% of transformer prices and 15% of power cable prices

Share of copper in the price of transformers and cables, and price impact of a higher copper price



Notes: MVA = mega volt-ampere. Subsea cables refer to 400-575 kV cables. Transformers refer to 66-154 kV power transformers. The 2026 price uses the peak 2026 copper price in May 2026.

Understanding the downstream product cost implications of critical mineral price increases

An important element, often missing in critical mineral policy discussions, is a quantitative assessment of the cost share of critical minerals in downstream products and the impact of changes in critical mineral prices on the prices of these products. The implications of this relationship can be significant.

First, understanding price impacts is essential for emergency response strategies. It helps identify where disruption risks are most severe, where downstream impacts could be critical and where temporary emergency support may be required to prevent broader economic spillovers.

Second, it is crucial for the design of policy tools aimed at supply chain diversification. Projects in geographically diverse regions generally have higher cost structures than incumbent suppliers, meaning that the additional cost of diversification needs to be borne by someone, whether governments, consumers or actors across the value chain. Understanding the magnitude of the price impact can therefore inform the design of appropriate policy instruments and burden-sharing mechanisms.

The relationship between material prices and downstream costs varies significantly across materials. For some materials, the material cost share in the downstream product is small. In such cases, higher material prices may have only a limited impact on final product prices. However, the reverse can also be true. If the material price share is high, the downstream product price can be sensitive to changes in material prices, making it more difficult to absorb higher material costs. These dynamics are highly relevant for the design of policy tools to support diversification. In this context, we evaluate the price share and cost implications of material price changes for three major critical mineral markets: batteries, rare earths and copper.

Battery materials

Batteries require a range of critical minerals to operate, including lithium hydroxide and lithium carbonate, several metal sulphates (nickel, cobalt and manganese), graphite and copper. In 2025, these materials comprised a quarter of the price of battery cells and almost 20% of the price of battery packs. Lithium and graphite are the largest material cost components, each comprising over 4% of the pack price, followed by nickel sulphate and copper, at over 3% each. Cobalt sulphate comprises around 2%, while manganese sulphate accounts for just 0.1% of the pack price due to its significantly lower price than other materials. Despite accounting for a relatively high share of the price of cells and packs, critical minerals comprise only a small share of EV and storage system prices, accounting for just 3% of an average EV price. This is even lower for storage systems, where just 2% of the price is attributable to critical minerals, predominantly due to the dominance of lithium iron phosphate chemistries for storage, which require no nickel or cobalt.

Battery material prices have seen high volatility in recent years, particularly for lithium, cobalt and nickel. The lithium price increased ninefold from January 2021 to December 2022 alone. Tripling the price of all critical minerals in batteries would increase the price of battery packs by over a third, a major increase that would have significant consequences for the competitiveness of batteries, with likely consequences for storage system and EV producers in terms of downsizing and demand destruction. The competitiveness of battery manufacturers in geographically diverse regions can be significantly affected by increases in material prices, particularly as they compete with established, low-cost incumbent producers. However, a tripling of mineral prices would increase the final price of EVs and storage systems by only around 5%, a notable but much more limited impact. For end users, EV consumers and grid developers, the price impacts may be manageable. However, original equipment manufacturers (OEMs), storage system producers and battery purchasers would face a significant increase in input costs as battery pack prices rise. In the case of non-vertically integrated producers, the impact on final product prices could be higher due to additional margins along the value chain, or lower if upstream and midstream suppliers absorb part of the increase in material costs.

Rare earth elements

The case is more pronounced for rare earth elements. Rare earth elements comprise 40% of the final price of neodymium-iron-boron (NdFeB) permanent magnets. Dysprosium represents the largest share, at almost 20% of the magnet price, followed by neodymium-praseodymium, at almost 15%. Terbium is used in very small amounts in many NdFeB permanent magnets to improve high-temperature performance and resistance to demagnetisation. However, as the price of terbium is over ten times higher than that of neodymium-praseodymium, it is responsible for around 10% of the value of a permanent magnet. For an EV motor, rare earths comprise around 5% of the total price, a significantly smaller share due to the high value added of the motor and the small volumes of rare earth elements used. Further downstream, rare earths account for an almost negligible fraction of the value of the products. Rare earths account for less than 1% of the value of an EV, less than 0.1% of the value of an internal combustion engine (ICE) vehicle and less than 0.001% of a wide-body aircraft, despite being critical to all of these downstream products.

Tripling the price of all magnet rare earths would almost double the price of permanent magnets, with significant impacts on prospective magnet manufacturers competing against incumbent producers. The higher magnet prices would also create challenges for motor producers, which typically operate with thin margins. Tripling rare earth prices would increase motor prices by 10%. The impact on motor prices is significant and may incentivise carmakers and OEMs to increase research into technologies that reduce rare earth intensity in magnets and motors. However, it is unlikely to be cost prohibitive for automakers and would not stop OEMs from being able to purchase rare earth-based motors. The impact on final consumer prices would be minimal. Even a tripling of rare earth prices would increase the price of an ICE vehicle by only around 0.1%, making the effect largely imperceptible to consumers. Therefore, the impacts are more acute for magnet and motor producers, but the costs could be more easily absorbed downstream.

Copper

In today's electricity system, two of the major products that are highly dependent on copper are transformers and power cables. Prices for power transformers have almost doubled since 2019, predominantly due to manufacturing bottlenecks and insufficient production capacity to meet surging demand from grid development. Copper has also seen exceptional price rises to record highs from the end of 2025 through 2026. Therefore, we assessed the share of copper in the price of transformers and subsea power cables based on 2023 data to reflect typical circumstances. In 2023, copper comprised around 10% of the power transformer price and 15% of the subsea high-voltage power cable price, a significant but not dominant cost component. However, when considering these costs with 2026 peak prices from May 2026, representing a 66% increase from the 2023 average price, this increases the transformer price by 7% and the subsea cable price by 10%, representing significant cost increases for grid developers and providers. This price increase is significant but not prohibitive, suggesting some scope for transformer and cable prices to absorb changes in copper prices. While sustained periods of high copper prices could place upward pressure on grid investment costs, they are unlikely to fundamentally undermine the economic viability of transmission and distribution projects.

A mineral security premium could be an insurance policy for strategic and economic security

Some important conclusions can be drawn by combining the analysis of risk exposure with the downstream cost implications. Major strategic and economic losses are at stake from critical minerals export controls and disruptions, given the wide range of high-value products and strategic sectors that depend on these materials. While supply diversification remains the only durable solution to these structural risks, projects in geographically diverse regions generally have higher cost profiles than incumbent producers. In many cases, operating costs can be around 50% higher than in established supply bases, which can materially affect investment decisions (refer to the following Policy and market frameworks section in Chapter 3).

This creates a central policy challenge: diversified supply is needed by both governments and consumers, but it is less clear who should bear the additional cost or how this cost gap can be addressed. Recent efforts have often focused on introducing a "sustainability premium" linked to environmental, social and governance performance. However, such premiums have not emerged at meaningful scale in practice.

In the current context, characterised by rising geopolitical tensions, the additional cost of diversification may instead be viewed as a form of economic insurance against major security risks. In this context, a "mineral security premium" may be a more appropriate framing. Such a premium reflects the idea that societies already pay for risk management across multiple domains, including energy security, infrastructure resilience and financial risk. Given the rising frequency of export controls and geopolitical disruptions, this form of insurance is becoming increasingly relevant and is something consumers and policy makers may need to price in to enhance economic and business security.

In the case of rare earths, fully implemented export controls could result in an estimated USD 6.5 trillion of downstream economic value at risk per year for countries outside China, whereas a tripling in rare earth prices would increase the price of a conventional car by just 0.1%. Against this backdrop, the estimated downstream price impact of around 0.1% appears to be a relatively modest cost for enhanced economic security.

Because downstream price impacts are generally modest in end-use applications, a large share of the diversification cost can be absorbed without significant effects on consumers. However, it is important to note that diversification may also entail additional costs beyond higher material prices, including supplier qualification, product testing and certification processes, and other switching costs associated with establishing new supply relationships.

The price impacts are more pronounced in specific intermediate segments, such as motor manufacturing and battery production, where input cost sensitivity is higher. In these cases, targeted policy support may be required. More broadly, the appropriate financing of a security premium could be shared across governments, industry and consumers, depending on where in the value chain the cost burden can be most effectively absorbed.

A clearer understanding of the cost implications is therefore essential to inform policy design. Governments need to consider how best to structure policy tools and burden-sharing mechanisms, and at which point in the value chain intervention would be most effective. In this context, quantifying downstream impacts helps clarify how costs and risks are distributed across governments, industry and consumers. Ultimately, the issue is one of strategic risk management, and framing it as such through a security premium may help unlock the investment needed to accelerate the development of diversified supply.

Emergency response measures protect against elevated risks of supply disruptions

Developing diversified sources of supply for critical minerals is a clear priority to increase the long-term resilience of supply chains. However, it inevitably takes time to develop new projects in both mining and refining. Emergency preparedness measures can provide short-term protective and mitigative actions to safeguard countries from supply shocks while they develop new, diversified sources of supply.

At the centre of emergency preparedness, response measures provide relief to disrupted supply chains, acting on the supply and/or demand side. On the supply side, unlocking spare production capacity and commissioning new projects in an accelerated time frame can help make up for lost supply in the event of a disruption. For countries with existing stockpiling systems, the release of stockpiled material is also a key option, providing a temporary buffer. On the demand side, temporary allocation of available supply to strategic industries, incentives for efficiency and substitution, and rationing could also help withstand supply shortages.

Redirecting available supply to priority industries could help reduce the economic impact of disruptions, but countries would need to conduct a prioritisation exercise ahead of a crisis. Many countries have experience in conducting similar exercises for the oil sector, providing lessons that can be adapted to different industry structures.

Beyond the selection of possible response measures, emergency preparedness includes close market monitoring to promptly identify disruptions and react in time, the development of protocols for the rapid implementation of emergency response measures, and exercises to stress-test systems and identify vulnerabilities and potential responses.

Tabletop exercises can simulate a realistic supply disruption and help countries develop co-ordinated response measures. These exercises offer opportunities to improve common understanding of domestic and global risk exposure, test emergency procedures, and co-ordinate the management and exchange of available supply. The process of simulating supply disruptions through exercises may also help build domestic data-gathering capabilities and strengthen emergency response capacity.

Emergency procedures

An essential element of emergency preparedness is the ability to identify and quickly react to acute market disruptions. The establishment of emergency procedures is key to achieving this goal and involves several steps:

1. Establishing market monitoring systems with access to information such as supply, demand and trade of high-risk

materials. This would enable the creation of early-warning systems to provide signals of potential supply shocks.

2. Setting up government-industry monitoring groups to exchange information on market developments. This would include designated contact points that centralise information and communicate the implementation of security measures through secure channels.

3. Playing an active role in international platforms, such as the IEA Critical Minerals Security Programme, that facilitate information exchange and the co-ordination of response measures.

In preparation for potential supply disruptions, governments can plan measures that would increase readiness for emergencies:

1. Mapping industrial players supplying or using high-risk materials and improving data quality and monitoring efforts.

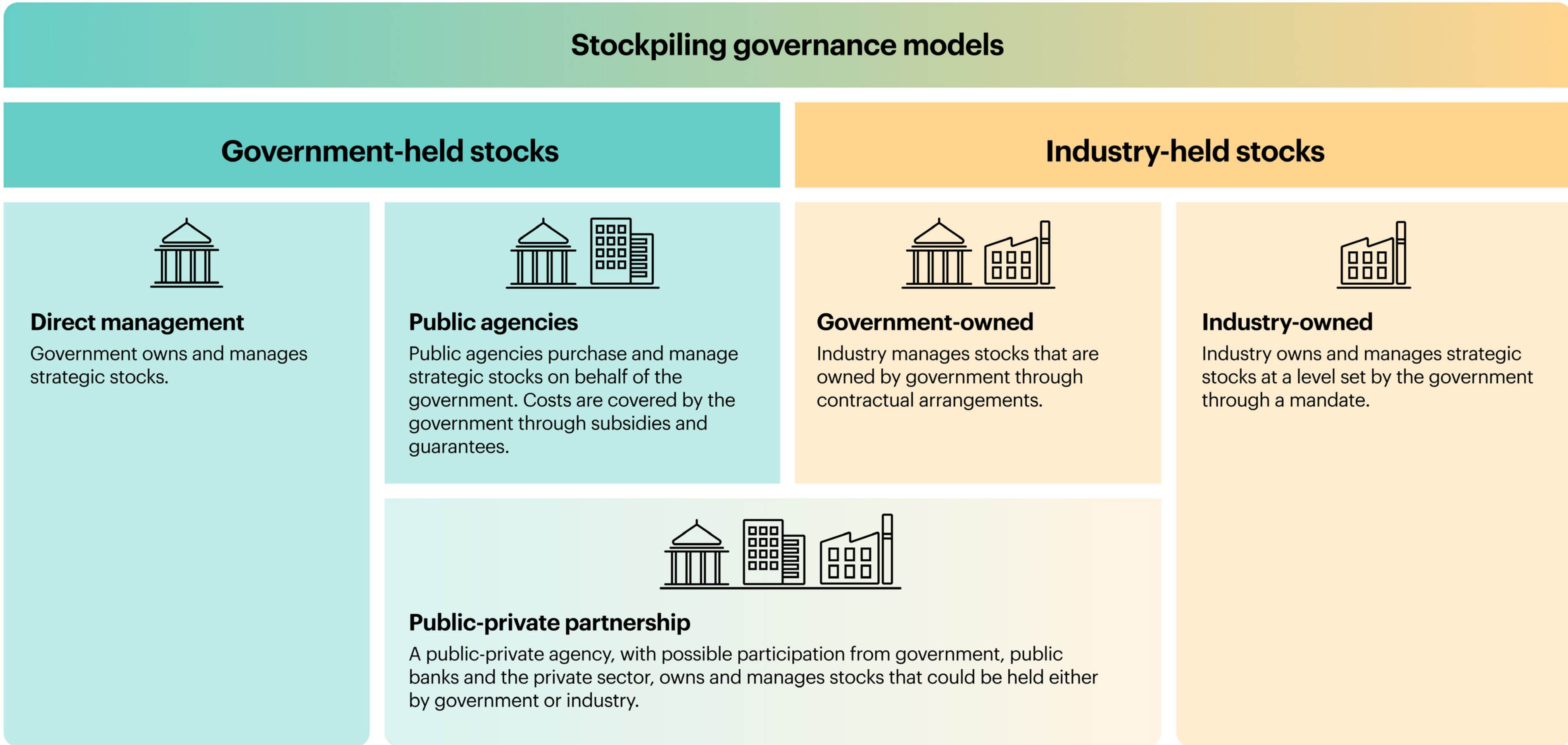
2. Identifying critical sectors that would need to be prioritised in case of supply shortages.

3. Preparing a set of measures that would be considered in case of an emergency. These can act on the supply side, such as stockpile releases, production ramp-up or quick commissioning of new projects, or on the demand side, such as the prioritisation of specific sectors and incentives for efficient material use.

4. Creating, through specific agreements, an international network of partner countries that would be able to support, if possible, with additional supply or diplomatic engagement.

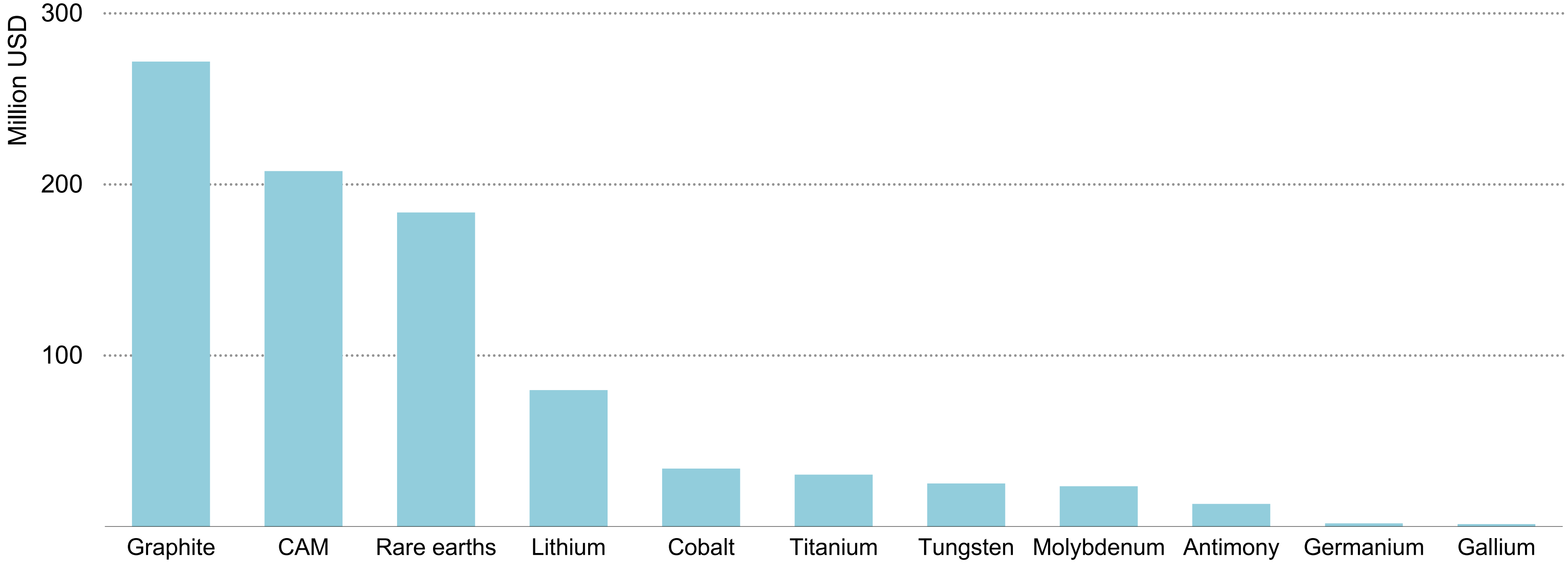
Stockpiling governance models should leverage government financing and industry expertise to ensure cost-efficient systems tailored to specific materials

Critical mineral stockpiling governance models



The cost of stockpiling materials exposed to the highest risk is less than USD 900 million at the global level

Operating cost of stockpiling materials for countries outside the largest supplier



Notes: CAM = cathode active material. The cost of stockpiling is equivalent to one year of imports from the largest supplier. Graphite includes artificial and spherical graphite; rare earths include magnet rare earth oxides and metals, neodymium-iron-boron powder and alloy, permanent magnetic sheets and permanent magnets; lithium includes lithium hydroxide and lithium carbonate; cobalt refers to unwrought cobalt; titanium includes titanium powder, shapes, sponge, tubes and pipes, and unwrought titanium; tungsten includes ammonium paratungsten, tungsten carbides, oxides and hydroxides, powders, trioxides, and wrought and unwrought tungsten; molybdenum includes molybdenum powders and roasted molybdenum; antimony includes antimony hydrides, sulphide, wrought antimony and oxides; germanium includes wrought and unwrought germanium; and gallium includes wrought and unwrought gallium.

The feasibility of stockpiling varies by material, but warehousing challenges can be overcome through temperature control, packaging and stock rotation

Assessment of material properties and stockpiling warehousing requirements for selected strategic minerals

	Material properties				Warehousing requirements			
	Hygroscopicity	Reactivity	Hazardousness	Fragility	Temperature	Packaging	Transport	Stock rotation
Anode material	Medium	Low	Medium	Low	Low	Medium	Low	Medium
Antimony trioxide	High	Low	Low	Low	Low	High	Low	Low
Black mass	High	Low	Medium	Low	Low	Medium	Low	Low
Cathode active material	Medium	Medium	Medium	Medium	Low	High	Low	High
Chromium (ferrochromium)	Low	Medium	Low	Low	Low	Medium	Low	Low
Cobalt sulphate	Medium	High	High	High	Low	High	High	High
Cobalt (unwrought)	Low	Medium	Medium	High	Low	Medium	High	Low
Copper cathode	Low	Low	Low	Low	Low	Low	Low	Low
Gallium metal	Low	High	Medium	Low	High	Medium	High	Low
Germanium metal	Low	Low	Low	Medium	Low	Medium	High	Low
Graphite (coated spherical)	Medium	Low	Medium	Low	Low	Medium	Low	Medium
Indium ingot	Low	Low	High	Low	Low	Medium	Low	Low
Lithium hydroxide	High	High	High	Low	Low	High	High	High
Lithium carbonate	High	Low	Low	Low	Low	Medium	Medium	Low
Manganese sulphate	Medium	High	High	Low	Low	High	High	Low
Molybdic oxide	Low	Low	Low	Low	Low	Medium	Low	Low
Nickel sulphate	High	High	High	High	Low	High	High	High
Niobium pentoxide	Low	Low	Low	Low	Low	Medium	Low	Low
Magnet rare earth oxides	High	Low	Low	Medium	Low	Medium	Low	Low
Magnet rare earth metals	Medium	Medium	Low	High	Low	High	Low	Low
Rare earth magnets	Medium	Low	Low	High	Low	High	High	Medium
Silicon metal	Low	Low	Low	High	Low	Medium	Low	Low
Tantalum metal	Low	Low	Low	Low	Low	Medium	Low	Low
Elemental tellurium ingots	Low	Low	Medium	Medium	Low	Medium	High	Low
Titanium ingots	Low	Medium	Medium	Low	Low	High	Low	High
Tungsten ingots/rods	Low	Low	Medium	Low	Low	Medium	Low	Low
Vanadium pentoxide	Low	High	High	High	Low	High	High	Low
Zirconium ingots	Low	Medium	Medium	Low	Low	Medium	Low	Low

High / Medium / Low

Notes: Magnet rare earth oxides and metals include neodymium, dysprosium, praseodymium and terbium. The scores assigned to material properties and warehousing requirements indicate how each material compares with the others, based on materials' safety data sheets and industry interviews. Hygroscopicity is the material's sensitivity to humidity, reactivity refers to its tendency to react with air, hazardousness indicates potential physical and health hazards, and fragility reflects the risk of damaging the material when handling it. Temperature refers to the need for delicate temperature control in the warehouse, packaging indicates the need for advanced packaging, such as storage in inert gas, transport reflects the need for special caution when transporting the material, and stock rotation refers to the frequency at which stocks need to be replaced because of their short shelf lives.

Strategic stockpiling provides a supply buffer to gain time in case of sudden disruptions

Strategic stockpiles of critical minerals, held specifically for emergency purposes with the involvement of the government, can play an important role in providing emergency supply in case of severe supply disruptions. Even when they are not used, they send a signal to markets that sudden supply shocks or export restrictions need not immediately cripple the system.

In the oil market, strategic stocks have been proven effective over many decades as a tool to prevent and respond to supply disruptions. Since the creation of the IEA, there have been six collective actions. The sixth and largest collective action was implemented on 11 March 2026 in response to disruptions stemming from the conflict in the Middle East. Critical mineral markets operate in a very different context from oil markets. However, stockpiles can still play an important role in providing emergency supply and protecting industries and jobs. Some countries, such as Japan, Korea and the United States, hold strategic stockpiles of critical minerals that have protected industries during past supply disruptions.

One of the key steps in emergency preparedness is the identification of possible vulnerabilities, typically through risk assessments. A fundamental risk assessment involves classifying minerals according to the risks associated with them. The IEA Critical Minerals Stockpiling Assessment Framework was developed to analyse the risks and challenges for each material across multiple dimensions: supply risk, availability of alternative supply routes, strategic importance and feasibility of stockpiling.

The feasibility of stockpiling varies by material, as each mineral takes different forms along its supply chain. The form most suitable for stockpiling is generally the imported form, which is most exposed to disruption risks and can be used directly domestically in case of a disruption, without the need for further processing abroad. A broad assessment of the properties of strategic materials imported by IEA Member countries highlights a number of warehousing challenges for certain minerals, such as hygroscopicity (sensitivity to humidity), reactivity, hazardousness and fragility. For example, lithium hydroxide is highly sensitive to humidity and degrades quickly in air, reducing its shelf life to around six months, while lithium carbonate can be stored for much longer. Gallium has a melting point of around 30 °C. These warehousing challenges can be overcome, for example, by controlling warehouse temperature and humidity, using advanced packaging to minimise contact with air and moisture, and rotating stocks of materials with short shelf lives. However, these additional requirements increase the cost and complexity of stockpiling.

Stockpiling governance

Strategic stockpiling systems can follow a spectrum of governance models that can be grouped into two broad categories based on where the minerals are physically stored: government-held models and industry-held models, each with two main options. For government-held (centralised) stockpiling models, the government owns and manages the stockpiles, either directly or through a public agency acting on its behalf. Industry-held (decentralised) models require companies to store strategic stocks in addition to their existing commercial inventories. A public-private partnership that owns and manages the stocks can also be established, combining the advantages of government-held stocks, such as lower financing costs, and industry-held stocks, such as a close relationship with the private companies that ultimately use the materials.

The appropriate stockpiling governance model varies by material and depends on the domestic context and supply chain structures. In the case of rare earths, for example, the storage of more upstream materials such as rare earth oxides or metals, which could be used by multiple downstream magnet manufacturers, could benefit from stronger government involvement and centralised stockpiling. When stockpiling materials that are closer to downstream products, such as rare earth permanent magnets, industry-held models may be better suited, as each company can store the specific materials it needs and rotate stocks more efficiently. Stockpiled materials should be imported materials that are capable of being rapidly deployed. For example, if there are no domestic magnet manufacturing facilities, it would be beneficial to directly stockpile the permanent magnets required domestically.

Stockpiling costs

The total cost of stockpiling comprises both the initial purchase cost and the operating cost. However, the investment to purchase the material is transformed into an asset that is later sold, either for stock rotation or for a stock release. The real cost is therefore the operating cost of stockpiling, which comprises the financing cost, warehousing cost, logistics cost, material losses and discount. The discount cost is associated with the need to refresh stocks by selling them at a discount before they reach the end of their shelf life.

The net annual cost of stockpiling the 11 high-risk materials identified by the IEA Critical Minerals Stockpiling Assessment Framework amounts to less than USD 900 million. The purchase cost, which is converted into the stockpile's asset value, is USD 9.2 billion. This amount, while significant, is quickly dwarfed by the potential direct economic impact of supply disruptions, which can be as high as USD 6.5 trillion in the case of rare earth disruptions and over USD 300 billion for graphite disruptions.

International co-ordination

While the objective of stockpiles is to strengthen the security of domestic supply, co-ordination with international partners can help achieve greater security more efficiently and quickly. Alignment on

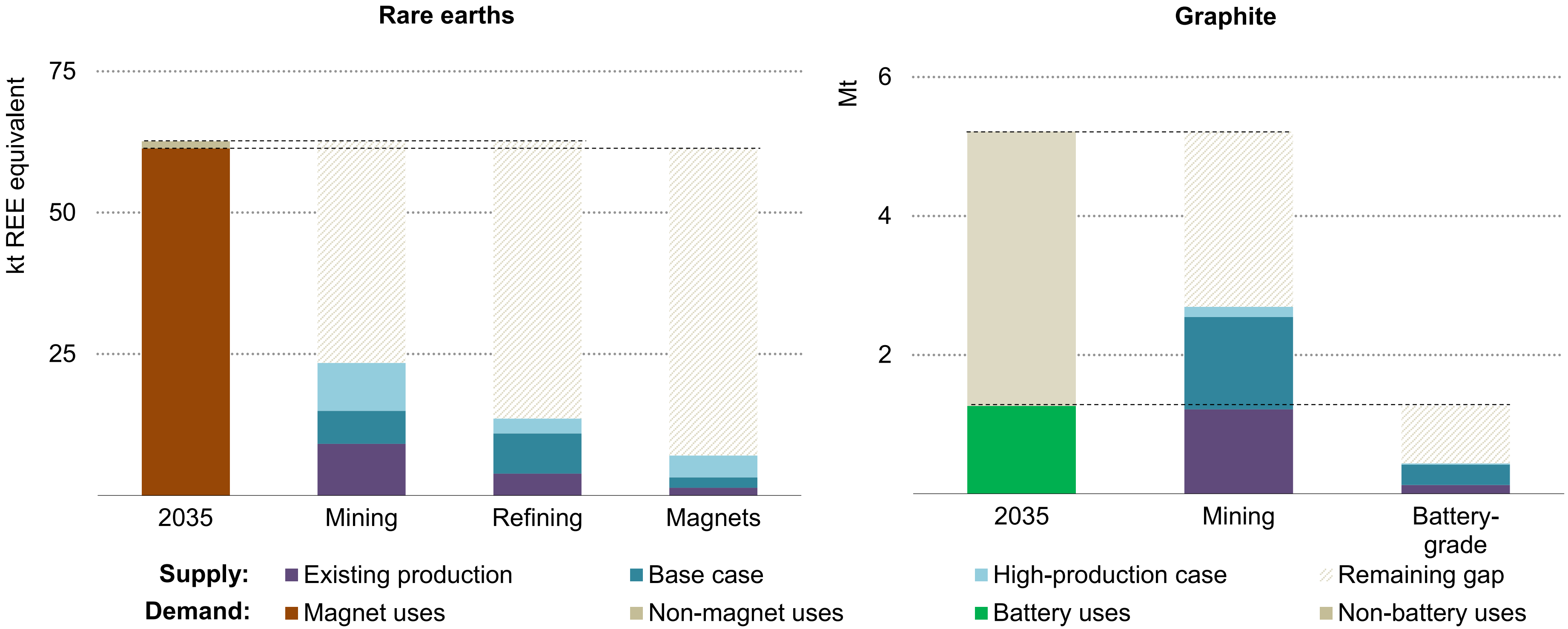
the timing of stockpile purchases and the establishment of principles for releases can help ensure that markets are not distorted. When procuring stocks, countries could also agree to support strategic projects that would increase global diversification or aggregate demand. When compatible with domestic policies, countries might co-locate stocks for greater efficiency, particularly for low-volume

materials, or reserve production in countries with production infrastructure for emergency use. Close dialogue among partners also facilitates the transfer of knowledge on efficient stockpile management.

Policy and market frameworks to diversify supply chains

Meeting demand through diversified supply sources requires major new capacities across mineral value chains

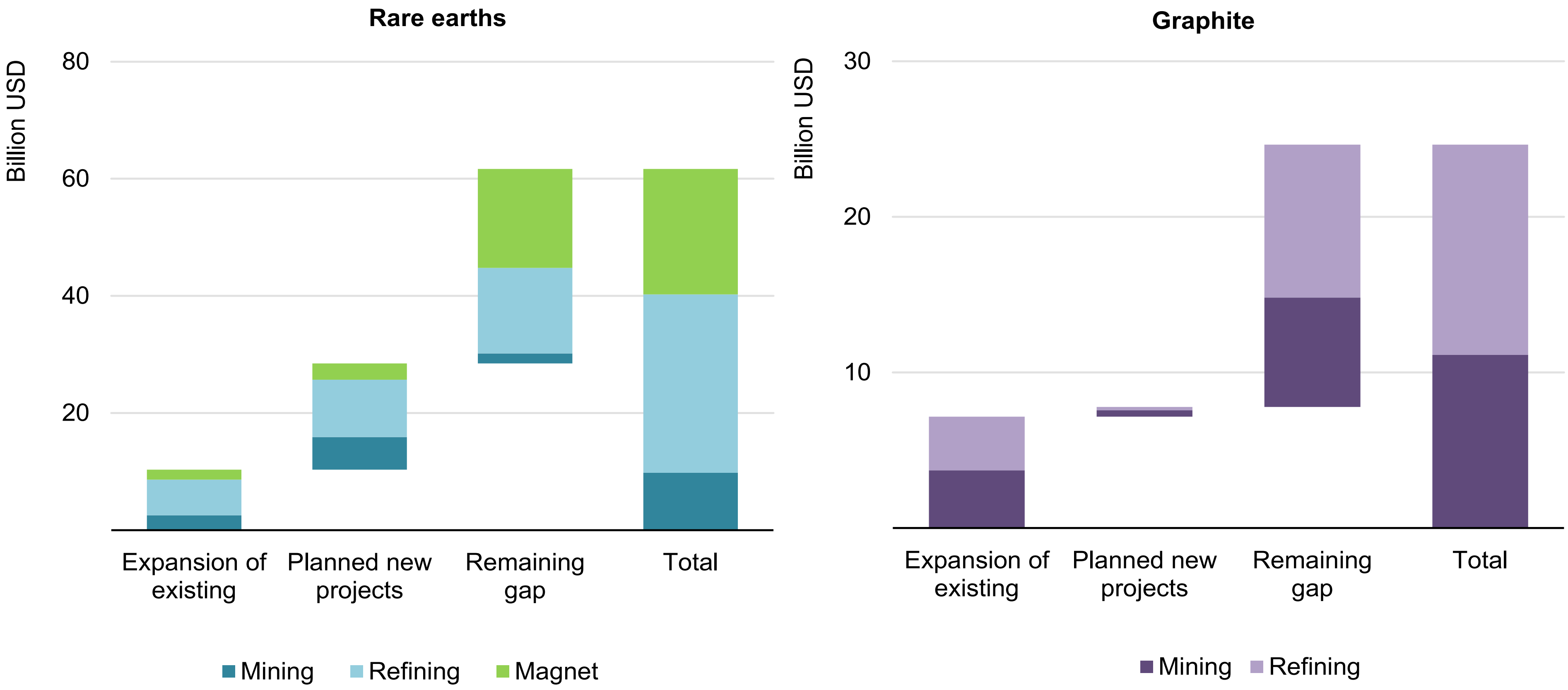
Demand and production from existing and announced projects outside the top producer, 2035



Notes: REE = rare earth elements. Recycling has the potential to reduce the remaining gaps. Rare earths are for magnet rare earths only (neodymium, praseodymium, terbium and dysprosium).

In the case of rare earths and graphite, closing the supply gaps requires just under USD 90 billion in investment outside the dominant supplier

Investment requirements to 2035 to meet projected demand outside the top producer



Notes: Investment requirements are estimated by multiplying the gap between projected supply and primary supply requirements by capital intensity. Capital intensities are estimated using reported capital expenditure and production capacity.

Sources: IEA analysis based on data from company reporting, Wood Mackenzie and S&P Capital IQ.

An essential first step towards long-term supply chain security and diversification is understanding the required scale of supply additions and investment

Developing diversified critical mineral supply chains requires a clear understanding of current and future needs. Without this, it is difficult to assess the need for capacity expansion, estimate investment requirements and co-ordinate policy targets effectively. While demand is relatively well understood in large markets, such as copper and battery metals, many smaller strategic minerals, including rare earths and graphite, have more limited data visibility on future requirements.

An "N-1" assessment of demand and supply can provide a useful way of assessing the required capacity additions. For example, in both rare earths and graphite, the largest global supplier is also the largest consumer. It is therefore valuable to examine demand and production capacity excluding this supplier (and consumer). Outside this market, existing supply remains insufficient to meet demand, leaving countries dependent on large-scale imports. This dependence exposes strategic downstream industries to supply risks, as highlighted by recent export controls.

For rare earths, current supply outside the dominant supplier accounts for approximately 50% of mining, 30% of refining and 15% of magnet demand. Although capacity expansions and new supply are expected to emerge in geographically diverse regions over the next decade, they remain insufficient to meet growing demand. By 2035, a gap of over 40% for mining, 50% for refining and just over 80% for magnet manufacturing persists.

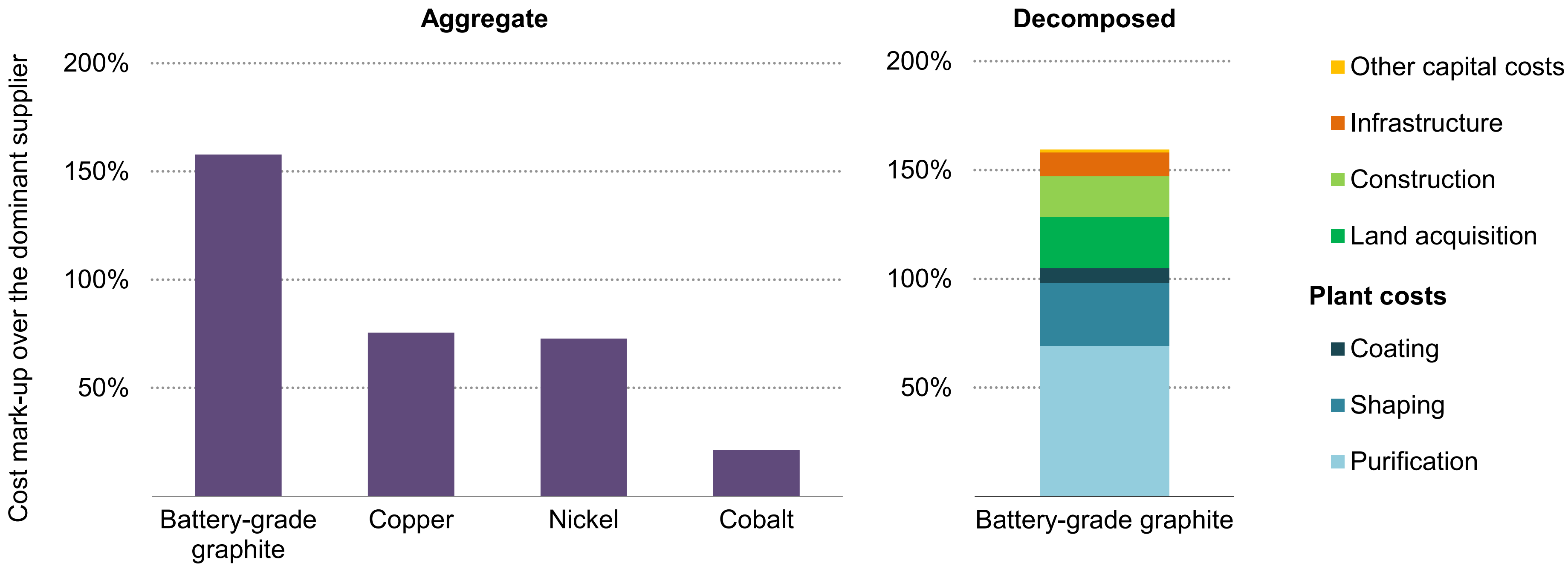
A similar dynamic is observed in graphite. Despite emerging demand outside the dominant supplier, current diversified supply meets only about 50% of mined and battery-grade graphite demand. Announced projects will expand capacity but are not sufficient to close the gap by 2035.

Closing these gaps requires just over USD 60 billion in rare earth investment and almost USD 30 billion in graphite investment over the next decade, including financing for announced projects and for the additional capacity needed to close the remaining supply gap. Refining requires the largest amount of investment across rare earths and graphite. For rare earths, magnet manufacturing also requires substantial investment of USD 21 billion.

Despite the strategic importance of diversification, persistent cost and financing challenges have impeded investment in diversified supply chains. The most fundamental constraint is the structural cost differential between projects in incumbent regions and those in geographically diverse jurisdictions.

Capital costs for critical mineral refining projects range from 20% to over 150% higher in the rest of the world compared to the dominant supplier, driven by facilities and equipment costs

Capital cost differentials between the top producer and the rest of the world

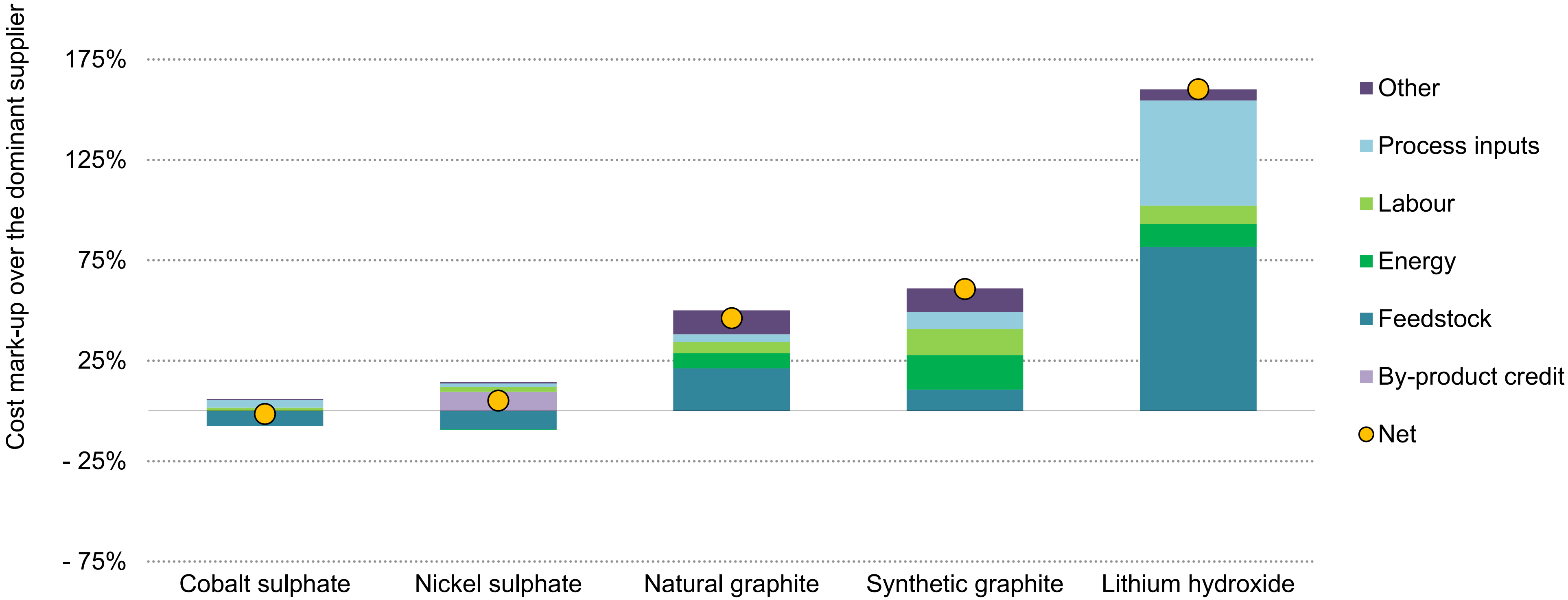


Notes: Plant costs refer to the cost of process facilities and the associated equipment directly involved in transforming ore, concentrate, intermediates or chemicals into the final product. Other capital costs refer to contingency, indirect costs and other expenses. The dominant supplier is Indonesia for nickel and China for all other materials. The aggregate capital cost figures are for refining.

Sources: IEA analysis based on data from company reporting, S&P Capital IQ and Wood Mackenzie.

Operating costs are 50% higher in the rest of the world compared to the dominant supplier, largely driven by feedstock, energy and process input costs

Operating cost differentials between the top producer and the rest of the world

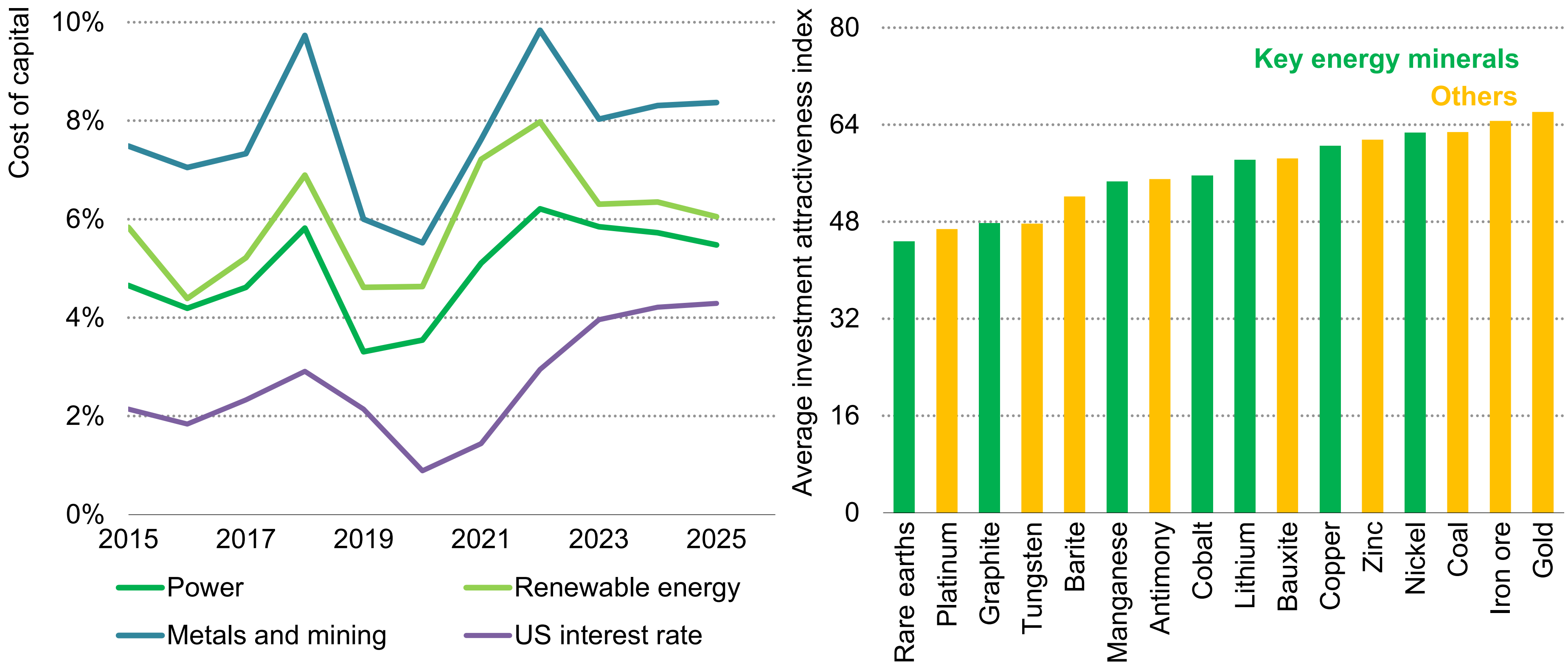


Notes: Process inputs refer to reagents, reactants and consumables. Other costs include general and administrative, tailings, and royalty costs.

Sources: IEA analysis based on data from company reporting; S&P Capital IQ; Wood Mackenzie; and Bhuwalka, K. et al. (2026), Securing the Supply of Graphite for Batteries.

Costs of capital for critical mineral projects tend to be higher than those for other energy sectors due to higher market volatility and a low leverage ratio

Cost of capital and average investment attractiveness in selected industries and minerals



Notes: The cost of capital for each sector is calculated as the average for relevant companies operating in the United States and Europe, with the full list of companies included in each industry available from Damodaran (2026). Investment indexes are calculated by weighting investment attractiveness indexes from the Annual Survey of Mining Companies by country-proven reserves, as in Vespignani and Smyth (2024).

Sources: IEA analysis based on data from Damodaran (2026), Cost of Capital by Industry Sector; and Vespignani and Smyth (2024), Artificial Intelligence Investments Reduce Risks to Critical Mineral Supply.

Higher costs and market conditions are constraining investment in diversification

Multiple factors have hampered investment in diversification, but one of the most persistent barriers is economic. Across critical mineral value chains, projects in geographically diverse regions face structurally higher costs than incumbent producers, both in terms of upfront investment and ongoing operational costs. These disadvantages are compounded by volatile prices, demand uncertainty in smaller markets and weak downstream ecosystems, all of which undermine project bankability and make diversification difficult to achieve through market forces alone.

IEA analysis indicates that capital costs for refining projects in the rest of the world are significantly higher than in today's leading producing countries, ranging from 20% to over 150%. Decomposing the factors driving this difference for battery-grade graphite, the largest are the over 100% higher plant costs, reflecting the benefits that incumbent producers derive from larger industrial bases, more standardised plant designs and better access to technology. Construction costs are also over 20% more expensive, due in part to the lack of supporting infrastructure and specialised engineering capabilities, and contingency and indirect capital costs, which are 50% higher.

Operating costs are also significantly higher outside the leading producer, averaging around 50% above incumbent levels, with the main drivers varying significantly depending on the mineral and processing route. Feedstock costs are a major component across all minerals and an important source of cost differentials in several cases. For graphite and lithium hydroxide, greater reliance on imported intermediates and less-integrated processing ecosystems outside the dominant supplier, China, contribute to higher feedstock costs. By contrast, feedstock costs for cobalt sulphate and nickel sulphate are lower on average outside China, reflecting the ability of other major producing regions to secure domestic feedstock. Higher process input costs, including reagents and consumables, also play an important role in driving the cost differential, particularly for lithium refining, which relies on sulphuric acid, soda ash and other purification reagents. Economies of scale, plant utilisation rates and process efficiencies in incumbent processing hubs can further reinforce these advantages.

The differences are particularly important in refining, where margins are often thin and competitiveness depends heavily on access to low-cost inputs, scale and process optimisation. The result is that even where projects can secure financing and reach production, sustaining operations may remain challenging in the face of low-cost incumbent supply.

Beyond individual cost components, incumbent producers often benefit from integrated industrial clusters in which by-products and waste streams from one industry serve as inputs for another, lowering overall operating costs and improving system efficiency. These ecosystems benefits can also include shared infrastructure, such as water treatment facilities, logistics networks and waste management systems, which reduce costs for individual operations.

Market structure further worsens these cost disadvantages. In many mineral markets, limited price transparency makes it difficult to form reliable revenue expectations or design effective support mechanisms. At the same time, demand uncertainty remains high, especially for smaller strategic minerals where future consumption depends on the pace of downstream industrial development, technology choices and policy commitments. Relatively small physical market sizes can also mean that a limited number of new projects can lead to excess supply, raising downside price risks and weakening project bankability. In highly concentrated markets, prices are often set by the lowest-cost producers, limiting the ability of higher-cost diversified projects to recover their full costs.

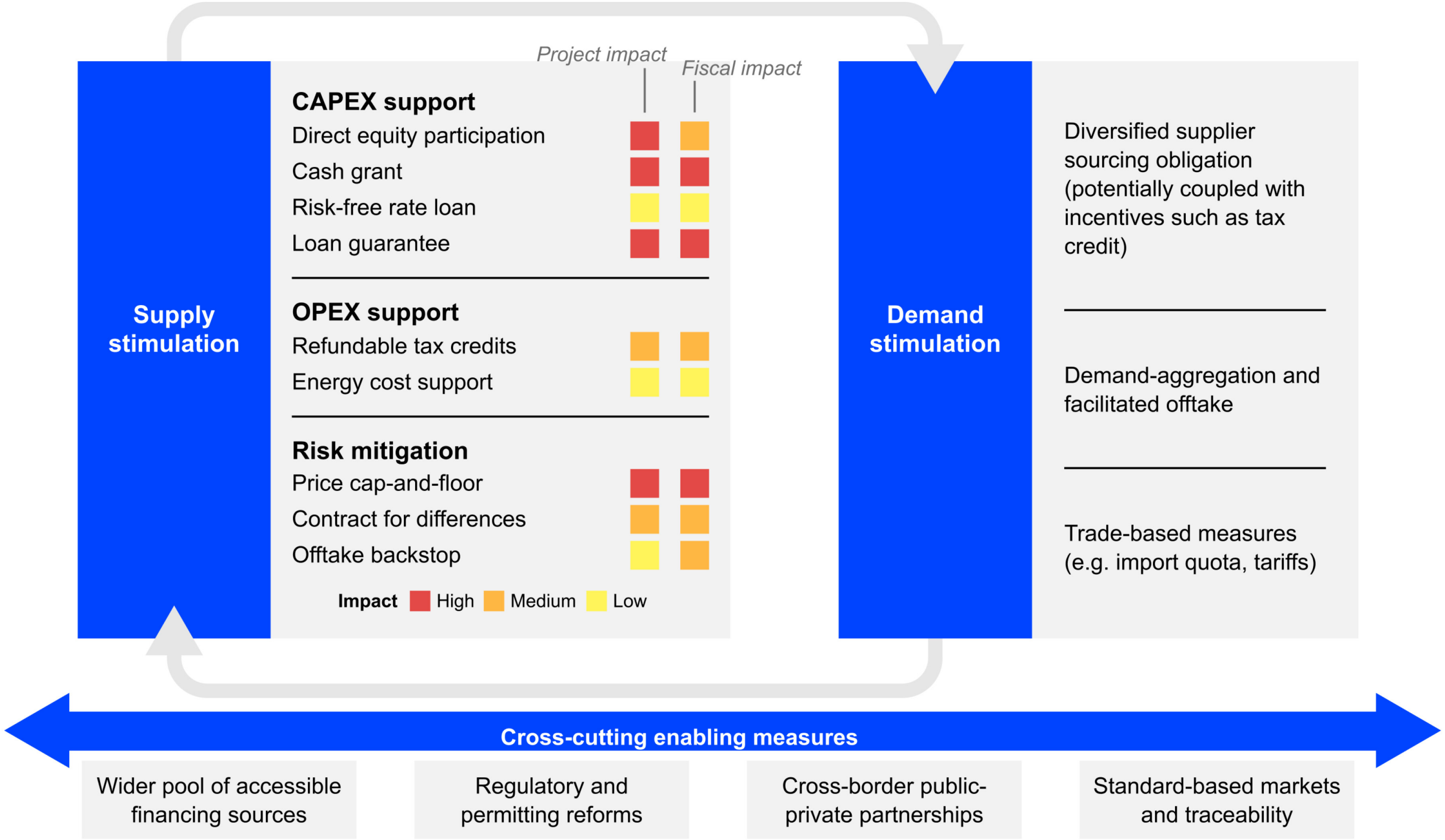
Taken together, these factors contribute to an elevated risk profile for critical mineral projects. Opaque pricing and uncertain offtake weaken confidence in future cash flows and make it more difficult to secure long-term contracts or debt financing. Additional uncertainties around resource and product quality, offtaker creditworthiness, interdependencies across the supply chain and project development risks, such as cost overruns, further erode investor confidence.

As a result, access to debt financing is often constrained, leading to lower leverage ratios and greater reliance on equity. This raises the overall cost of capital for critical mineral supply chain investments, resulting in much higher financing costs than in traditional energy sectors. Over the past ten years, metals and mining companies headquartered in Europe and the United States have paid an almost 50% premium on raising capital relative to companies operating in power generation. Challenges in raising debt financing also force companies to rely on a much higher share of expensive equity financing, pushing up their costs of capital.

Building diversified critical mineral supply chains will require the cultivation of an ecosystem that addresses the key structural barriers preventing competitive supply from coming and staying online. This will require a co-ordinated package of policies that addresses market and financing challenges, including investment risk, market structure, lack of technology and operational know-how, and co-ordination gaps, while balancing incentives for both supply-side and demand-side development. No single instrument will be sufficient on its own; rather, measures need to reinforce each other to shift supply chains in a meaningful way.

A combination of targeted supply- and demand-side measures is required to de-risk projects and crowd in private capital in order to build diversified critical mineral supply chains

Supply- and demand-side policy tools to support diversification



Notes: CAPEX = capital expenditure; OPEX = operating expenditure.

Targeted capital expenditure and operating expenditure support can de-risk projects and crowd in private capital

Support measures on the supply side can improve project viability by easing upfront financing needs or operational risks. These measures broadly fall into three groups: capital expenditure (CAPEX) measures, such as equity, grants, concession loans and loan guarantees; operating expenditure (OPEX) support, which can reduce operating cost drivers such as through facilitating access to competitively priced feedstock or energy cost reductions; and risk-mitigation measures that reduce price and volume risks, such as contracts for difference or volume-based tools such as offtake backstops. CAPEX and OPEX support can help improve bankability, crowd in private capital and accelerate final investment decisions, while risk mitigation measures can improve financing conditions by reducing price and volume risks.

CAPEX support

Governments can support strategic projects through a variety of capital support mechanisms, such as equity, concessional loans, guarantees and grants, to ease upfront capital constraints and improve bankability.

Equity investments allow governments to take a direct stake, which may be particularly relevant for strategic projects. Public equity participation can strengthen project balance sheets, reduce the amount of private capital needed at the outset and signal strong government backing, which can help attract additional investors. This can be particularly valuable for high-risk, capital-intensive projects with long return horizons. However, such investments require clear and robust governance frameworks, including well-defined shareholder rights and obligations, robust conflict-of-interest safeguards, indemnification clauses, arbitration mechanisms and pre-agreed dispute resolution procedures to ensure transparency, avoid conflicts of interest and allocate risk appropriately. Measures should clearly specify who absorbs any losses, how cost overruns or delays are managed and the terms under which private co-investment is structured. Mechanisms should also be designed in a way that ensures the recouping of upside returns, which can help align incentives and ensure that support delivers long-term public value.

Governments can also provide concessional loans, loan guarantees or grants to reduce early-stage risks and unlock commercial lending, particularly in regions with weaker financial ecosystems. Concessional loans featuring below-market interest rates, longer tenors or grace periods can significantly improve project economics and help de-risk capital-intensive phases. Loan guarantees can unlock commercial lending by reducing lenders' credit exposure, making them particularly useful in jurisdictions with less mature financial markets or high political risks. Grants, while more fiscally demanding, can be used in targeted ways to support pre-commercial stages, such as feasibility studies, pilot plants and technology qualification, or to lower the cost of installing strategic infrastructure to enable multiple projects. These forms of support can be tailored to project needs and deployed in combination to maximise impact.

Project eligibility for capital support can be determined through a strategic assessment of priority segments, taking into account where supply gaps are most acute and where diversification benefits are greatest. Alternatively, support can be allocated via competitive auctions to ensure transparent and efficient allocation. Governments can also prioritise projects in nascent industries, such as magnet manufacturing, or those adopting less mature technologies.

OPEX support

While CAPEX support measures can help bring forward new projects, sustaining their operations may require complementary OPEX measures that work more directly on operating cost drivers to improve project competitiveness. Key operating cost components include feedstock, energy, reagents, labour, logistics and environmental management.

Targeted measures can reduce the cost gaps faced by diversified players by lowering input costs, improving access to infrastructure and enabling operational efficiencies. These measures could include facilitating access to competitively priced feedstock through integration or offtake agreements; reducing energy costs via preferential tariffs, long-term power contracts or access to low-cost renewable electricity; supporting the domestic supply of key reagents and process inputs; and investing in shared infrastructure, such as transport, utilities and waste treatment.

Risk mitigation

Building diversified supply also requires reducing both price and volume risks, enabling projects to operate through periods of market volatility. This can be particularly useful for materials with small market sizes, high levels of concentration and significant potential economic impacts in the event of disruptions, although their use must be carefully assessed against the potential fiscal costs.

Risk mitigation: Revenue stabilisation mechanisms (price-based)

Price-based mechanisms are designed to reduce revenue uncertainty by ensuring that operators receive a guaranteed minimum revenue for their output. These can be implemented through a two-sided contract for difference, or a price cap-and-floor mechanism, where there is an agreed strike price and reference price. These mechanisms provide support to an operator when market prices fall below the strike price and require repayment to the government when prices exceed it, thereby reducing revenue volatility while limiting fiscal exposure. The operator then sells its products at regular market prices and settles the difference between the strike price and the reference price, improving bankability and allowing sustained production in volatile markets, with limited distortion to downstream pricing as products continue to be sold at market prices.

Contracts for difference have been used widely in European renewable electricity markets, where they have helped finance 33% to 50% of new offshore wind capacity since the late 2000s. More recently, they have started to be used in some mineral markets, particularly in small, nascent markets such as rare earths.

However, effective design is critical to ensure success, including setting the strike and reference prices (see box 3.1 for more information) and determining the length and allocation of contracts. Contract allocation can be undertaken through bilateral negotiation or competitive auctions. In auction-based approaches, governments set a budget or capacity target and award contracts to the lowest bids, with successive rounds used to bring forward additional projects as market conditions, price dynamics and project developments evolve. Contracts are typically time-bound, with durations in the power generation sector often around 15 years.

It is also crucial to ensure that markets remain competitive. To incentivise cost reductions over time, eligibility for price-based mechanisms could be linked to performance targets, or strike prices could be adjusted progressively, including through successive allocation rounds, to encourage projects to narrow the cost gap with incumbent producers while limiting fiscal costs.

Risk mitigation: Demand assurance mechanisms (volume-based)

In addition to price, predictable and bankable demand is critical for investment decisions. Even when prices are favourable, uncertainty around future offtake can prevent projects from reaching final investment decisions or scaling to commercially viable levels. Volume-based mechanisms address this by providing demand certainty, reducing revenue risk and improving bankability, typically by guaranteeing a minimum level of sales rather than a minimum price.

In practice, these can be operationalised through contractual clauses such as offtake backstops, where a public entity guarantees minimum purchases or payments if commercial demand falls short. This provides producers with an assured market while allowing governments to support supply chain deployment and, in some cases, build strategic reserves. Recent examples include government agreements with MP Materials and Nouveau Monde Graphite.

These tools have long been used in infrastructure, electricity and commodity markets. In some export projects for liquefied natural gas, state-backed utilities or buyers commit to long-term minimum volumes through take-or-pay contracts, effectively underwriting project viability. While often commercial rather than purely governmental, similar structures could be publicly backed in strategic sectors.

Design considerations include determining guaranteed volumes, eligibility criteria, contract duration and risk-sharing arrangements, while balancing improvements in investment attractiveness against fiscal exposure and risks of oversupply. As with other instruments, co-ordination across countries can strengthen demand signals, expand the pool of eligible projects and improve overall effectiveness.

Box 3.1 Price support measures require appropriate strike and reference prices

Effective design of strike and reference prices is crucial to ensure the success of price-based mechanisms. Strike prices must balance project viability with fiscal cost: if set too low, they fail to support investment; if set too high, they create excessive public liabilities. For example, under the United Kingdom's contract for difference system for renewable energy, no offshore wind developer bid for support during Allocation Round 5 in 2023, as industry actors judged that the strike price was too low and did not account for inflation in input costs.

The **strike price** can be determined in several ways. Cost-based methods can use production costs over a defined period of time, adding a margin for profit or using a percentile of the global cost curve. Market-based approaches can also be used, such as historical multi-year average prices or forward-looking price forecasts, potentially adjusted for regional cost differences. These can be simpler, though they may be uncertain in markets with low price transparency and may fail to support high-cost entrants if priced do not reflect current market conditions. Finally, a competitive bid process or bilateral negotiation can allow operators to bid their required price. Competitive bids can reveal true costs through competition but require sufficiently large project pools. Bilateral contracts can allow for flexibility but risk less efficient outcomes.

The **reference market price** determines whether the operator is entitled to fiscal support or must repay the government. It can be set in several ways. The actual realised sale price is the most accurate, as it reflects the actual price received by the producer, but it requires verification through reporting or auditing. Safeguards, such as cross-checking sales prices against independent indices or requiring evidence of competitive marketing, are also necessary to ensure that there are still incentives to secure the highest possible contract prices.

Another option is to use a published market price or index that would apply regardless of the individual negotiated price. This would depend heavily on market transparency and the credibility of available indexes, and would be more difficult in thin, opaque markets where many transactions occur off-exchange and published prices may not reflect actual traded values. Reference prices could also use a weighted average of global prices over a defined period of time, anchoring them in broader market trends.

Many critical mineral markets face heterogeneity in product quality and specifications, which can lead to significant variation in realised prices. Price mechanisms should therefore be designed to account for grade, purity or performance differences to ensure appropriate incentives and avoid mispricing.

Potential approaches to determining the appropriate strike and reference prices

Approach	How it is calculated	Key data requirements	Considerations
Strike price			
Cost-based	Operating cost per unit + return	Individual project-level CAPEX, OPEX, output and cost of capital	Ensures project viability, but causes information asymmetry and depends on cost assumptions
Cost curve benchmark	Cost of marginal (e.g. non-incumbent) producer	Global projects' CAPEX, OPEX, output and cost of capital	Requires robust cost data and may not reflect project-specific risks
Historical price	Average past prices, with possible adjustments	Historical price series, ex-China premiums	Transparent and simple, but may reflect unrepresentative market conditions
Forward-looking price	Expected future market price	Price forecasts	Highly uncertain
Auction-based	Lowest price bid by developers	Bids from competing projects	Requires sufficient competition and credible bids
Negotiated	Agreed price based on costs and market benchmarks	Project costs, benchmarks	Potentially inconsistent
Reference market price			
Realised sales price	Actual price received by producer	Contract prices, reporting/audit data	High accuracy, but limited transparency and higher administrative burden
Published price index	External benchmark price at time of sale	Price reporting agency/index data	Transparent and simple; may not reflect realised contract prices
Average price	Average of market prices over a defined period	Time series of prices	Reduces volatility, but introduces timing mismatches with realised sales
Auction-based	Proposed adjustment factor to external benchmark price	Price reporting agency/index data and bids from competing projects	Requires sufficient competition and credible bids; may not reflect realised contract prices

Demand-side policies can help shift sourcing decisions towards diversified supply

Supply-side tools can help bring diversified projects online, but in competitive markets dominated by low-cost producers, downstream users often lack incentives to switch suppliers. Demand-side policies can address this by generating predictable demand for diversified supply, helping projects secure long-term offtake agreements and investment. These tools are most effective when applied in contexts where cost gaps are moderate and there is access to refining technology or where such technology is being developed.

Diversified sourcing obligations

Diversified sourcing obligations require or incentivise manufacturers to source a share of inputs from non-dominant suppliers, shifting demand towards diversified supply. They can be implemented through regulations, such as minimum local content requirements that mandate a minimum share of inputs to be sourced domestically or from diversified suppliers. They can also be combined with fiscal incentives, such as tax credits or deductions conditional on a minimum percentage of inputs being sourced locally or from diversified sources. In strategic sectors, such measures may also extend to restrictions on sourcing from designated foreign entities of concern across supply chains.

Obligations can be applied to specific downstream products, such as EVs or data centres, or to various segments of the supply chain.

To remain effective and manageable, obligations should be phased in over time in line with project pipelines, allowing downstream manufacturers to gradually adapt to the sourcing requirements. While such measures may increase costs, impacts on downstream product prices are typically small and could be mitigated through targeted incentives that aim to offset any cost burdens, such as tax credits.

Demand aggregation and facilitated offtake

Demand aggregation and facilitated offtake can help create a consistent, sizeable and growing demand base. This is particularly relevant in value chains or segments where downstream supply chains are more nascent, such as EVs, new energy technologies and high-tech manufacturing. In the absence of growth in downstream capabilities in diversified regions, upstream and midstream projects may face weak or uncertain offtake, limiting investment and increasing exposure to price volatility. Policy measures that nurture strategic downstream industries in energy, automotive and high tech, and aggregate their demand, can underpin long-term contracts and support financing decisions. Countries with established manufacturing bases can also strengthen partnerships with regions that have significant end-use demand, reinforcing market confidence, enabling economies of scale and supporting the long-term competitiveness of emerging supply chains.

Trade-based measures

Trade-based mechanisms could shift demand by altering price competitiveness at the border, for example through tariffs, price bands or origin-based charges. By narrowing the price gap between low-cost incumbent supply and higher-cost diversified supply, these measures can help redirect demand towards diversified supply.

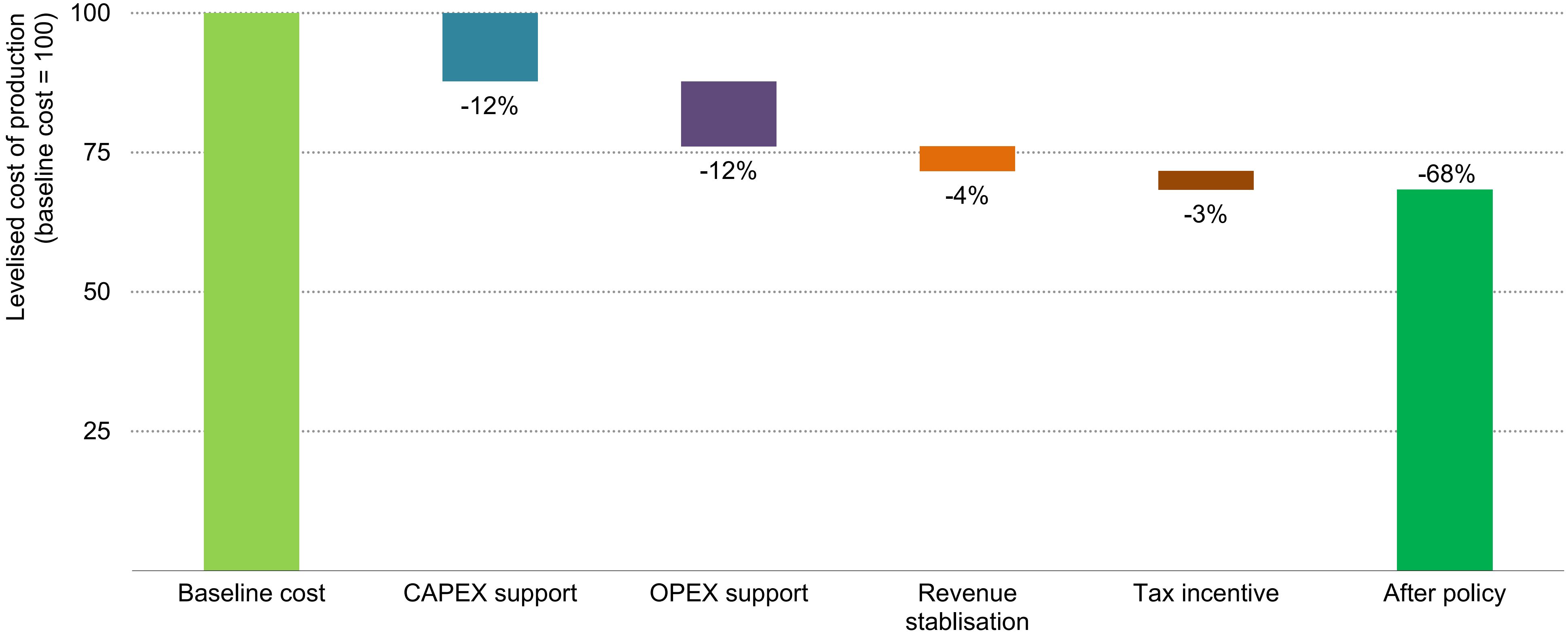
Their effectiveness depends on careful calibration of design elements. For measures such as price bands, if prices are set too low, they will fail to shift demand, whereas if they are too high, they can raise costs and fiscal risks. For measures such as tariffs, designing an effective approach would require detailed cost analysis across the value chain to determine appropriate tariff rates and assess where tariffs would be most applicable. Design must also account for downstream impacts, as higher input costs can affect the competitiveness of downstream manufacturing, potentially requiring mitigation measures such as revenue recycling.

Selected policy instruments and disbursements, 2025-2026

Type of instrument	Country	Amount	Description
Direct equity investment	United Kingdom	GBP 26.8 million	National Wealth Fund's direct equity investment in Cornish Lithium to support domestic tin extraction.
Conces-sional loan	Australia	AUD 1.65 billion	Concessional loan to Iluka Resources for the Eneabba rare earth refinery.
Loan guarantee	United States	Up to USD 250 billion	Loan guarantee authority extended to the Department of Energy's Energy Dominance Financing Office through FY2028.
Grant	Canada	CAD 1.5 billion	Non-repayable, repayable and grant funding for critical minerals projects, including mining, processing, transport and energy infrastructure, plus mine-site development and Indigenous engagement.
Offtake/ price floor	Japan	Undeter-mined	Agreement to purchase annual tonnage of neodymium-praseodymium until 2038 with an agreed market-linked floor price.

Different policy support options have varying impacts on the levelised cost of production…

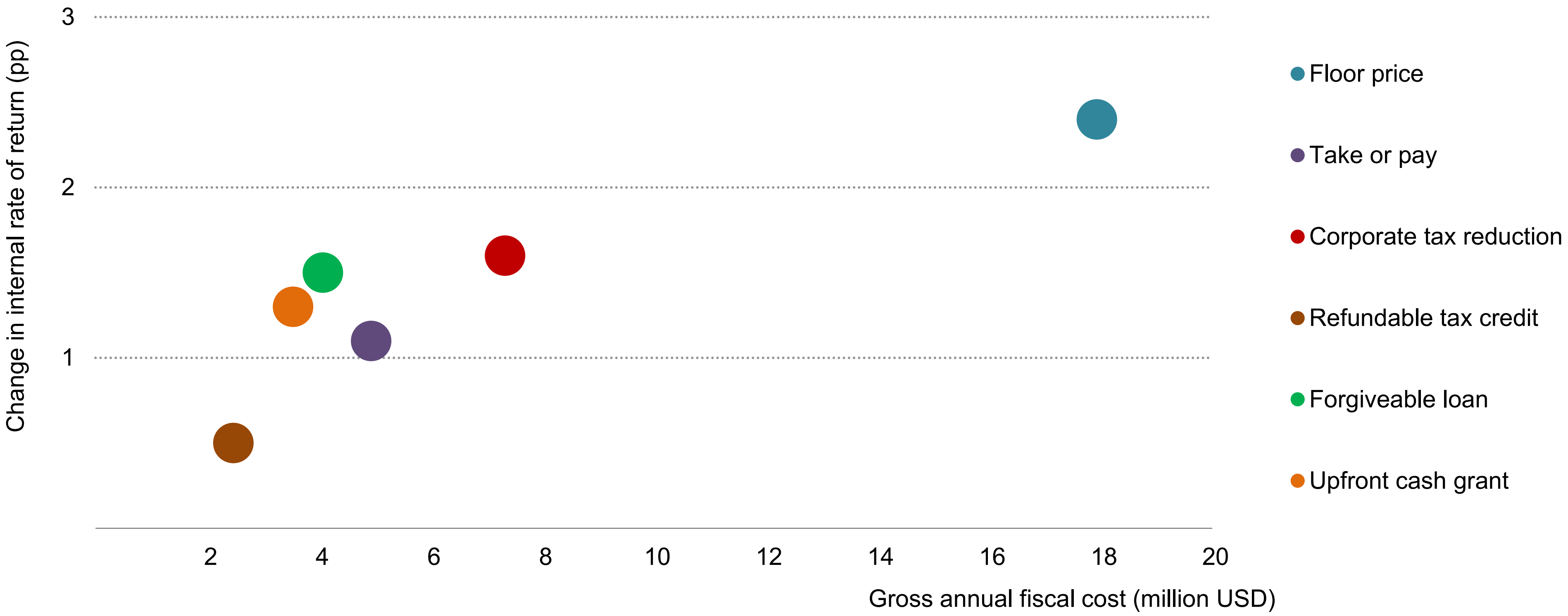
Impact of different policy support measures on the levelised cost of an average rare earth refining project



Notes: The levelised cost of production and the impact of cost reductions are estimated using a cash-flow model for an average diversified rare earth refining project. Policy support levels are set to have a fiscal cost of USD 100 million over the life of the project for CAPEX support, OPEX support and revenue stabilisation, while the tax incentive is a 5% reduction in the tax rate (USD 15 million gross fiscal cost).

…and different impacts on project economics and fiscal costs

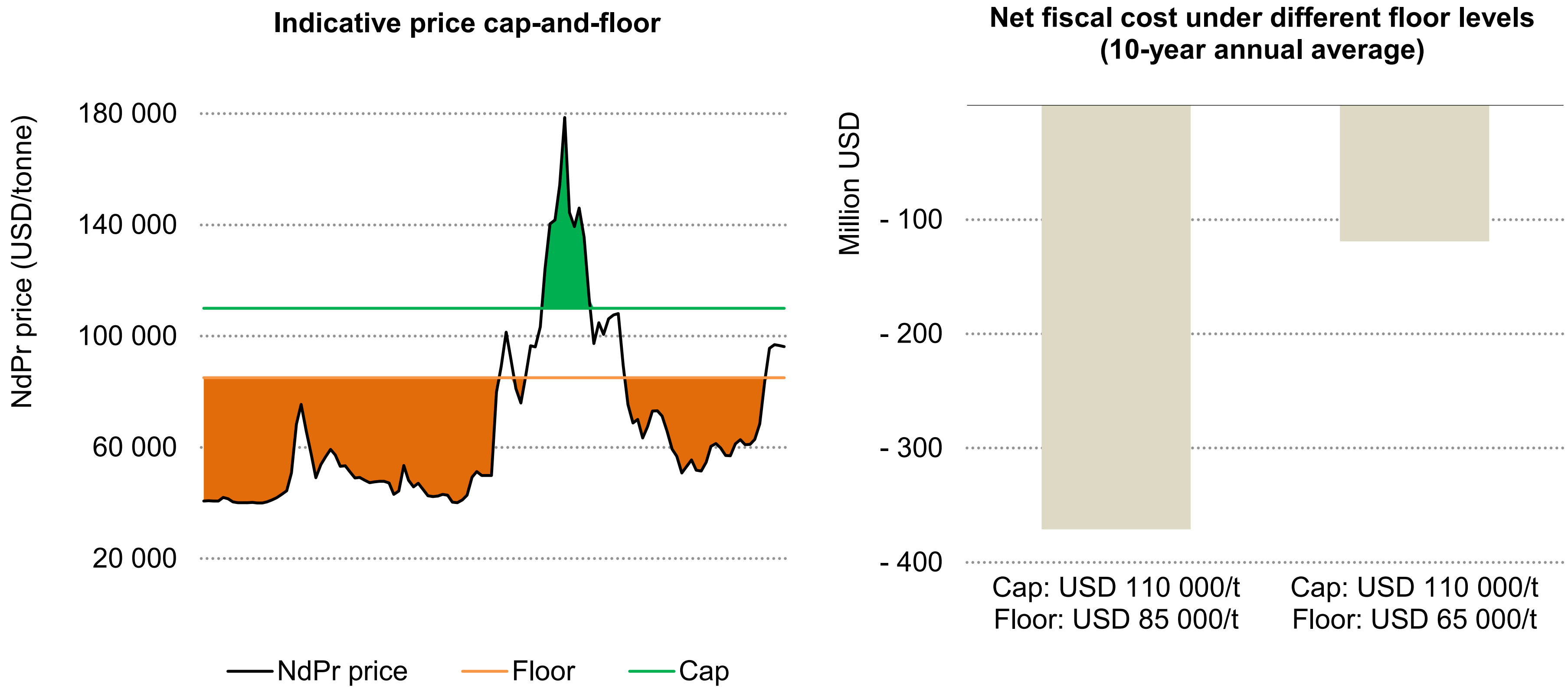
Impact of different policy support measures on the internal rate of return versus gross annual fiscal cost for an average rare earth refining project



Notes: pp = percentage points. The change in the internal rate of return and the impact on gross fiscal costs are estimated using a cash-flow model for an average diversified rare earth refining project. All results depend on assumptions used for the project and policy measures. For this analysis, the life of the processing facility is assumed to be 25 years. The price floor is set at USD 112 000/tonne of neodymium-praseodymium oxide; take or pay is set at 10% of annual volume; corporate tax rate is reduced from 25% to 15%; the refundable tax credit is 10% of operating costs; and the forgivable loan and upfront cash grant are set at 15% of initial upfront capital expenditure.

Policy support design matters for both fiscal impact and policy effectiveness

Cap-and-floor mechanism and fiscal cost to support half of refining demand outside the dominant supplier, 2026-2035



Note: NdPr = neodymium (Nd) and praseodymium. Fiscal cost refers to the cost of supporting ex-China projects to meet half of the remaining ex-China demand over the period to 2035, based on historical price movements over the last 10 years.

Effective policy design requires aligning instruments with specific market contexts, including market structure, scale and value chain characteristics

Different policy instruments affect project economics through distinct channels, and their impacts depend on the structure of each mineral market and value chain segment.

In small, opaque and volatile mineral markets (e.g. rare earths and gallium), supply chains are highly concentrated, with dominant price-setting producers and limited price transparency. Cost gaps between incumbent and diversified producers tend to be pronounced, reflecting factors such as scale, co-product economics, environmental compliance costs and technology lock-in. Price signals are often weak, limiting the ability of markets to incentivise new entry.

We evaluated the impact of different policy tools on the levelised cost of production and returns for a representative rare earth refining project outside the incumbent producer, using financial cash flow modelling. The results suggest that, for the same level of gross fiscal costs to governments, direct cost-reduction measures, particularly CAPEX and OPEX support, are among the most efficient instruments for lowering the levelised cost of production. By reducing either upfront investment requirements or ongoing operating costs, these measures directly improve the cost competitiveness of new refining projects, narrowing the competitiveness gap with incumbent producers.

By contrast, in large, liquid markets (e.g. copper and nickel), investment in diversified production is typically constrained by structural factors such as cost competitiveness, permitting, infrastructure availability and discoveries of new resources. In these cases, ongoing operating cost support is often less effective and can become fiscally prohibitive if applied at scale, given large volumes. Upfront capital support, such as concessional loans and loan guarantees, is generally better suited to addressing investment risk. Measures to accelerate permitting and support the build-out of enabling infrastructure (e.g. rail and power) can further support investment.

Battery metals markets (e.g. cobalt, lithium and graphite) are not as large and liquid as base metal markets but are more advanced than minor mineral markets. These markets are characterised by rapid demand growth, medium levels of concentration and strong linkages to downstream industries such as batteries and EVs. Competition is driven by a combination of energy and reagent costs, financing costs and integration with downstream offtake. Cost gaps for diversified producers may be relatively smaller than for strategic minor minerals, but bankability remains a constraint given project risks and price volatility. In this context, a blended approach may be better suited, combining upfront CAPEX support, such as grants or concessional finance, with targeted price or volume support, which can help de-risk investments, particularly in the early stages, allowing support to decline over time as technologies mature and cost gaps narrow.

Across the value chain, mining is typically capital-intensive and exposed to geological and development risk, making upfront capital support particularly relevant. Refining projects are more sensitive to costs and margins; in this case, operating cost tools may support competitiveness.

Demand-side measures can be applied across all markets, as they can provide volume guarantees or preferential market access that enable structural shifts in demand towards diversified supply. They may be particularly useful in large mineral markets, where capital support may be fiscally burdensome if applied at scale.

Public support must be carefully calibrated to reduce risk, crowd in private investment and enable bankability while ensuring that it does not sustain structurally uncompetitive production or create long-term fiscal liabilities. Policy makers need to assess capital and operating costs, cost gaps with incumbent producers and market-specific challenges, balancing policy effectiveness and fiscal cost, as different instruments have varying impacts on both the internal rate of return and public expenditure. For example, for an average rare earth refining project outside the incumbent producer, price cap-and-floor mechanisms produce a 2.4 percentage point change in the internal rate of return but an average annual gross fiscal cost of almost USD 18 million when applied during the first 15 years of repayment.

For strategic minerals and materials markets, the scale of support across the sector may not be overly fiscally burdensome given relatively small market sizes. We evaluated the fiscal cost of supporting rare earth refining projects located outside today's incumbent producer through a cap-and-floor contract for difference mechanism. Historical rare earth prices over the past decade were used to estimate support requirements, evaluating the impact of two different floor prices of USD 85 000 and USD 65 000 per tonne of total rare earth oxides, and a cap of USD 110 000 per tonne. The difference between market prices and this corridor defines the annual price gap that governments would either bridge or recover.

Projected supply outside China, including existing operations, expansions and planned projects, is compared with ex-China demand to estimate the volume of capacity requiring support. The analysis assumes that the mechanism covers the production needed to meet half of this demand by 2035. Multiplying this supported volume by the estimated price gap yields the fiscal cost.

Under these assumptions, the gross fiscal cost of such a cap-and-floor mechanism is estimated at around USD 3.7 billion through to 2035, equivalent to approximately USD 370 million per year under a floor price of USD 85 000 per tonne. Actual costs would depend on future price trajectories and the specific design of the support mechanism.

Cross-cutting enabling measures are required for a whole-of-ecosystem approach

Wider pool of accessible financing sources

High capital intensity, long lead times and specialised processing technology can limit critical minerals projects' ability to access traditional export credit agency and development finance institution financing. To address this, countries could create dedicated funding windows within existing institutions with terms tailored to critical mineral projects, including longer repayment periods, lower collateral requirements and co-financing for processing infrastructure. Co-ordinated approaches across countries could further scale financing by pooling balance sheet capacity and applying a shared rulebook for eligibility, risk mitigation and due diligence. This could reduce duplication and ensure that financing is targeted at projects with the highest strategic value globally.

Regulatory permitting reforms

Permitting complexity and fragmentation remain key barriers to project development. Greater co-ordination across countries, through common principles, harmonised standards and shared best practices, can improve predictability for investors operating across multiple countries and help avoid fragmented regulatory approaches that slow project development. Joint efforts with partner governments, including model legislation, technical guidance and capacity-building, could also help address these bottlenecks.

Price transparency and market development

Limited price transparency in many critical mineral markets constrains investment by reducing confidence in future revenues. Enhancing price discovery, particularly outside the dominant supplier, is therefore critical for stimulating diversified supply. Measures could include strengthening price reporting systems, leveraging alternative data and increasing transparency on long-term contracts. In some cases, state-backed exchanges or disclosure requirements can help establish more credible benchmarks. These approaches are already being utilised in some mineral markets, such as uranium.

Cross-border public-private partnerships

Given the global nature of supply chains, cross-border public-private partnerships can help develop integrated value chains linking upstream resources, processing capacity and end-use downstream manufacturing bases. Governments can facilitate this through co-ordinated project pipelines, shared financing packages and multi-country support agreements for integrated projects. Regional processing hubs, where processing or waste management infrastructure is jointly funded, can reduce duplication and lower barriers. Such partnerships would allow a bloc to leverage complementary strengths and create end-to-end supply chains that can compete with incumbent producers.

Box 3.2 Standards-based markets and traceability

The development of sustainable and responsible supply chains has a role to play in reducing concentration and enhancing diversification: not only can it unlock supply in diversified countries with high sustainability standards, but it can also mitigate the risk of supply chain disruptions associated with poor practices, such as labour strikes, government investigations and community backlash.

Any of the mechanisms outlined here could be adapted to incorporate standards-based criteria. For standards-based markets to emerge and function effectively, countries would need to establish clear and transparent criteria regarding what counts as "responsible" extraction, processing and trade. There are two broad categories of criteria that can be used: (1) performance-based indicators, which rely on measurable outcomes (e.g. GHG emissions intensity, water consumption and the rate of safety incidents); and (2) process- or policy-based indicators, which require the presence of specific corporate systems or policies (e.g. anti-bribery policies and safety audit protocols).

Existing voluntary industry initiatives, such as the Initiative for Responsible Mining Assurance or the Responsible Minerals Assurance Process, can be leveraged to create standards-based markets, for example by using certification under one of these initiatives as an indicator of good performance.

However, utilising these initiatives may also bring challenges. Existing initiatives do not consistently require clear and comparable disclosure of environmental or social metrics, instead sometimes focusing on wider due diligence efforts. Most voluntary mining standards were developed for large, consolidated sectors and are less applicable in smaller market contexts. Many of the smaller supply chains also involve highly specialised separation and refining steps for which robust, comparable indicators are still emerging. Thus, while existing voluntary standards can provide useful guidance, significant adaptation and targeted criteria-setting would be required for market access mechanisms to function credibly.

In addition to establishing common criteria for what counts as responsible production, standards-based markets also require a method to collect, report and verify data. When operators disclose verified data on performance, regulators and buyers can confirm that purchased material meets the criteria. Traceability systems, which can enable the collection and sharing of performance-related data, are thus a crucial bedrock for building standards-based markets. However, they require careful design and implementation to ensure interoperability, supported by international co-ordination and common standards, such as those being developed by the United Nations Transparency Protocol.

Technology, equipment and workforce

Diversified project development needs to be viewed through an ecosystem lens, paying special attention to technology, equipment and workforce bottlenecks

Indicative summary of the impact of different ecosystem bottlenecks on diversified project timelines and costs

Equipment and machinery
Very few companies outside dominant supplier for specialised processing, refining and downstream manufacturing equipment. Cost can be significantly higher and time taken to procure equipment with required specifications can span several months to years. Vulnerable to export controls.

Reagents
Dominant supplier controls the production of many chemical reagents such as sulphuric acid and soda ash. Costs for transport and storage in geographically diverse regions can often be higher. Vulnerable to disruption from geopolitical events and export controls.

Knowledge and skills
Achieving strict industry specifications requires accumulated operational knowledge and skilled workforce that requires time and infrastructure to build from scratch.

	Equipment and machinery	Reagents	Knowledge and skills
Rare earth elements	High exposure	Medium exposure	High exposure
Lithium	Medium exposure	High exposure	High exposure
Graphite	Medium exposure	Medium exposure	High exposure
Gallium	High exposure	High exposure	High exposure

For diversification efforts to succeed, existing gaps in technology, equipment and knowledge need to be addressed through innovation and policy support

The concentration of critical mineral processing and refining capacity has emerged as one of the most significant vulnerabilities in global supply chains. While mineral resource endowments are often geographically diverse, the intermediate processing and refining stages required to produce materials that conform to strict industry specifications for the manufacturing of batteries, magnets or semiconductors remain highly concentrated. This pattern is evident across minerals such as lithium, graphite, rare earth elements and gallium, where a single country has established dominant positions across several steps of the value chain.

In many cases, access to mineral feedstock is not the only hurdle to overcoming the high level of geographical concentration in processing and refining. In each mineral supply chain, competitiveness depends on a whole ecosystem comprising specialised technology, machinery, equipment, reagent availability, precise process control and optimisation, waste and environmental impact management, scientific and engineering expertise and integration with downstream manufacturing sectors. As a result, many of the barriers facing new entrants are complex and multifaceted. They arise from accumulated operating experience, industrial clustering and economies of scale.

In many cases, there are very few suppliers of specialised machinery and equipment outside China, making them more expensive and increasing the time required to acquire them. Even once the equipment is procured, process optimisation, a prerequisite for producing materials with low defect density that pass certification for high-tech industries, is often time-consuming. Given the presence of well-established chemical industries in many regions, reagents are often much more widely available than machinery, but still tend to be more expensive outside the dominant supplier, and infrastructure for their proper handling, storage and disposal adds to overall costs. In the current context, affected by events in the Middle East and the subsequent export control announcement from China, sulphuric acid, which serves as a reagent for the pre-processing of several critical minerals, including copper, lithium and rare earths, has emerged as an important bottleneck (see Chapter 1).

This section dives deeper into the essential ingredients for midstream processing of critical minerals, including technology, equipment, reagents and knowledge, using examples from rare earth elements, battery-grade lithium and graphite, and semiconductor-grade gallium.

The value chain for rare earth elements remains among the most geographically concentrated, and supply diversification calls for nurturing the entire ecosystem

Ecosystem bottlenecks for creating diversified magnet rare earth supply chains

	Mining	Refining		Magnet production	
Process	**Heap/in-situ leaching**	**Separation**	**Metallisation**	**Alloy production**	**Magnet production**
Description	Producing mixed REE compounds from ionic clay deposits	Producing single element oxides from mixed REE compounds	Refining the oxides to produce rare earth metals	Produce rare earth metal alloy powders for magnet production	Produce rare earth permanent magnets predominantly through sintering
Bottlenecks	Methods that avoid highly contaminating strong acids	Equilibrium data for processing different feeds Stainless steel cells and tanks for nitric acid routes Higher reagent costs	Electrolysis cells with high energy efficiency	Strip casters	Alignment presser Grain boundary diffusion equipment Magnet sintering empirical knowledge Precision cutting of magnet blocks

Legend: Equipment/machinery/reagent bottleneck; Knowledge bottleneck

Note: REE = rare earth element.

Processes for the separation of rare earth elements and magnet manufacturing face significant bottlenecks in the form of technology, equipment and knowledge gaps

While there has been a marked increase in announced rare earth mining projects across geographically diverse regions in recent years, the pipeline for separation and refining, alloy production and magnet manufacturing is much narrower and insufficient to meet projected industrial requirements outside China, making it a critical bottleneck to the development of diversified supply chains.

Rare earth refining and magnet production rely on a multitude of complex technical production processes, requiring specialised equipment, machinery, skills and training to produce magnets that conform to strict industry specifications. There are very few suppliers of rare earth refining and magnet production equipment and machinery outside China, and the time required to obtain the equipment can often span several years. There is an urgent need to nurture this industry in parallel with project development. China's 2023 export controls, which covered a wide range of rare earth processing equipment and technologies, highlighted the importance of addressing this issue.

Mining technologies and equipment are generally less of a bottleneck, although certain gaps remain, for example in the extraction of heavy rare earths from ionic adsorption clay (IAC) deposits without relying on the acid leaching methods commonly used in China and Myanmar. However, significant technology gaps remain in the separation, metallisation and magnet production stages.

Separation

There is a significant gap in knowledge and equilibrium data for solvent extraction used for rare earth separation, which is a complex process due to the similar chemical properties of many rare earth elements found together. This concern is particularly relevant for mixed feeds, such as monazite and bastnaesite. Another issue at the separation stage is that China predominantly uses chloride routes (hydrochloric acid) that require polyvinyl chloride (PVC) tanks and cells, whereas most suppliers outside China have favoured the nitric route (nitric acid), which requires stainless steel tanks and cells that are more expensive to produce. The nitric acid route also requires very strong wastewater management systems and land-use planning regulations, and there is limited experience in tackling this issue systematically outside China and Japan.

Aside from machinery and equipment, reagents could also be a bottleneck for diversified projects, as they account for 15-25% of conversion costs depending on the route used (chloride or nitric), and the acids are usually sold at lower prices in China than in most other regions.

Alloying, metallisation and magnet manufacturing

The priority areas where there is a stark deficiency of competitive equipment and machinery that meet industry specifications are alloy production, metallisation and magnet production. Equipment for these supply chain steps outside China could be 5-12 times more expensive and often has two to three times longer lead times than equipment from China. The increased costs and lead times are due to the limited number of equipment manufacturers outside China, which typically produce this equipment for other applications and have not optimised it for rare earth processing, which often requires some resizing and re-specification. Moreover, they have not yet achieved economies of scale, have not secured long-term established customers, and need time to customise and ramp up production. In some cases, there is only a single supplier of equipment and machinery outside China, meaning that a competitive landscape for efficient scaling does not exist.

For metallisation, particularly for light rare earth metals, there is a bottleneck in the design of energy-efficient equipment for the electrolysis step. Light rare earth metals typically use molten salt electrolysis, and to achieve competitive costs, the design of the electrolysis cells must be highly energy efficient. This is because energy is one of the largest cost factors in the metal conversion process. The design of highly energy-efficient electrolysis equipment remains closely held and is not widely available outside China. For heavy rare earth metals, vacuum induction chambers are used for calcination/reduction. This equipment is made by very few producers nd needs to be highly customised to scale the metals to size. Therefore, the design and development of energy-efficient electrolysis cells and vacuum chambers need to be a priority to achieve viable, economically competitive metallisation to support diversified projects.

In the production of alloys, a key process is strip casting to produce rare earth alloys with additives such as iron, gallium or zirconium (which make up less than 1% of the alloy by weight). Strip casters are another key piece of equipment with few suppliers available outside China. Jet milling equipment, used to produce alloy powder, has suppliers outside China but is more expensive.

However, some of the most critical equipment challenges are in magnet production. In the production of sintered magnets, the availability and quality of alignment pressers is a source of concern. There are a few suppliers outside China, but their pressers can be around ten times more expensive, and the technology and design are notably less advanced. Finally, the technology for grain boundary diffusion processes, used to apply heavy rare earth molecules as a coating to magnets, is subject to Chinese technology and equipment export controls. There is currently a single equipment supplier outside China, whose equipment is around 12 times more expensive and has a longer lead time. Grain boundary diffusion is also a highly patented process, with many ongoing litigation disputes, providing another barrier to successful development for emerging producers.

Beyond equipment and machinery, there are several areas with skill and knowledge bottlenecks. In the separation process, there is a considerable lack of equilibrium data for processing various feeds. The same is true for sintering furnaces for magnet production, where there are major empirical and heuristic knowledge gaps in the protocols needed to produce sintered magnets with the required specifications. This also extends to the high-precision cutting of magnet blocks, where, while the equipment needed exists outside China, limitations exist in process knowledge to achieve results at scale and speed. These are areas that require training, practice and time to hone techniques and build a skilled workforce.

Production of refined battery-grade lithium in geographically diverse regions hinges on honing process optimisation and operational know-how

Ecosystem bottlenecks for creating diversified battery-grade lithium supply chains

	Refining		Battery-grade lithium precursor production
Process	**Roasting and conversion**	**Purification**	**Crystallisation**
Description	Sulphuric acid roasting to obtain lithium sulphate suitable for extraction	Removal of impurities (Mg, Ca, Na, K, Al and B)	Conversion of purified lithium solutions into battery-grade lithium carbonate or lithium hydroxide
Bottlenecks	Construction of standardised designs; furnace optimisation and operating data (knowledge) Heat integration and thermal efficiency strongly influence operating costs (equipment/machinery/reagent) Access to and cost of sulphuric acid (equipment/machinery/reagent)	Operating data for achieving high recovery rates (knowledge) Maintaining battery-grade purity levels (knowledge) Different processes for different feedstocks (knowledge) Higher reagent costs (lime, soda ash, sodium hydroxide) (equipment/machinery/reagent)	Producing crystals with strictly controlled particle size distributions, morphology and impurity profiles (knowledge) Operating data as product quality is highly sensitive to operating conditions (knowledge) Costs related to testing and pilot operations to achieve battery-grade qualification (equipment/machinery/reagent)

Legend: Equipment/machinery/reagent bottleneck; Knowledge bottleneck

Note: Mg = magnesium; Ca = calcium; Na = sodium; K = potassium; Al = aluminium; B = boron.

Reagent costs and process optimisation play a more defining role than machinery in achieving impurity control and crystallisation for battery-grade lithium production

In the case of lithium, mining does not face significant technology and equipment bottlenecks. For hard-rock projects, mining and beneficiation produce spodumene concentrate, typically through crushing, grinding, dense media separation and flotation circuits. The required equipment, including crushers, grinding mills, flotation cells, thickeners and filtration systems, is supplied by a broad range of international companies, including Metso, FLSmidth and Weir Group. Although permitting, infrastructure and project financing can delay mine development, the technologies involved are mature and widely deployed. Unlike hard-rock operations, brine projects do not require mining and mineral beneficiation. Instead, lithium-bearing brines are pumped from underground aquifers and concentrated through a combination of evaporation, chemical treatment and refining. Brines vary significantly in lithium concentration and impurity composition, particularly in terms of the magnesium-to-lithium ratio. High magnesium concentrations can substantially increase reagent consumption and processing complexity. Process optimisation therefore requires extensive site-specific knowledge and long operating histories.

Chemical conversion and battery-grade refining stages face the most significant supply chain bottlenecks in the development of diversified supply chains.

Roasting and conversion

The first stage of hard-rock lithium refining converts naturally occurring alpha-spodumene into the more reactive beta-spodumene phase before sulphuric acid roasting converts lithium into lithium sulphate suitable for extraction. This stage determines downstream recovery rates and is one of the most energy-intensive steps in the refining process. The principal equipment includes rotary kilns, fluidised-bed roasters, acid dosing systems, gas-cleaning systems and heat-recovery units. Major suppliers include Metso, FLSmidth and thyssenkrupp Uhde.

The equipment itself is generally available internationally and is not subject to significant supply constraints. The bottleneck lies in the ability to operate these systems efficiently. Heat integration, thermal efficiency and furnace optimisation have a major influence on operating costs. Chinese engineering firms have commissioned dozens of lithium conversion facilities and have accumulated substantial operational knowledge that reduces energy consumption and commissioning risks.

Sulphuric acid is the principal reagent consumed during conversion. China benefits from one of the world's largest sulphuric acid industries, supported by extensive copper and zinc smelting sectors that generate the acid as a by-product. This provides refiners with lower reagent costs and greater supply security.

Engineering, procurement and construction capability also represents an important advantage. Chinese contractors have repeatedly delivered lithium conversion facilities and benefit from standardised designs, specialised subcontractor networks and extensive operating data. This frequently results in lower capital costs and shorter commissioning periods than for equivalent projects elsewhere. The concentration of lithium refining reflects both scale and accumulated expertise that give rise to competitive prices.

Purification

Following acid leaching, lithium-bearing solutions need to be purified to remove impurities, including magnesium, calcium, sodium, potassium, aluminium and boron. These contaminants can affect cathode active material (CAM) production and battery performance if not reduced to extremely low concentrations.

Purification circuits employ reactors, precipitation vessels, thickeners, filters and solid-liquid separation systems supplied by companies such as Andritz Group, Metso and FLSmidth. The principal reagents include lime, sodium hydroxide and soda ash. China possesses one of the world's largest chlor-alkali and soda ash industries, enabling refiners to access these inputs at lower cost and with shorter supply chains than many competitors.

Recent research highlights the importance of impurity management in battery-grade lithium production and notes that the largest cost component of lithium production comes from the impurity elimination process to satisfy battery-grade purity requirements of over 99.5%. However, refining specifications continue to evolve as battery technologies advance.

Once again, at this step, the primary bottleneck is process optimisation rather than equipment availability. Different feedstocks require different purification strategies, and achieving high recovery rates while maintaining battery-grade specifications requires experienced metallurgists and extensive operating data.

Crystallisation

Crystallisation converts purified lithium solutions into battery-grade lithium carbonate or lithium hydroxide. The purpose of crystallisation is not simply to recover lithium but to produce crystals with strictly controlled particle size distributions, morphology and impurity profiles. These characteristics influence cathode production, filtration behaviour and downstream battery performance.

The process uses evaporators, crystallisers, centrifuges and drying systems supplied by firms such as GEA Group, Veolia Water Technologies and Andritz.

Research on lithium carbonate crystallisation demonstrates that product quality is highly sensitive to operating conditions, and the lack of operating data makes optimising these conditions a significant technical challenge. As with the previous steps, the bottleneck is operational know-how. Several lithium projects outside China have experienced commissioning delays because battery-grade specifications proved more difficult to achieve than expected. Product qualification by cathode manufacturers can further extend the timeline to commercial production. Qualification can take months or even several years, particularly for automotive battery supply chains.

Overall, the principal bottlenecks in lithium processing are concentrated in purification and crystallisation. Unlike rare earth elements, equipment availability is generally not the major constraint, and most key processing equipment can be sourced internationally. The more significant challenges relate to reagent costs, process optimisation, impurity control and battery-grade product consistency.

Efforts to diversify lithium refining capacity should focus on developing refining expertise alongside physical infrastructure. Pilot plants, demonstration facilities and workforce development programmes can accelerate the accumulation of operational knowledge. Closer integration with chemical producers may reduce reagent costs, while partnerships with cathode and battery manufacturers can support and accelerate product qualification. Over time, operational experience is likely to be as important as capital investment in determining competitiveness for battery-grade lithium production in geographically diverse regions.

Battery-grade graphite production is one of the most energy-intensive steps in battery supply chains, and diversified producers face high energy and environmental barriers

Ecosystem bottlenecks for creating diversified battery-grade graphite supply chains

	Refining		Battery-grade graphite production	
Process	**Purification**	**Micronisation and spheronisation**	**Graphitisation**	**Carbon coating**
Description	Removal of silica and other impurities using hydrofluoric acid	Conversion of graphite flakes into spherical particles	Improving conductivity and crystalline structure by heating spheronised graphite to 3000 ^{0}C	Coating with carbon to improve battery performance, cycle life and coulombic efficiency
Bottlenecks	Fluoropolymer-lined reactors, corrosion-resistant pumps and waste-treatment infrastructure; Handling and procurement costs for HF; Methods that avoid highly contaminating acids	Jet mills, impact mills, air classifiers and specialised spheronisation systems; Yield optimisation controlled by proprietary knowledge	Furnaces with high energy efficiency and utilisation rate; Novel graphitisation techniques to reduce energy intensity	Specialised thermal treatment systems, carbon precursor materials; Operating data to achieve uniform coating thickness and surface properties; Costs related to testing and pilot operations to achieve battery-grade qualification

Legend: Equipment/machinery/reagent bottleneck — Knowledge bottleneck

Note: HF = hydrofluoric acid.

Extremely high energy intensity, limited equipment suppliers and relatively high reagent costs are key challenges faced by battery-grade graphite producers in geographically diverse regions

Natural graphite mining and beneficiation remain concentrated in China, although not to the same extent as midstream refining and downstream anode production. The strongest concentration, however, is seen in spherical graphite and anode material production.

Mining is followed by crushing, grinding and flotation to produce graphite concentrate. The required equipment, including crushers, grinding mills, flotation cells, thickeners and filtration systems, is supplied by some international companies, including Metso, FLSmidth, Eriez and Weir Group. The mining and beneficiation technologies themselves are mature. However, concentrate quality can significantly influence downstream purification costs and anode performance, meaning that access to high-quality flake graphite deposits remains commercially important.

Synthetic graphite production represents an additional and strategically important component of the graphite supply chain. Synthetic graphite is most commonly produced through the calcination and graphitisation of petroleum coke or needle coke at temperatures approaching 3 000 °C. The process relies on calcination systems, high-temperature graphitisation furnaces and carbon-processing equipment supplied by very few non-Chinese firms, such as Mersen and ECM Technologies. Synthetic graphite production is highly energy-intensive and depends on access to petroleum coke, needle coke and competitively priced electricity. China has developed substantial advantages in synthetic graphite production due to its large furnace capacity, integrated hydrocarbon production industry and lower processing costs. Synthetic graphite is becoming increasingly important in EV batteries, particularly for high-performance anodes.

China's strong presence in purification, spheronisation, graphitisation and synthetic graphite production reinforces its advantage in graphite mining.

Purification

Battery-grade graphite generally requires purity levels exceeding 99.95% carbon. The dominant industrial route uses hydrofluoric acid to remove silica and other mineral impurities.

The process relies on fluoropolymer-lined reactors, corrosion-resistant pumps, filtration systems and waste-treatment infrastructure. The limited number of diversified suppliers includes De Dietrich Process Systems and Pfaudler. The principal reagent is hydrofluoric acid, which requires infrastructure for safe handling, transport and disposal, as it is extremely corrosive. China benefits from one of the world's largest fluorochemical industries, providing cost advantages and extensive waste-treatment infrastructure. Environmental impact and waste treatment can be major challenges for new entrants.

Alternative thermal purification routes could reduce dependence on hydrofluoric acid but require significantly higher energy consumption in an already energy-intensive value chain, creating a competitiveness challenge.

Micronisation and spheronisation

Natural graphite flakes must be converted into spherical particles before they can be used in lithium-ion battery anodes. This process uses jet mills, impact mills, air classifiers and specialised spheronisation systems supplied by a few specialised equipment producers, including NETZSCH Grinding & Dispersing and Bühler Group, increasing the time required to acquire the equipment in geographically diverse regions.

In addition to the equipment bottleneck, there is also a knowledge gap in yield optimisation. During particle shaping, a substantial proportion of feed material can be lost. Small improvements in yield can significantly improve project economics, but much of the industrial knowledge remains proprietary, creating barriers for new entrants.

Graphitisation

Graphitisation improves conductivity and crystalline structure by heating the spheronised graphite to temperatures approaching 3 000 ºC. This step is identical to the one needed for the production of synthetic graphite.

The bottlenecks are related to limited equipment suppliers but, more importantly, the very high energy intensity of the process. Graphitisation is among the most electricity-intensive stages in the entire battery supply chain and is therefore highly sensitive to electricity prices, furnace efficiencies and utilisation rates. Chinese producers benefit from extensive installed furnace capacity, lower electricity costs and a mature ecosystem of furnace suppliers and maintenance providers.

Novel graphitisation technologies, such as induction furnaces and bio-graphite production, were described in last year's Global Critical Minerals Outlook, but most of these alternatives require significant investment and research to reach maturity.

Carbon coating

Following graphitisation, graphite particles are coated with carbon to improve battery performance, cycle life and coulombic efficiency. This stage uses specialised thermal treatment systems and carbon precursor materials, including petroleum pitch and coal-tar pitch. China benefits from large domestic supplies of these precursor materials and from integration with broader carbon materials industries.

The bottlenecks for diversified players here are both precursor availability and process control, including maintaining consistent precursor quality. Variations in coating thickness and surface properties can significantly affect battery performance.

Finally, qualification by battery manufacturers is often one of the longest stages of market entry for graphite products. New suppliers must demonstrate consistent performance through extensive testing programmes before materials can be incorporated into commercial batteries. This process can take several years and requires stable production quality throughout.

Chinese producers benefit from proximity to battery manufacturers, established commercial relationships and continuous quality feedback from downstream users. Furthermore, China's export licensing requirements for certain graphite products and processing technologies, introduced in 2023, further highlight the strategic importance of graphite processing capabilities within battery supply chains.

Overall, principal bottlenecks in graphite processing are hydrofluoric acid management, yield optimisation during spheronisation, graphitisation economics, carbon coating consistency and customer qualification. Equipment is available internationally but from only a handful of suppliers, and process performance depends heavily on accumulated expertise and industrial integration.

Diversification efforts should focus on building complete anode material ecosystems rather than standalone processing facilities. Alternative purification technologies may help reduce environmental constraints, while access to competitively priced electricity will be essential for project feasibility. Closer collaboration with battery manufacturers can accelerate the qualification process, and investment in building stronger workforces skilled in materials engineering can improve competitiveness over the longer term.

Semiconductor-grade gallium production is almost entirely concentrated in one country, and diversified producers must address significant gaps in technology and operational know-how

Ecosystem bottlenecks for creating diversified semiconductor-grade gallium supply chains

	Refining	Semiconductor-grade material production	
Process	Ultra-high-purity refining	Gallium arsenide crystal growth	Gallium nitride epitaxial growth
Description	Removal of impurities to achieve purity levels ranging from 6N to 8N	Crystal growth using LEC and VGF furnaces	Deposition of atomically controlled layers from precursor gases onto wafers in MOCVD reactors
Bottlenecks	Vacuum distillation systems, zone-refining systems and ultra-clean-handling equipment	Highly specialised and customised furnaces	Access to precursor gallium-containing gases
	Advanced analytical laboratories, specialised mass spectrometers to detect extremely small concentrations of impurities	Extremely precise thermal management, pressure control and impurity control to minimise crystal defects, dislocations and compositional variations	Extremely precise temperature uniformity, gas flow distribution, chamber pressure and precursor delivery to minimise defects
	Operating data and expertise		

Legend: Equipment/machinery/reagent bottleneck (red) Knowledge bottleneck (yellow)

Notes: LEC = liquid-encapsulated Czochralski; VGF = vertical gradient freeze; MOCVD = metal-organic chemical vapour deposition. 6N to 8N indicate purity levels from 99.9999% to 99.999999%.

Technically demanding processes, equipment and reagent constraints, and knowledge gaps make the gallium value chain one of the most specialised among high-tech materials

Most primary gallium production occurs through recovery from Bayer-process alumina refining streams, although smaller quantities are also recovered as by-products from zinc processing and zinc refinery residues. Recovery from alumina production remains the dominant source because gallium becomes concentrated in Bayer liquor during the refining of bauxite into alumina. The dominant recovery technologies are ion exchange and solvent extraction. Ion exchange systems employ specialised resins that selectively remove gallium from Bayer liquor. The handful of suppliers outside China include Lanxess and DuPont Water Solutions.

Despite the limited number of equipment suppliers for gallium recovery in geographically diverse regions, access to large Bayer liquor streams is a more important determinant of production economics than access to equipment. Nearly all refined production of gallium today occurs in China, as the country benefits from being the world's largest alumina producer and therefore possesses the largest potential source of gallium-bearing Bayer liquor. In addition, specialised ion exchange resins also represent a bottleneck for diversification. Performance depends on selectivity, resistance to fouling and long-term stability, characteristics that are often supported by proprietary formulations and accumulated operational know-how. China's export licensing requirements imposed on gallium-related products in 2023 and 2024 further underscore the strategic importance of these supply chains.

Ultra-high-purity refining

Semiconductor-grade gallium typically requires purity levels ranging from 6N up to 8N (99.9999% to 99.999999%), depending on the application and device requirements. Manufacturing of gallium arsenide and gallium nitride, the downstream products of gallium that play central roles in applications relying on semiconducting materials, is particularly sensitive to trace metallic and oxygen impurities, making contamination control and analytical capability critical. The purification process relies on vacuum distillation systems, zone-refining systems and ultra-clean handling equipment supplied by a few specialised firms, such as PVA TePla and ECM Technologies.

To achieve such purity levels, trace contaminants at parts-per-million, parts-per-billion or even parts-per-trillion levels can affect crystal growth, epitaxy and semiconductor device performance. Advanced analytical laboratories equipped with inductively coupled plasma mass spectrometry and glow discharge mass spectrometry to detect extremely small concentrations of impurities therefore become essential components of the production process, as does the expertise required to operate these facilities and maintain rigorous contamination control standards. Very few suppliers exist globally for this ultra-specialised laboratory equipment, and the time required for equipment procurement can be a significant component of the total fabrication time.

Gallium arsenide wafer production

Gallium arsenide (GaAs) is used in high-frequency and high-performance electronic and optoelectronic applications, including radio frequency chips, satellite communications, solar cells, light-emitting diodes and defence systems.

Gallium arsenide production begins with crystal growth using liquid encapsulated-Czochralski (LEC) and vertical gradient freeze (VGF) furnaces. These systems create large, defect-free single crystals that are subsequently sliced, polished and processed into semiconductor wafers. Liquid-encapsulated Czochralski furnaces produce large single-crystal gallium arsenide ingots by slowly pulling a crystal seed from molten gallium arsenide while the melt is covered by a boron oxide encapsulant. The encapsulant suppresses arsenic evaporation, which would otherwise destabilise the melt at the high temperatures required for crystal growth. Vertical gradient freeze furnaces instead solidify the melt under carefully controlled temperature gradients, reducing thermal stress and improving crystal uniformity. Both systems require extremely precise thermal management, pressure control and impurity control to minimise crystal defects, dislocations and compositional variations.

The process becomes more complex when producing compound semiconductors that incorporate indium, such as indium gallium arsenide (InGaAs) or indium gallium phosphide (InGaP). These materials require stricter compositional control because small variations in indium concentration can significantly alter electronic and optical properties. Maintaining uniform alloy composition during crystal growth therefore introduces additional process-control challenges and increases sensitivity to temperature fluctuations and precursor purity. Specialised equipment suppliers are, once again, fairly limited, and furnace settings often need to be customised for the exact composition needed. PVA TePla is one of the few notable specialised crystal growth equipment manufacturers outside China.

The key challenge is defect control. Crystal quality depends on precise thermal management, impurity control and process stability, and achieving commercially competitive yields requires significant operational expertise. Wafering and polishing also require specialised equipment and process knowledge to achieve the surface quality demanded by semiconductor manufacturers.

Gallium nitride epitaxy

Gallium nitride (GaN) is increasingly used in power electronics, fast chargers, electric vehicles, radar systems and advanced telecommunications infrastructure because of its ability to operate at high voltages, frequencies and temperatures.

Gallium nitride manufacturing is predominantly carried out in metal-organic chemical vapour deposition (MOCVD) reactors, which deposit atomically controlled semiconductor layers onto wafers. Precursor gases such as trimethylgallium and ammonia decompose at elevated temperatures and react on the wafer surface to form gallium nitride layers with highly controlled thickness and composition. The reactors must maintain precise temperature uniformity, gas flow distribution, chamber pressure and precursor delivery in order to minimise crystal defects and achieve high device performance. As with gallium arsenide, the process becomes more complex for mixed semiconductors, such as indium gallium nitride (InGaN), which are widely used in light-emitting diodes and advanced optoelectronic devices. Incorporating indium requires tighter control of growth temperature and precursor flow. Maintaining uniform composition across the wafer while avoiding crystal defects represents a major process-engineering challenge. The market for MOCVD reactors outside China is concentrated among a very small number of suppliers, particularly Aixtron and Veeco Instruments. The supply of semiconductor-grade trimethylgallium is also concentrated among a limited number of specialist chemical manufacturers, creating additional supply chain dependency.

The bottlenecks for semiconductor-grade gallium production in geographically diverse regions encompass equipment, reagents and knowledge. Specialist expertise, process recipes, yield optimisation, and equipment and reagent procurement lead times are all concerns. Unlike many stages in lithium and graphite processing, equipment concentration itself constitutes a significant barrier. Gallium arsenide and gallium nitride manufacturing also require highly controlled cleanroom facilities to minimise particulate contamination and airborne impurities during wafer fabrication and epitaxial growth. The construction and operation of these facilities significantly increase capital costs and operational complexity. Semiconductor cleanrooms also require ultra-high-purity gases, specialised chemical-delivery systems and continuous contamination monitoring. The considerations extend beyond infrastructure alone. Maintaining cleanroom performance requires highly trained operators, rigorous process discipline and extensive operational experience.

An additional concern is the safe handling of substances: arsenic-based compounds are highly toxic and require strict handling, ventilation and waste management systems during crystal growth, wafer fabrication and semiconductor processing. Metal-organic precursors used in epitaxy, including trimethylgallium, are pyrophoric and highly reactive, requiring specialised gas-handling systems and tightly controlled operating environments.

Overall, diversification efforts should focus on expanding materials science capabilities and strengthening downstream manufacturing. Investment in specialist workforce development, pilot-scale facilities and partnerships with equipment suppliers can accelerate progress. Given the technical complexity of the value chain, successful diversification is likely to require sustained industrial investment over an extended period.

Closing existing technology, equipment and knowledge gaps in geographically diverse regions requires a holistic approach encompassing innovation, policy and co-operation

The gaps in costs and lead times observed today are a function of the high levels of supply chain concentration and the lack of major industrial bases outside China. As efforts to diversify supplies ramp up, there is potential for competitive markets for equipment and machinery to emerge.

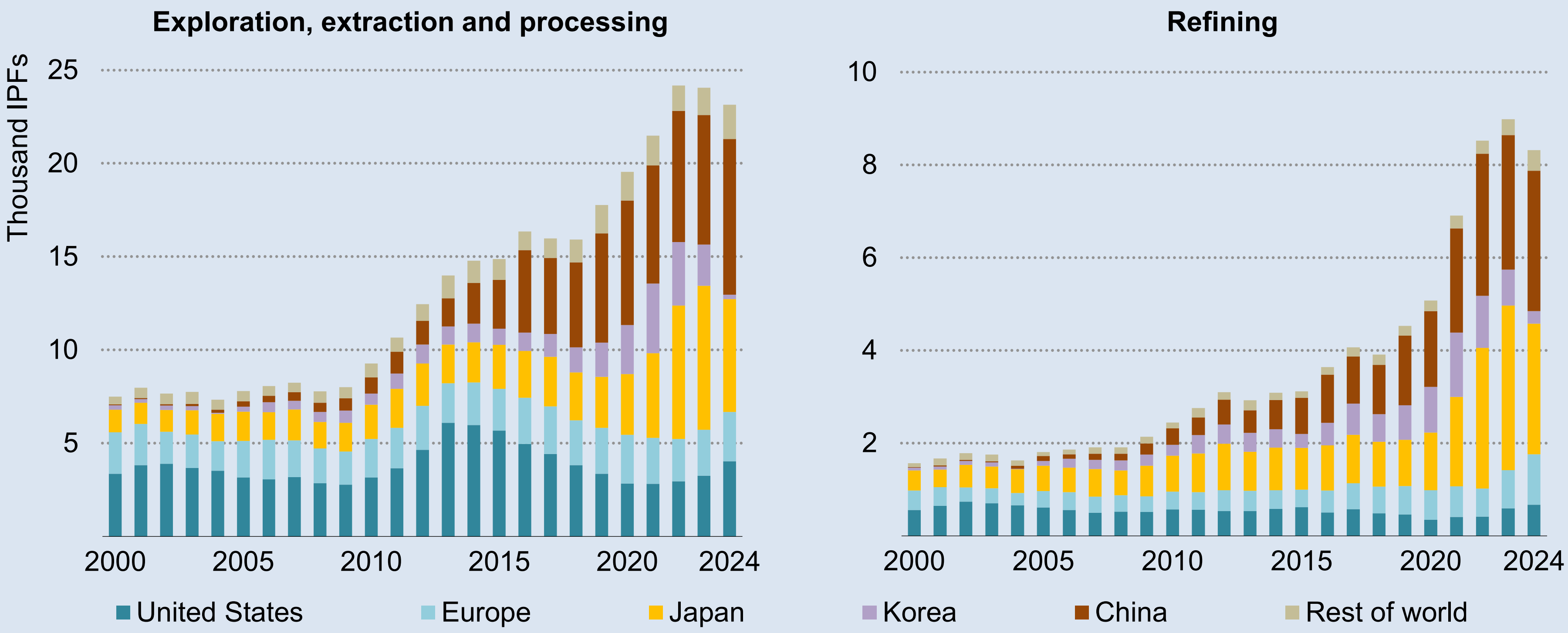
Innovation is a critical enabler of efforts to diversify supply chains, as new entrants face substantial technical, economic and environmental barriers across mining, separation and refining. Tracking the scale of patents across mineral value chains reveals that progress in supply-side innovation has been concentrated in one country over the last decade (Box 3.3). To develop successful mineral production ecosystems in geographically diverse regions, the first and highest priority is to address gaps in knowledge, equipment costs and lead times. Providing targeted subsidies and incentives to existing and emerging equipment and machinery producers can be effective in reducing both lead times and equipment and machinery costs through economies of scale. Building a consortium of domestic or international equipment producers to co-ordinate the production of components and equipment can also realise scale advantages more effectively, leveraging technology and skills transfer between partners and facilitating product certification.

Second, providing financial support both at the direct capital cost and operating cost levels, or through other de-risking measures, such as loan guarantees or lowered interest rates, can help diversified equipment producers and new entrants to secure and scale their operations. These measures strengthen the business case for producers and also incentivise private investment in the sector by reducing perceived risks. Unlocking private investment can accelerate the development of diversified ecosystems, where scale and speed are both key drivers for building competitive businesses.

Finally, even if the whole ecosystem is successfully created, long-term operations can only be sustained if there is demand for these diversified players. It is therefore critical to simultaneously stimulate demand, for example by introducing incentives or mandates to use magnets or batteries produced using a share of materials, processing technology and equipment originating from diverse sources. Nurturing downstream manufacturing industries or partnering with like-minded countries that have strong industrial demand bases will be a major factor in sustaining operations for diverse upstream players. Co-ordination among key diversified players may also improve negotiating positions in the event of patent disputes.

Box 3.3 Patents across critical mineral value chains reveal remarkable progress in innovation but high geographical concentration

Global patenting trends in critical mineral technology areas, 2000-2024



Notes: IPFs = international patent families, based on fractional counts. As a first attempt, the IEA defines critical minerals sectors using Cooperative Patent Classification codes combined with keyword searches for extraction, processing and materials technologies, as well as digital and automation applications linked to critical minerals. Data for 2020-2024 have been nowcast based on historical data, with a variable factor for the main patenting countries and a fixed factor for the rest of the countries.

Source: IEA analysis based on European Patent Office PATSTAT patents database (Spring 2025 edition, accessed through the OECD Micro-data Lab: Intellectual Property Database).

The dynamism of the technology innovation landscape for critical minerals is reflected in increased patenting activity across the sector. The trends appear in several regions at every stage of the value chain: exploration, extraction, refining and recycling. Since 2021, the level of patenting globally has been around three times higher than the level seen prior to 2010. These patents mostly relate to exploration and extraction technologies, demonstrating a continued commercial interest in new ways to tap into mineral resource endowments. However, the marked increase in China's contributions to the total patent pool since the 2010s mirrors the role the country has played as the leading producer of a wide range of minerals over the last 15 years. As of 2024, China accounted for more than 35% of patents within international patent families and files the highest number of national patent families. Moreover, as highlighted in the section above, innovation in the midstream has also been predominantly concentrated in China over the last decade, while Japan has maintained a consistently high share of the total since 2000.

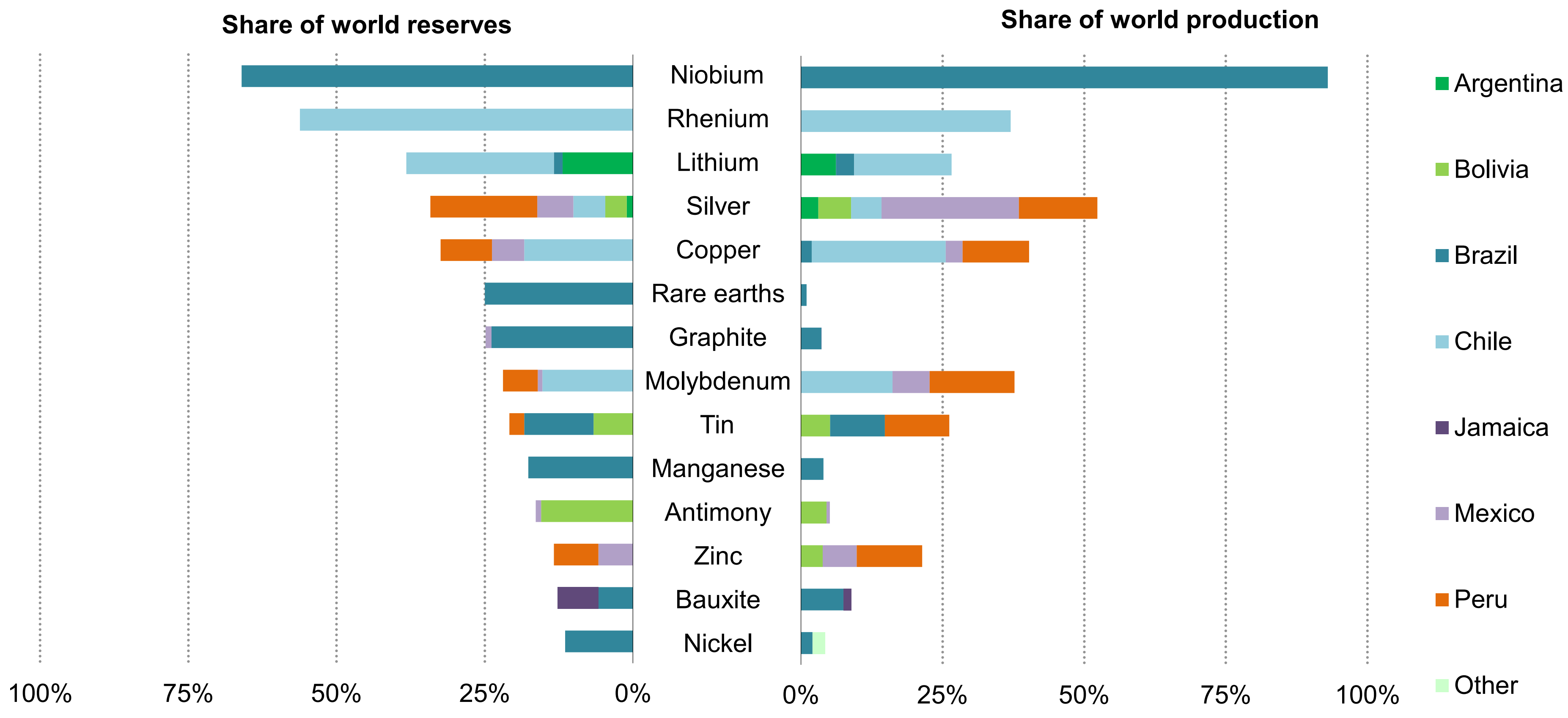
A recent joint report published by the European Patent Office and the IEA, Battery Circularity, shows that there has also been rapid increase in patenting for battery recycling technologies, at 42% per year on average since 2017, growing faster than any other category of patents related to batteries. This follows a growing focus on diversifying supply chains to reduce mineral supply risks in importing regions and improving environmental performance. However, China also represents two-thirds of all patents relating to battery recycling.

Despite having limited domestic extraction or refining, Japan's contribution to innovation in critical minerals is noteworthy. This indicates that major Japanese battery manufacturers seek to manage their supply chains to mitigate supply risks and remain competitive.

4. Special focus on Latin America and the Caribbean

Latin America and the Caribbean holds significant reserves of multiple critical minerals, with considerable scope for further development

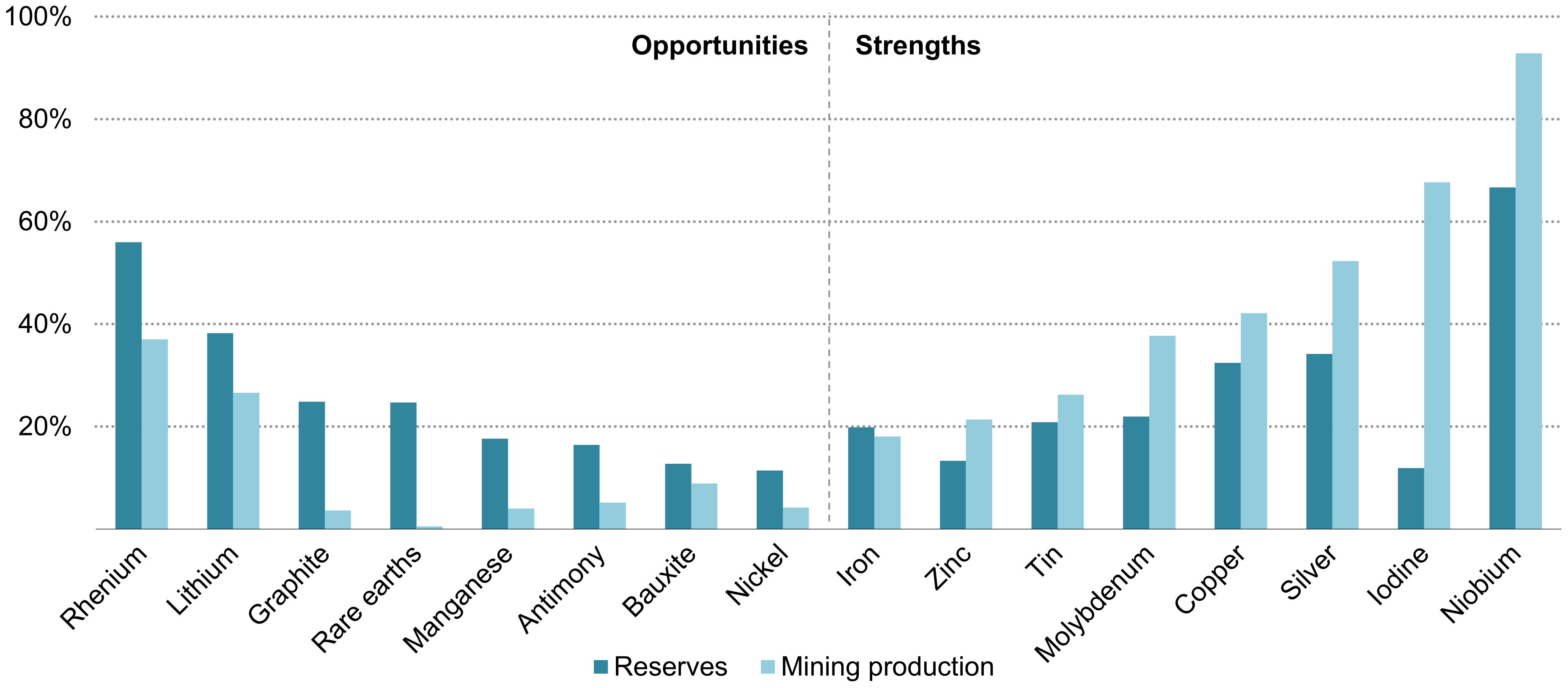
Shares of global reserves and production for selected minerals in Latin America and the Caribbean



Source: IEA analysis based on data from the United States Geological Survey (2026), Mineral Commodity Summaries 2026.

The region combines established mining capabilities with emerging opportunities in critical minerals, particularly for key energy materials such as lithium, copper, graphite and rare earths

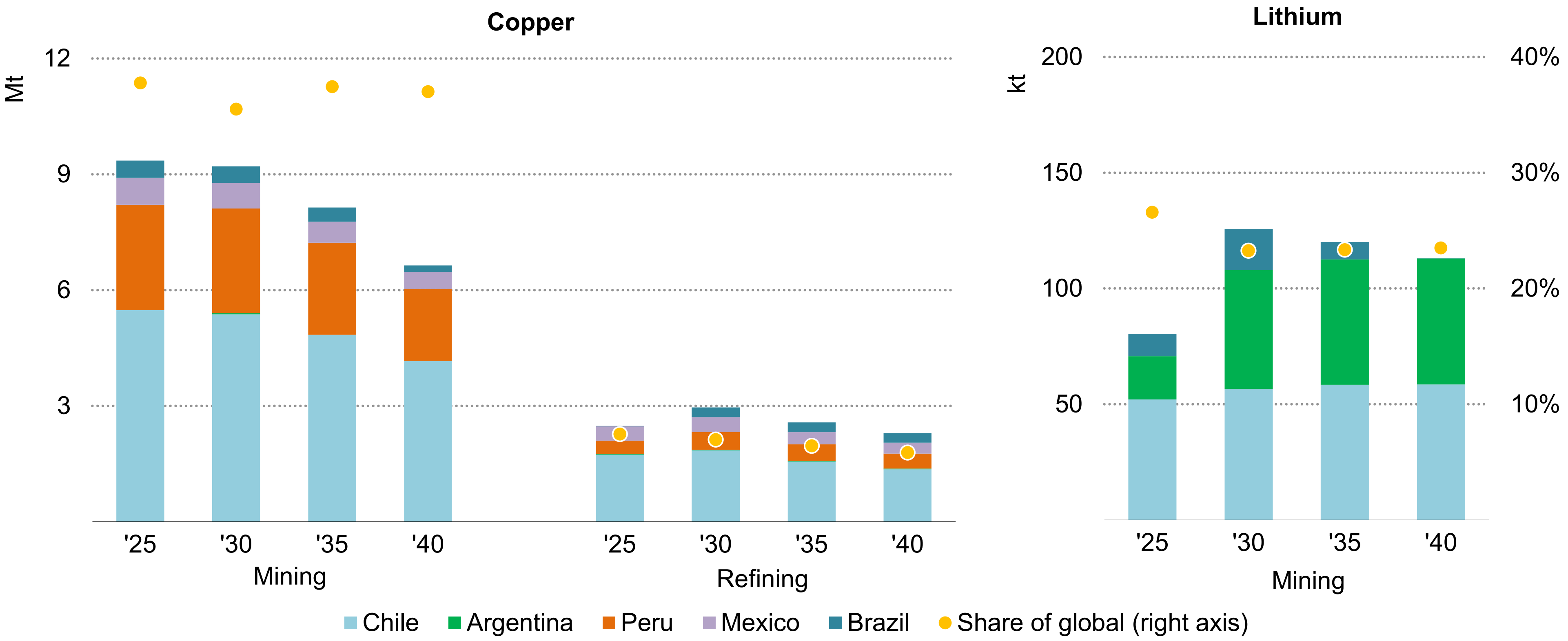
Latin America and the Caribbean's shares of global reserves and mining output for selected minerals, 2025



Source: IEA analysis based on data from the United States Geological Survey (2026), Mineral Commodity Summaries 2026.

Latin America and the Caribbean is expected to maintain its global market share in the mining of key minerals such as copper and lithium, but faces strong competitive pressures in refining

Copper and lithium output in Latin America and the Caribbean in the base case, 2025-2040



Note: Lithium mining covers extraction from hard-rock ores and brines.

Latin America and the Caribbean is a leading global mineral producer with significant untapped resources

Latin America and the Caribbean (LAC) is a major supplier of critical minerals, supported by a large and diverse resource base. The region holds significant shares of global resources of lithium, copper, silver and graphite, alongside important reserves of molybdenum and tin, and established production of specialty minerals such as niobium and rhenium. This endowment underpins LAC's strategic importance for a wide range of technologies, including those central to the energy transition as well as high-technology, aerospace and defence applications.

LAC also has significant potential to help diversify highly concentrated global mineral supply chains while strengthening its own economic development. Expanding processing and downstream activities could enable the region to capture greater value from its mineral resources.

Current production landscape

The production of base metals is a key strength for the region, accounting for at least one-fifth of global production of copper, molybdenum, tin and zinc. Chile, Peru and Mexico together accounted for almost 40% of global mined copper supply in 2025. For molybdenum, a by-product of copper production, LAC countries account for just under 40% of global production, mainly from Chile and Peru.

LAC also hosts significant production of speciality minerals. Brazil accounts for more than 90% of global production of niobium, a mineral used mainly as an alloying material for steel, but with growing applications in superconductors and electronics. Chile produces over one-third of the world's rhenium, another by-product of copper that is essential for specialised heat-resistant steels. The region is also a major producer of silver, accounting for more than half of global supply, mainly from Mexico, Peru, Bolivia and Argentina, despite holding one-third of global reserves.

Lithium resources are concentrated in the so-called "lithium triangle", comprising Argentina, Bolivia and Chile. However, these resources have not been developed equally across the three countries: Chile is an established lithium producer, while Argentina is rapidly emerging as a major producer, with several projects at the production stage or in the early stages of development. The two countries together account for more than one-third of global lithium reserves and one-quarter of total production. Bolivia, by contrast, has not yet fully exploited its lithium resources, despite large, estimated resources. Several early-stage projects are underway, aiming to develop lithium production in the country. Beyond lithium, the region also offers additional opportunities to expand mineral production, including sizeable resources of graphite, nickel and rare earths, predominantly in Brazil.

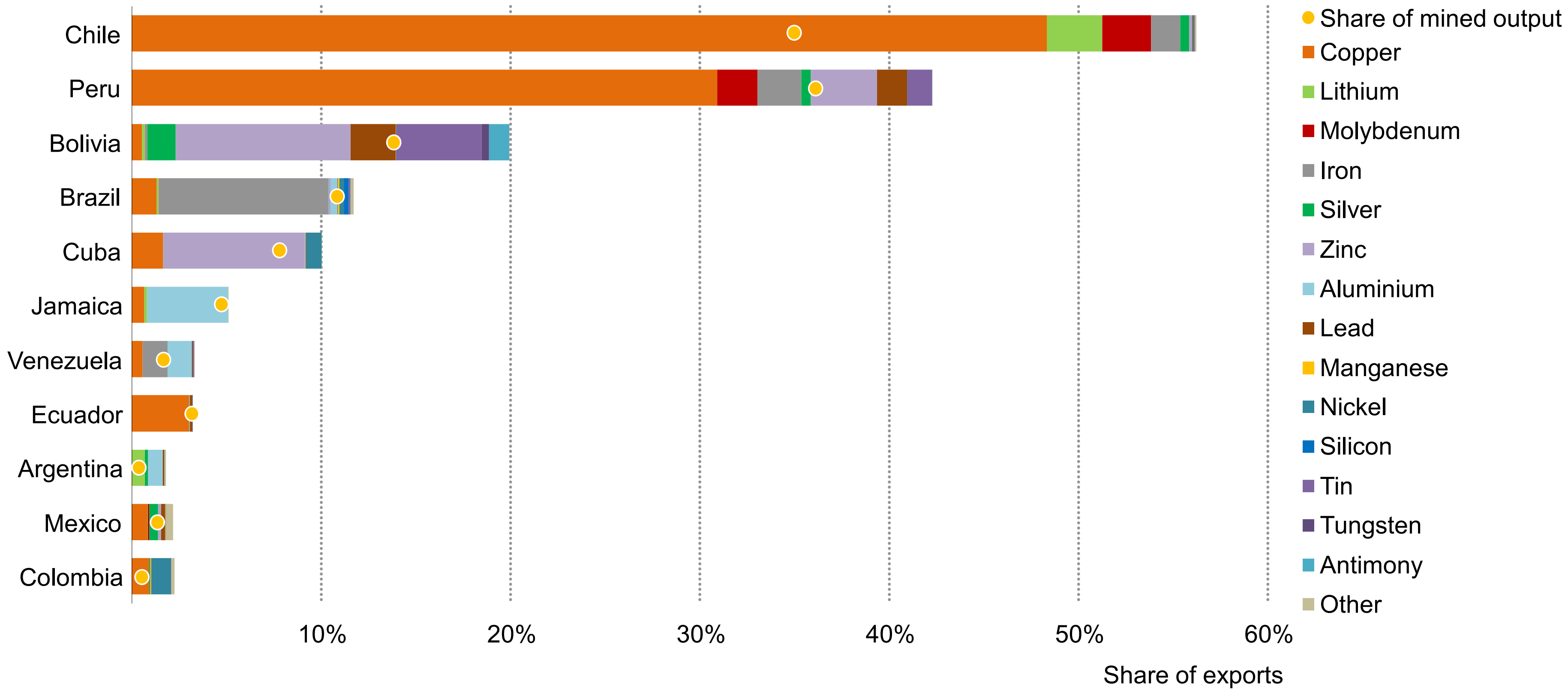
Outlook

Looking ahead, the copper project pipeline suggests mounting difficulties in sustaining current production levels, with constraints visible in Chile and Peru and major implications for the global copper mining industry. Lithium mining, by contrast, benefits from a strong pipeline of investment in Argentina, as well as scope to increase production in Chile and Brazil. Overall, regional output is expected to grow by close to 50% between today and the end of the decade. The region's share in global copper and lithium mining, currently 40% and 25%, respectively, is projected to remain broadly stable to 2040.

Additional production, especially if combined with investment in refining facilities, would support economic diversification and increase global supply security, which remains highly concentrated in a small number of countries.

Exports of critical minerals account for a large share of total exports in many Latin America and the Caribbean economies

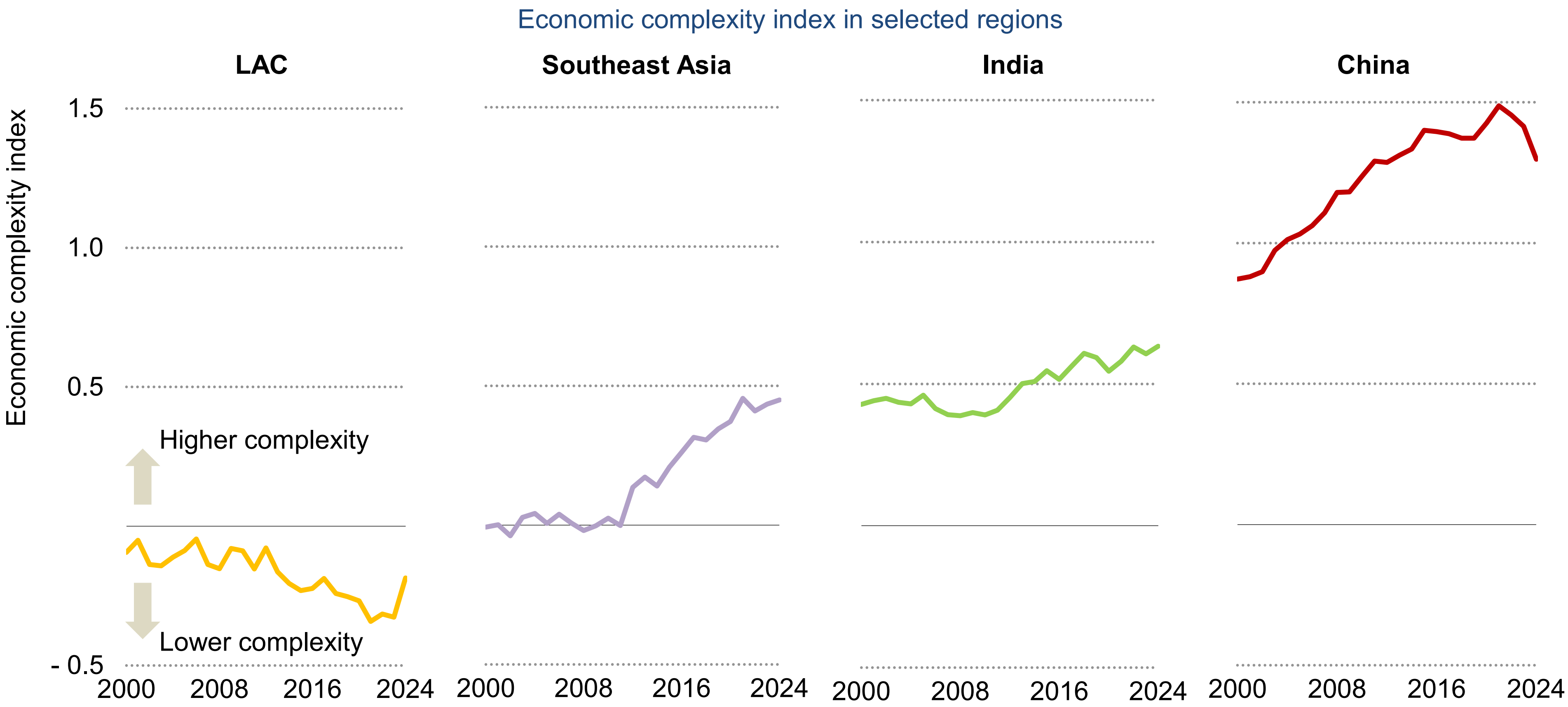
Shares of selected critical minerals exports in total export value in Latin America and the Caribbean, 2024



Notes: The chart shows the share by value of minerals exports over total value of exports of each country. The share of mined output indicates the share of value of mined material over total export value. Total values include mined and refined materials. Aluminium includes bauxite. "Other" includes chromium, cobalt, titanium, graphite, niobium, platinum group metals and vanadium.

Source: IEA analysis based on data from Harvard University (2026), Growth Lab Trade Data (database), accessed 15 June 2026.

Raw materials remain central to LAC's exports, resulting in lower economic complexity than in other regions where exports have increasingly diversified towards higher value-added products

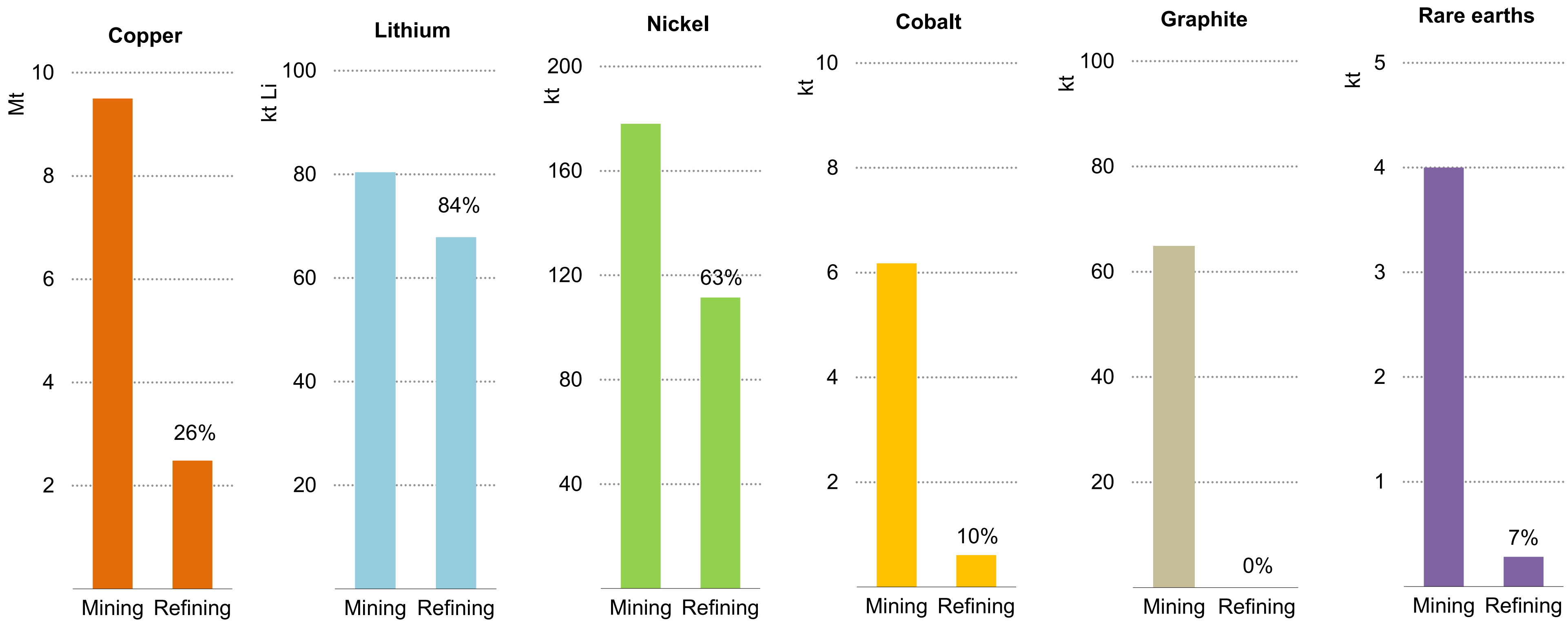


Note: The economic complexity of a country is calculated based on the diversity and sophistication of a country's exports. Countries that export a wide range of products that few other countries can produce tend to have higher economic complexity.

Source: IEA analysis based on data from Harvard University (2026), Growth Lab Trade Data (database), accessed 15 June 2026.

Latin America and the Caribbean currently refines a low share of the minerals it produces

Production of mined and refined material in the Latin America and the Caribbean region, 2025



Progress along the critical minerals value chain would increase economic benefits for the region

Several LAC countries rely on critical minerals for a substantial share of their export revenues. In Chile and Peru, these minerals account for 55% and 40% of export revenues, respectively. However, exports remain concentrated in raw or minimally processed forms, limiting domestic value addition and participation in higher-value segments of global supply chains.

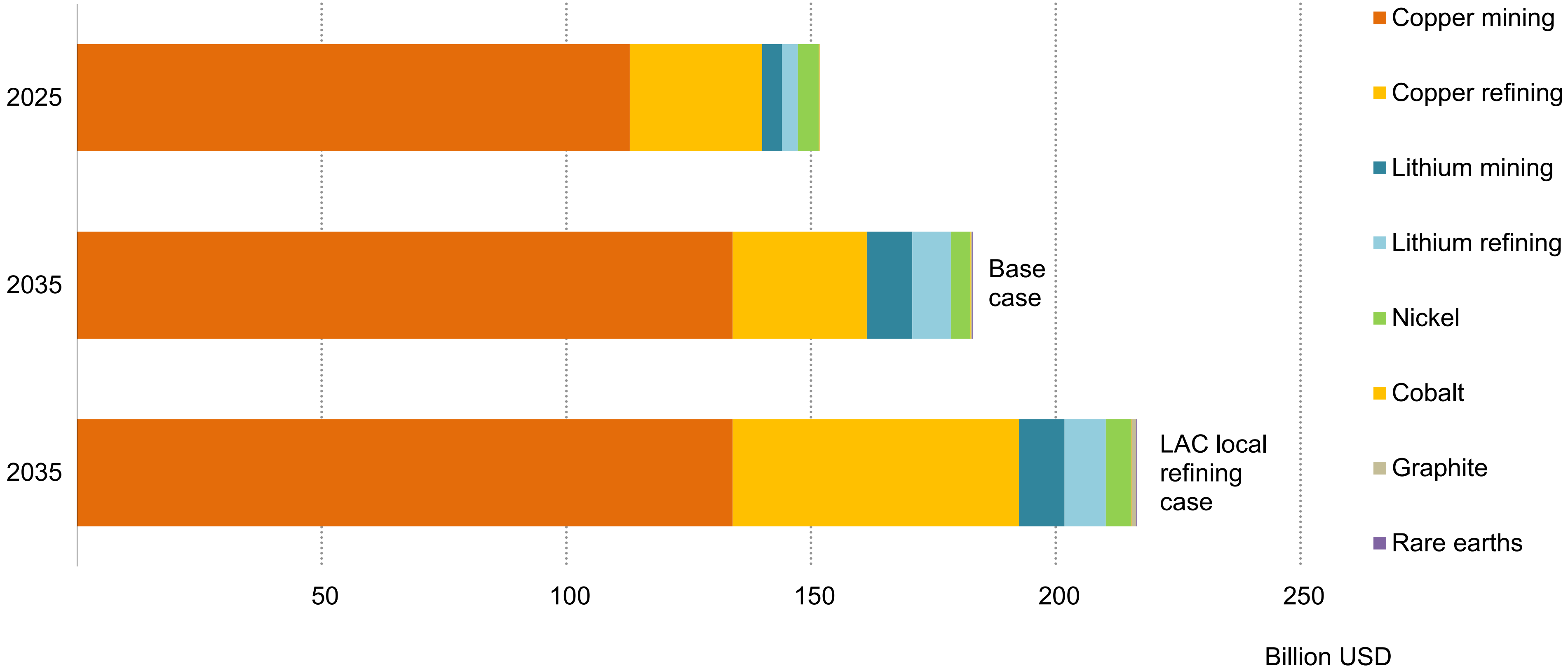
This export structure is reflected in relatively low levels of economic complexity. The Economic Complexity Index (ECI), which reflects the productive capabilities of an economy, inferred from the diversity of its export basket and the ubiquity of the products it exports globally, remains below that of other emerging markets and developing economies, including in Southeast Asia, India and China.

Over the period from 2000 to 2023, economic complexity in LAC declined, largely driven by an increasing concentration of exports in unprocessed commodities, including mineral and energy products. Despite a modest improvement in complexity in 2024, the region continues to face structural constraints in moving up mineral value chains. In 2025, countries in the region refined just 26% of the copper they extracted, 10% of cobalt and 7% of rare earths, and there are no graphite refining facilities in LAC countries. The lithium value chain is slightly different, as full chemical transformation is only needed when lithium is extracted from spodumene rocks, whereas lithium from brines is already in ionic form. Most lithium extracted in LAC comes from brine.

While opportunities for value addition vary across countries depending on their resource base and existing industrial capabilities, further development of refining, processing and manufacturing of intermediate and finished products would enable higher local value added and strengthen linkages with domestic industry. In resource-rich regions with polymetallic deposits, expanding the recovery of by-products from existing operations represents an important option. Such efforts would also enhance resilience to commodity price volatility and position LAC more favourably within rapidly expanding energy supply chains.

Local refining of regional mining output would increase sectoral economic benefits by one-fifth

Economic value of critical minerals production in the base case and the Latin America and the Caribbean local refining case



Notes: The Latin America and the Caribbean local refining case assumes that all of the mined output from the region in 2035 in the base case is refined locally. For copper, the share of mined output refined locally is set at two-thirds of the mined output. For nickel, cobalt, graphite and rare earths, values are the sum of both mining and refining.

Expanding to downstream processing and beyond

There is a clear opportunity for the region to move beyond extraction into higher-value activities. Recently, policy attention has turned to smelting and refining, lithium hydroxide processing, cathode and precursor production, and stronger domestic manufacturing and mining-service industries. Chile is looking into expanding local refining and greater value addition in both the lithium and copper sectors, including through partnerships between the state-owned Codelco and private companies. Brazil's Nova Indústria policy targets batteries, electric vehicles (EVs) and strategic mineral processing as priority sectors. Brazil has undertaken efforts to move up the mineral value chain into the midstream and downstream segments through strategic initiatives. The MagBras Project aims to establish a complete domestic value chain for rare earth permanent magnets, securing technological autonomy and mastering the entire production cycle from mineral extraction to manufacturing and recycling. The state-owned company CEITEC is upgrading its industrial infrastructure to produce power components based on silicon carbide, directly linking advanced materials processing to high-tech industrial applications. In Argentina, the new Incentive Regime for Large Investments seeks not only to support mining-related activities but also to support infrastructure for mining project development, as well as the technology sector, including clean energy technologies.

Potential benefits for LAC economies

Based on the distribution of the base case project pipeline, the LAC region has the opportunity to capture around USD 185 billion of economic value by 2035. Of this, only one-fifth is expected to come from refining, as most extracted material is exported for processing abroad. An analytical case study that assumes all mined lithium, nickel, cobalt, graphite and rare earths and two-thirds of mined copper are refined locally suggests that local refining can significantly increase benefits for local economies. If local refining were to be expanded to its full potential, the economic benefit would rise to around USD 220 billion in 2035.

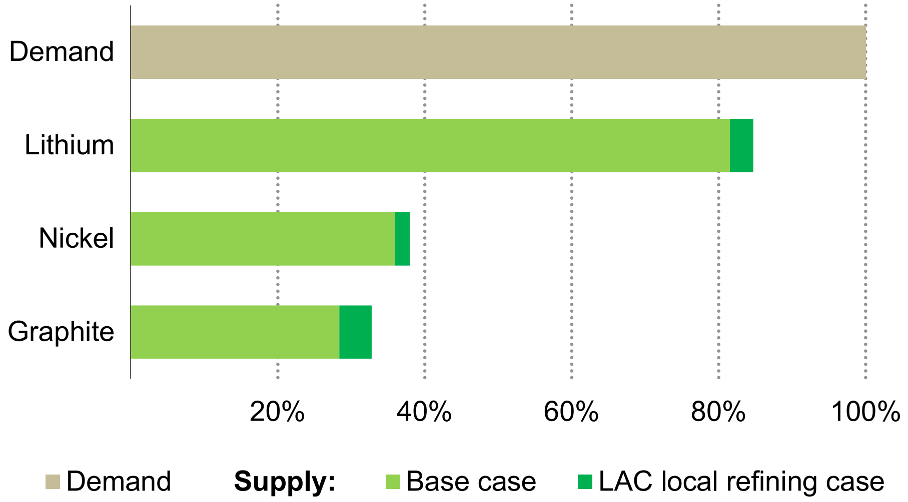
Potential benefits for global supply security

Increasing regional refining capacity for critical minerals extracted in LAC could also strengthen global supply security and reduce exposure to highly concentrated supply chains. In the base case, today's leading refining country, China, is projected to account for 91% of battery-grade graphite production in 2035, alongside 66% of lithium and 50% of nickel refining. This high degree of concentration points to persistent global imbalances. For graphite, nickel and lithium, refined material available outside the dominant supplier covers around 28%, 36% and 82% of demand, respectively, in regions outside the dominant suppliers (see the N-1 analysis in Chapter 2).

In the LAC local refining case, global supply imbalances would improve. Additional regional refining capacity could contribute around

10 kt of lithium, 55 kt of nickel and close to 70 kt of graphite to diversified supply sources by 2035. While modest, these additions would help narrow projected supply gaps and enhance resilience against disruptions.

Global N-1 supply-demand balance for selected critical minerals, 2035



Notes: The N-1 supply excludes production volumes from the largest producer from total global supply, and N-1 demand excludes consumption by that country from total global demand. The LAC local refining case assumes a major expansion of regional refining capacity, enabling local processing of base-case mined production by 2035. LAC: Latin America and the Caribbean.

Latin America and the Caribbean has structural advantages that enable lower emissions intensity compared with other producing regions, but growing water demand poses a rising challenge

GHG emissions reduction

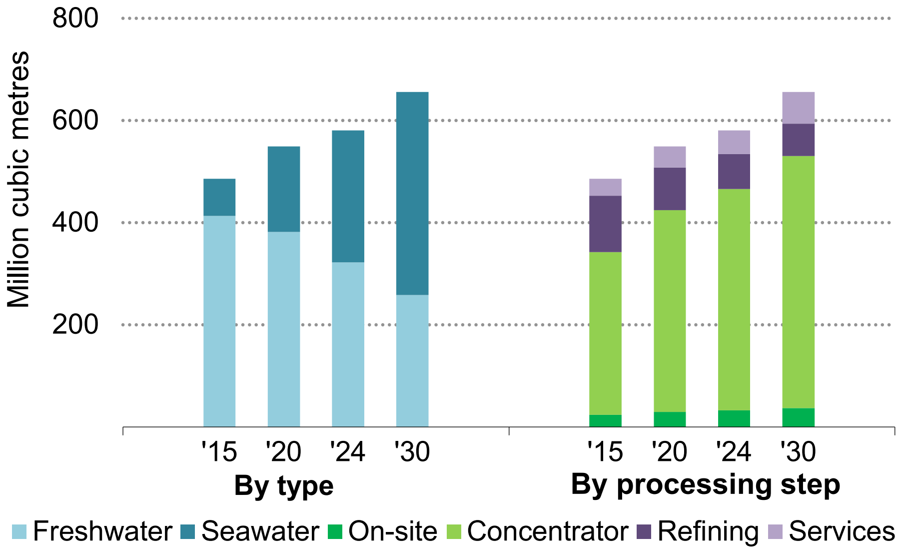
Mining and processing activities are energy intensive activities that can generate substantial greenhouse gas (GHG) emissions, particularly where operations rely on fossil fuel-based energy sources. With renewables accounting for more than 60% of electricity generation, driven primarily by hydro-rich countries such as Brazil and Colombia, and an increasing contribution from solar and wind in Chile, the LAC region holds structural advantages, with mineral production involving notably lower emissions intensity than in other producing regions.

Several mining companies in the region are increasingly integrating renewable energy into their operations as part of their decarbonisation strategies. Recent examples include projects by Vale in Brazil and by Codelco in Chile. Chile's Atacama region, with some of the world's highest solar irradiation levels, offers particularly strong conditions for low-emissions electricity and more sustainable practices. In Argentina, at the Lindero mine, the integration of solar power generation and battery storage into the existing energy system has succeeded in reducing annual diesel consumption by approximately 40%. Beyond the electrification of facilities, further emissions reduction measures in the mining sector include the electrification of vehicles such as heavy-duty trucks, energy-efficient crushing technologies and the optimisation of processing. However, the deployment of these solutions remains uneven, as many mining operations are located in remote areas with limited grid access and therefore continue to rely heavily on fossil fuels for operational reliability. Continued infrastructure investment and supportive policy frameworks will be essential to further reduce the region's emissions intensity. In particular, expanding access to renewable electricity, strengthening transmission infrastructure and facilitating long-term power purchase agreements will be critical.

Water usage

In LAC, water demand in mining is increasing due to a combination of structural factors. Declining ore grades have led to higher volumes of ore being processed, which in turn increases water demand. A rising share of sulphide ores in copper production is further increasing the water requirements associated with flotation processes. For instance, total water demand from copper mining in Chile is projected to increase notably, reaching over 650 million m^3 by 2035.

Water consumption in copper production in the high-production case in Chile, 2015-2030



Note: The high-production case considers projects at a reasonably advanced stage of development.
Source: IEA analysis based on data from the Chilean Copper Commission.

While mining is becoming more water-intensive, many mines in the region are located in arid deserts and mountainous areas, where water resources are already scarce and essential for local communities, agriculture and ecosystems. This makes securing a sufficient water supply an urgent challenge and raises concerns around competing uses. In response, some companies are implementing measures to reduce dependence on freshwater. For example, the Quellaveco copper project in Peru has achieved lower water-use intensity through high recirculation rates of approximately 85%. The project is also supported by multipurpose water storage infrastructure, which contributes not only to mining operations but also to local water management, including flow regulation and the supply of water for agricultural use, developed through a multi-stakeholder dialogue involving government authorities and local communities. In Chile, there has been a pronounced shift towards the use of desalinated seawater for mining operations, helping to reduce freshwater consumption. This transition is being supported by public policy, with a recently established framework that regulates the use of seawater for desalination. However, desalination and long-distance water transport are both capital and energy intensive, highlighting the close linkages between water use, energy consumption and GHG emissions.

In lithium extraction from brine, concerns persist regarding groundwater depletion and impacts on ecosystems. Brine extraction in high-altitude salt flats can affect interconnected water systems that support local biodiversity and communities, highlighting the need for careful resource management and improved monitoring. In Chile's Atacama salt flats, around 70% of the water footprint per tonne of lithium product is associated with concentrated brine production, while in the conversion to lithium carbonate, the final stage of lithium production, the use of desalinated water helps mitigate pressures on scarce freshwater resources. In recent years in Atacama, operational improvements, including higher brine recovery rates and lower energy consumption in processing stages, have contributed to reducing water intensity.

Water scarcity remains one of the most significant constraints on mining expansion in the LAC region. Addressing this challenge will require a combination of infrastructure investment, technological innovation, such as through further adoption of direct lithium extraction technologies, and strengthened governance frameworks to ensure sustainable water use. Promoting dialogue and co-ordination with other water-intensive sectors such as agriculture, as well as with local communities, is also essential. Comprehensive approaches to ensure the long-term sustainability of water use will reduce project-level uncertainty and strengthen the social acceptance of mining projects in the region.

Latin America and the Caribbean countries have policy tools to overcome the risks and challenges that hinder the development of critical minerals projects, but stronger implementation efforts are needed

Policy tools in the region target key risks and challenges:

- Cost of capital
- Market and price risks
- Environmental management
- Regulatory uncertainty
- Infrastructure
- Technology gaps

Note: ECLAC = Economic Commission for Latin America and the Caribbean; RD&I = research, development and innovation.

Policy pathways to address market, regulatory and technological barriers

A broad set of risks creates challenges for expanding the critical minerals value chain in LAC. These range from regulatory uncertainty to technology gaps and affect both the timing and scale of private investment. Enhanced policy frameworks can reduce uncertainty, lower financing costs and improve project bankability.

Cost of capital. Reducing the cost of capital is critical for scaling up investment in critical mineral projects, as elevated risk perceptions, particularly in emerging regions or new segments of the value chain, often translate into high financing costs. Policy instruments such as public credit guarantees can lower lender risk and improve project bankability, while public-private partnerships allow governments to share risks with private investors, especially for large or strategic projects, helping to crowd in private capital. For example, Argentina's Incentive Regime for Large Investments offers tax reductions and other benefits to facilitate the realisation of long-term investment, while Chile's Novandino Litio is an example of how public-private partnership can support financing for mineral development projects.

Market and price risks. Managing market and price risks is essential for the viability of critical mineral projects, as commodity price volatility and uncertain demand, particularly for downstream processing, can weaken investment incentives. The development of processing hubs in the region, including by leveraging existing regional and international collaboration platforms, can create economies of scale, lower unit costs and improve resilience to price swings. Regional and international traceability systems in support of diversification and sustainability would also be beneficial for projects in the region, especially if they are extended beyond mining to support the development of refining and processing facilities. For example, Colombia's Mining Traceability System introduced a digital platform to track mineral origins and could be used to foster diversified projects and incentivise sustainable practices.

Environmental management. While the region has extensive experience in large-scale mining, particularly for bauxite, iron, gold and copper, new critical mineral projects may emerge in new locations, requiring careful environmental planning and management of impacts related to water, emissions, noise, dust, and mine closure and rehabilitation. LAC countries already have environmental regulations applicable to mining, and some have recently updated their policy frameworks. Mexico's 2023 mining reform increased water and socio-environmental scrutiny in the awarding of mining concessions, and Peru's updated mine closure law makes mine closure and rehabilitation a continuous legal obligation, requiring upfront financial guarantees and regular updates of mine closure plans. Brazil's National Policy on Critical and Strategic Minerals embeds environmental criteria into the selection of priority projects. Colombia, Chile and Brazil are also advancing emissions trading systems, creating incentives to reduce emissions across industrial sectors. Industry standards complement regulatory measures. Chile's mining sector is targeting carbon neutrality, while its two largest lithium producers, Albemarle and Novandino, have completed independent audits of their Salar de Atacama operations against the Initiative for Responsible Mining (IRMA) standard, lending a higher degree of transparency to environmental and social performance.

Permitting and regulatory uncertainty. Unpredictable and fragmented regulatory frameworks can delay the development of new projects and undermine investor confidence. The total time for permitting and project development in Chile can span between 54 and 139 months for exploration, mining and desalination projects, depending on project complexity, with the longest time frames associated with desalination plants and tailings storage facilities. Governments, however, have access to a range of policy instruments to help reduce permitting times. Establishing centralised permitting authorities, one-stop shops or dedicated agencies to co-ordinate regulatory approvals can reduce institutional fragmentation and accelerate permitting timelines by limiting duplication across institutions. At the same time, efforts to streamline permitting processes need to ensure that environmental and social safeguards are upheld, as insufficient consultation or impact assessment can lead to project delays, social opposition and cost escalation over the project life cycle. Examples in this direction include the Environmental Impact Assessment System centralised permitting system in Chile. In addition, permitting processes are often structured sequentially, meaning that delays or bottlenecks at a single stage can slow overall project progress. Allowing key regulatory and administrative processes to proceed in parallel, where appropriate, can accelerate decision-making while maintaining robust regulatory oversight. Peru's Digital Single Window serves as a one-stop shop, integrating nine public entities involved in mining permitting and helping to streamline processing times.

Infrastructure. Transport, energy, water and logistics infrastructure can constrain the development of critical mineral projects, as weak connectivity and limited access to resources raise costs and project risks. Regional integration through cross-border infrastructure planning and harmonised standards can help LAC countries improve connectivity and facilitate trade. Co-ordinated and targeted public investment via direct financing or co-financing of enabling infrastructure, such as roads, ports and power supply, can reduce upfront risks, attract private capital and ensure reliable access to the necessary infrastructure for mining and processing operations. New infrastructure projects can be designed to deliver tangible benefits for local communities, including employment and skills development, while strengthening the foundation for broader regional economic development. Examples of shared infrastructure include Brazil's Carajás corridor, including railway and port development, and Chile's solar-powered ENAPAC desalination project.

Technology gaps. While the region is in some cases at the forefront of deploying new mining technologies, technology gaps could still constrain the development of midstream refining and processing projects. For metal refining and product manufacturing, advanced processing operations are required, such as the production of battery precursors and cathodes, rare earth separation and magnet manufacturing. These generally require advanced manufacturing know-how, access to specific material inputs and proprietary knowledge. Addressing these gaps will require sustained investment in research and development, skills and innovation ecosystems, alongside stronger collaboration with chemical and processing companies.

Public investment in research and development (R&D). Support for applied research, pilot projects and demonstration plants can help de-risk emerging technologies and accelerate their adoption. International collaboration with advanced economies, multilateral institutions and industry partners can also facilitate technology transfer, skills development and institutional learning. The Brazilian Development Bank and the Brazilian Innovation Agency have provided funding for R&D and innovation activities, including in midstream and downstream supply chain segments. In 2026, the Chilean Production Development Corporation awarded three R&D projects focused on recovering cobalt and rare earths from tailings and mine waste as part of the programme "R&D Challenges for Sustainable Productive Development". The IDB LAC Minerals by the Inter-American Development Bank (IDB) aims to mobilise financing, knowledge and connections in the region to support the innovation cycle of critical mineral projects from early stages to scale-up, while also providing a link to the IDB Invest financing scheme.

Potential for regional synergies

Chile and Peru have mature copper industries supported by specialised suppliers, geological expertise and export infrastructure. Brazil combines diversified mining output with metallurgical capabilities, while Mexico's automotive and electronics manufacturing base could support deeper downstream integration. These advantages, if combined, could help reduce barriers to investment in critical mineral projects, although transport, power and water infrastructure will still need to expand in key mining corridors.

Regional co-ordination and partnerships are becoming more important as countries seek finance, technology and market access. Institutions such as the IDB, Economic Commission for Latin America and the Caribbean (ECLAC), the Development Bank of Latin America and the Caribbean, and the Latin American and Caribbean Energy Organization can facilitate co-ordinated mining and industrial strategies across the region. For example, the Permanent Forum for Technical Dialogue on Lithium, established and operated by ECLAC since 2022, promotes sustainable extraction and industrial activities through regional integration, technical exchange and lesson sharing. It brings together state-owned enterprises and technical agencies from Argentina, Bolivia, Chile and Mexico, while regularly inviting subnational authorities and private actors and fostering dialogue with countries outside the LAC region.

Latin America and the Caribbean countries are developing dedicated critical mineral policy strategies and updating policy frameworks to attract investment and better integrate into global supply chains

Countries in the region exhibit diverse critical mineral policy strategies, reflecting differences in resource endowments and positions in value chains. Many producers are seeking to strengthen international partnerships to attract investment and improve integration into global value chains. This section provides an overview of recent policy developments in the region, with a focus on investment promotion, as well as on key regional and international partnerships. Risks and challenges to policy implementation are discussed in more detail later in the chapter.

Argentina

Since 1993, Argentina's Mining Investment Regime has provided incentives such as a 30-year guarantee of fiscal and foreign exchange stability for new projects. In 2024, Argentina launched the Incentive Regime for Large Investments, aimed at attracting investment in large projects, including in the mining sector. Building on existing incentives, the initiative progressively eliminates the requirement to repatriate export proceeds and sets a maximum corporate income tax rate of 25%, in addition to providing benefits including accelerated depreciation and exemptions from import and export duties. It will remain open for applications until July 2027, providing additional opportunities compared with the existing mining investment framework. It also establishes minimum investment thresholds for eligible projects. As of June 2026, nine mining projects had been approved for a total of USD 10 billion, mainly for lithium, copper and gold.

Argentina is also actively advancing bilateral co-operation aimed at integrating its critical mineral production into global supply chains. Since 2023, Argentina has signed memoranda of understanding (MoUs) with a diverse set of partners, including Canada, the European Commission, India and the United Arab Emilates (UAE), highlighting its multi-regional engagement strategies. In February 2026, it also concluded a landmark framework with the United States on mining and refining. Co-operation among provincial governments has also been strengthened; in April 2026, the governors of Salta, Catamarca and Jujuy signed a joint agreement to enhance governance, infrastructure and the development of the lithium value chain under the current regulatory framework.

Bolivia

Bolivia has sought to promote investment in mineral exploration by adjusting its regulatory framework and signing bilateral agreements. In April 2026, the government convened regional dialogues on lithium development in Potosí, Uyuni, and Oruro which informed a strategic roadmap emphasising environmental safeguards, water resource protection and inclusive regional development, alongside efforts to strengthen the legal framework governing the sector. At the end of 2025, a supreme decree established that investment in the mining sector qualifies as a strategic priority, granting eligible projects access to incentives including a 15-year fiscal stability period, reduced taxes and a fast-track approval procedure.

Brazil

Brazil aims to further develop domestic supply chains, including by officially launching its National Mining Policy Council, which sets long-term guidelines for the mining sector and strives to position the country as a key global supplier of critical minerals. In 2026, the government is updating its National Mining Plan 2050, following public consultation. The Ministry of Mines and Energy and the Brazilian Geological Survey also launched the 2026 edition of the Overview of Critical and Strategic Minerals Potential of Brazil to present Brazil's potential for critical minerals with up-to-date data on production, reserves, national programmes and thematic studies. In May 2026, the Critical and Strategic Minerals Bill, which establishes the country's first National Critical and Strategic Minerals Policy, was sent to the Senate. The policy focuses on accelerating supply chain development through nine policy instruments. In June 2026, Brazil's Ministry of Mines and Energy, in partnership with the Inter-American Development Bank, launched a technical study to support the development of a national rare earth strategy.

To promote foreign direct investment, the Ministry of Mines and Energy launched Brazil's Critical Minerals: A Guide for Foreign Investors 2026, providing an overview of administrative processes, regulatory frameworks, public support for new mining projects, and environmental, social and governance considerations.

Chile

Ongoing reforms of Chile's regulatory framework aim to attract private investment while promoting value addition and sustainability in mining. Its National Mining Policy 2050 from 2022 targets a halving of environmental and sector-specific permitting times by 2050. Its 2024 National Lithium Strategy includes special provisions to ensure that a portion of lithium produced is sold at a preferential price when used by refining and battery industries. The 2025 Framework Law on Sectoral Authorizations aims to reduce permitting times between 30% and 70%. In January 2026, Chile launched its National Critical Minerals Strategy to consolidate its role in global supply chains through five strategic pillars, one of which includes attracting responsible investment. In April 2026, the National Reconstruction and Economic Development Bill, which includes a proposed reduction in corporate taxes along with employment incentives and faster environmental permitting, was submitted to Congress for approval. In May 2026, a bill was introduced to reform Chile's mining concession maintenance regime, simplifying compliance requirements and expanding eligibility for reduced mining licence fees to provide greater legal certainty and support mining project development.

At the regional level, Chile has advanced three major corridor projects to strengthen regional connectivity, reduce transport costs and enhance access to global markets. These include three bi-oceanic corridors, Capricorn, Central and Northern Patagonian, which connect the Atlantic and Pacific Oceans through a network of roads and infrastructure, facilitating the movement of critical minerals across participating countries such as Argentina, Bolivia, Brazil and Peru. In 2026, Chile and Argentina agreed to reactivate the Administrative Commission of the Chile-Argentina Mining Integration and Complementation Treaty to foster mining co-operation. At the international level, since 2025, Chile has signed MoUs with India and the United States to promote investment, exploration, value-added processing and technology transfer.

Colombia

Colombia's critical minerals strategy is framed by its National Mining Development Plan 2024-2035, which identifies copper, nickel, phosphates and manganese as priority strategic minerals and promotes their development through streamlined permitting procedures, competitive bidding rounds and enhanced traceability. In 2025, the country launched its first tender round, offering 14 strategic mining areas for the development of copper, gold and polymetallic minerals.

Colombia is seeking to improve the efficiency and transparency of its mining governance framework through a combination of regulatory reforms and institutional initiatives. In 2026, the National Mining Agency introduced two draft regulatory resolutions to streamline permitting procedures, including shortening consultation periods from 216 to 90 days, while maintaining inclusive stakeholder engagement, and revising the assessment of financial viability for mining concessions. In parallel, in May 2026, Colombia launched the Mineral Traceability Platform to strengthen compliance and transparency mechanisms across the value chain. In 2025, the Colombian Commission of Mineral Resources and Reserves updated the Colombian Standard for the Public Reporting of Exploration Results, Mineral Resources and Reserves (ECRR), strengthening sustainability requirements for mining projects.

Mexico

Stated policy objectives in Mexico focus on reinforcing critical minerals as a strategic and sovereign resource while promoting stronger environmental and social requirements. Amendments to the Mining Law approved in May 2023 expand consultation rules and processes, prioritise water for domestic use, and require all mining concessions to be allocated through public bidding following approval of necessary environmental, social and labour permits. Originally established in 1992 as a structural reform of the sector's governance framework, the Mining Law seeks to enhance environmental and social safeguards. It introduces consultation and compensation requirements for Indigenous communities, prioritisation of water use for human consumption and requirements to recycle at least 60% of concessioned water. Downstream processing developments are also encouraged under Mexico's National Plan 2025-2030, which promotes increased investment in scientific and technological research and reduced patent registration times. Mexico seeks to strengthen international co-operation, with the aim of consolidating mining-related value chains to foster greater regional integration beyond the national level. These efforts aim to address supply chain risks while promoting value creation and retention in both Mexico and the North American region.

Peru

Peru's current efforts are focused on promoting investment in mining exploration. In 2022, the VAT refund for mining exploration was extended until 2027 to attract new investment. To reduce uncertainty during the exploration phase, Peru is finalising its National Geological Map, which will provide complete coverage of its territory by the end of 2026. It has also established international partnerships to support the mining sector. In 2025 and 2026, Peru signed MoUs with Canada, the United States (one in the context of the Critical Minerals Ministerial and another with Proinversion) and Chile to advance investment and access to technology, information and expertise exchange. Furthermore, the Ministry of Foreign Affairs, along with the Canada-Peru Chamber of Commerce, published Peru's Mining & Metals Investment Guide 2025/2026 with an updated overview of the sector, its potential and the applicable tax and legal frameworks.

Venezuela

Venezuela enacted the new Ley Orgánica de Minas [Organic Mining Law] in April 2026, opening the mining sector to foreign and private investment while maintaining state ownership of mineral resources. The law grants strategic mineral ownership to the state and allows domestic and international companies to operate through concessions and joint ventures, with renewable mining rights granted for up to 30 years. It also introduces clearer licensing procedures, royalty regimes and international arbitration mechanisms to strengthen investor confidence.

Caribbean countries

Countries in the Caribbean region are intensifying international co-operation to attract investment in critical minerals and strengthen their role in emerging supply chains. In the Dominican Republic, efforts are focused on exploring rare earth potential as a key economic opportunity. The country is strengthening mining governance with the creation of the Dominican Mining Company, Emidom, in 2024 and plans to adopt new mining legislation to support critical mineral investment. Jamaica approved an Industrial Minerals Policy in 2024 to attract investment into its mining sector. In addition to supporting investment in its established bauxite and alumina industries, the policy has helped attract major international partners exploring for gold and copper.

Achieving social acceptance and delivering high-quality projects require sustained, transparent and inclusive engagement with local stakeholders

The importance of involving local communities when developing new projects is at the centre of regional frameworks such as the Escazú Agreement, a treaty supporting the rights of individuals and communities to access environmental information and participate in decision-making processes. In many countries across the region, public participation is embedded within environmental impact assessment processes, with a strong emphasis on the rights of Indigenous peoples. The United Nations and the International Labour Organization also recognise the principle of free, prior and informed consent for Indigenous communities in relation to authorisation for mineral exploration and project development.

Specific consultation and stakeholder engagement frameworks vary across the region in terms of legal requirements, implementation capacity and conflict intensity. The Escazú Agreement, built on binding principles of access to information, public participation and environmental justice, is progressively reshaping how Latin American states govern stakeholder engagement, including in extractive industries. Chile's Senate ratification in June 2022 strengthened public consultation requirements in environmental licensing processes. Colombia's Pollutant Release and Transfer Register, phased in from 2025, provides affected communities with the right to access data on industrial emissions for the first time. Colombia's Law 2273, upheld as constitutional by the Constitutional Court in August 2024, makes treaty obligations directly enforceable in national courts. Cutting across all pillars, Mexico's SEMARNAT implementation roadmap and the regional 2024-2030 Action Plan on Environmental Defenders establish protective mechanisms for environmental defenders.

Countries in the region have specific frameworks supporting the participation of Indigenous or Native Peoples. In 2011, Peru enacted the Law on the Right to Prior Consultation of Indigenous or Native Peoples, which provides guidelines for structured dialogue between the state and Indigenous communities. In Mexico, the National Institute of Indigenous Peoples launched guidelines in 2019 for implementing the right to the free, prior and informed consent of Indigenous peoples. In 2018, Paraguay enacted the Protocol for the Process of Consultation and Free, Prior and Informed Consent with the Indigenous Peoples Living in Paraguay.

Mining companies play a significant role in shaping stakeholder engagement practices. For instance, some have developed their own community consultation frameworks and defined how the views of affected communities are incorporated into operational decision-making. The Somos Choapa programme in Chile demonstrates the efforts that the private sector can make to facilitate multi-stakeholder dialogue.

There are still areas for improvement, alongside accumulated lessons on effective stakeholder engagement in the region. In particular, engagement as a first step and greater accessibility of information, covering not only project benefits but also environmental risks, are essential for enabling local communities to make informed decisions. Best practices, which can be grounded in the principle of free, prior and informed consent, should ensure that information is transparent, culturally appropriate and available in the native languages of affected communities, with clear and accessible explanations of technical aspects. Strengthening these elements can enhance the effectiveness of consultation processes and positively influence project viability and continuity. Such practices include sustained engagement, not only prior to project initiation but throughout the entire project life cycle, including post-closure, and may entail participatory monitoring mechanisms during project implementation and the delivery of tangible benefits to local communities. Social inclusion in projects is crucial to support the sustainable growth of the sector in the region.

Beyond consultation and participation mechanisms, ensuring that local communities benefit from mining activities is another important area of policy action. Across LAC, governments have established a range of legal and fiscal frameworks to channel a share of mining revenues to subnational authorities and affected communities. While approaches vary, these mechanisms aim to strengthen the local value generated by mining projects and help align community interests with project outcomes. This is the case in Peru, where mining revenues including royalties are allocated to subnational governments based on production levels. However, challenges can remain in ensuring that benefits are distributed equitably and effectively, highlighting the need for continued improvements to benefit-sharing frameworks.

Overall, meaningful engagement with local communities requires both public and private actors to strengthen sustained, transparent, inclusive, culturally appropriate and genuine mechanisms that enable communities to exercise their rights while supporting stable and resilient mineral supply chains.

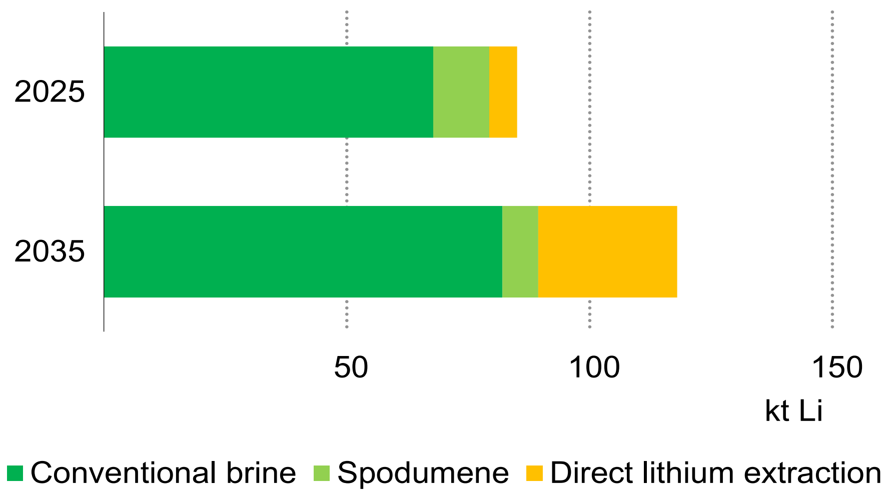
New exploration, mining, refining, manufacturing and recycling technologies can be key drivers of economic development in the region, if supported by enabling policies

From upstream exploration and mining to refining, manufacturing and recycling, a range of emerging technologies can enhance efficiency, deepen value addition and promote economic development. Supportive policies will be crucial for deploying these innovations.

Upstream

Direct lithium extraction (DLE) is among the most promising technologies for delivering new projects and production in the region. Existing projects extract lithium from brines in evaporation ponds, where the brine is allowed to evaporate and the resulting solution is then refined into lithium carbonate or lithium hydroxide. In contrast, in a typical DLE process, lithium ions are extracted from brine through adsorption, ion exchange, solvent extraction, or membrane and electrochemical methods. Once lithium ions are recovered, they are converted into lithium carbonate or lithium hydroxide. DLE technologies aim to achieve over 90% recovery, significantly higher than the 40-60% recovery typically achieved in conventional brine-based extraction. Additionally, DLE offers the potential to access lithium deposits that were previously hard to reach or too costly to extract. However, new DLE projects will need to overcome cost and operational challenges that have slowed adoption to date.

Lithium production in LAC by project type



Globally, DLE accounts for almost 10% of lithium supply, although in most cases it is combined with traditional evaporation ponds. The main large-scale DLE projects outside China are currently located in Argentina. The Fénix facility, acquired by Rio Tinto in 2025, has been operating for more than 30 years, combining adsorption DLE with conventional pond evaporation. Two new DLE projects are being developed in Argentina: Eramet's Centenario (planning 24 kt Li production capacity by 2027) and Rio Tinto's Rincón (planning 60 kt Li production capacity when fully expanded). In Bolivia, a consortium including CATL and Uranium One Group aimed to build

DLE plants in the Salar de Uyuni region, but the project has been suspended following a court order. In Chile, Albemarle has started the environmental review for a DLE project in the Antofagasta region, and the Novandino partnership between Codelco and SQM is planning new projects in the Atacama Desert.

Ionic adsorption clay is a method used to extract rare earth elements from ionic adsorption deposits. Brazil is at the forefront of the development of ionic adsorption clay projects, as Serra Verde aims to produce 6.4 kt of rare earth oxides from the Pela Ema deposit by the end of 2027 using ionic adsorption clay technology and low-emissions electricity. Further potential has been identified in the country, with projects in the advanced permitting or feasibility stages.

Integration of renewables and advanced water management is key for the region to leverage its comparative advantages and develop shared infrastructure that would contribute to countries' development and economic growth. The region already hosts innovative facilities that integrate mining operations with renewable energy production and advanced water management systems, such as Teck Resources' Quebrada Blanca Phase 2 copper mine in Chile. Among other innovative technologies, the University of Concepción is developing hydrogen-based processes for copper concentrate, which have the potential to significantly reduce emissions.

Digitalisation and the integration of artificial intelligence (AI) in critical mineral development can bring significant benefits along the value chain. AI can support mineral exploration by creating mineral perspective maps based on geology. The Instituto de Tecnologías Limpias in Chile is developing digital twins and modular water solutions to optimise mining operations and resource use. The Chilean National Mining Society is also working on district-level digital mapping to integrate information on ownership and facility type with infrastructure data. In Brazil, a project developed in collaboration with Canada is using AI to model nickel deposits, with initial findings expected by 2027. AI-optimised drilling can lift output, reduce costs and enable the development of deeper or lower-grade deposits. Automation improves operational safety by reducing manual work in hazardous tasks. Innovative technologies also have the potential to improve tailings management, unlocking new resources and reducing environmental impacts. The emergence of a digitally educated workforce is likely to support a gradual expansion in the adoption of digital solutions.

Midstream

Advanced hydrometallurgical routes, including new heap leaching techniques, pressure leaching and bioleaching, are particularly relevant for LAC producers facing declining ore grades and rising costs. In Chile and Peru, where copper production is increasingly constrained by lower grades and water stress, such methods can support the economic processing of low-grade sulphide ores and historic tailings while reducing reliance on energy-intensive smelting. In Brazil and Colombia, where nickel laterite deposits are present, bioleaching has potential applications for nickel laterites and polymetallic residues, supporting higher recovery rates and extending mine life. The successful deployment and commercial viability of these technologies will depend on market conditions, as well as progress in scaling up deployment and reducing costs.

New rare earth separation technologies, including alternative solvent systems, ion exchange processes and membrane-based techniques, could lower environmental impacts, improving the feasibility of local or regional rare earth processing hubs. One key challenge in rare earth separation is the concentration of technological knowledge, machinery manufacturing and skilled workforces in incumbent producing regions (see Chapter 3). Investment in technological development programmes can play a critical role in building local capabilities, supporting the development of domestic knowledge and manufacturing bases, and facilitating the gradual localisation of separation and processing activities.

Microwave-assisted calcination and heating is an emerging technology with potential applications in selected mineral processing steps. While these technologies are still at the early stages of commercial readiness, they could contribute to incremental energy efficiency gains for LAC producers operating in power-constrained systems or regions with high electricity costs, such as parts of the Caribbean and remote mining regions in South America.

Downstream

Innovative anode technologies could be particularly relevant for LAC, where resource endowments and low-emissions power sources create opportunities for value-added battery supply chains. In Brazil, collaborative efforts between domestic and international firms have explored alternative anode chemistries, including lithium-ion batteries based on niobium-containing materials, illustrating the potential for leveraging the country's unique mineral base.

Beyond niobium, Brazil hosts established production of graphite and silicon, highlighting potential for the development of silicon-carbon anode composites. These materials are attracting growing interest as battery manufacturers seek higher energy density and improved performance. In addition, Brazil's relatively low-emissions electricity mix adds to the advantages of domestic graphite processing and anode manufacturing, particularly as battery manufacturers seek lower life cycle emissions and higher sustainability standards.

Recycling

Recycling can offer significant opportunities in the region. The e-waste collection rate is currently at just 3%, lower than the global average of 22%, with some high-performing regions reaching 58%. Innovative technologies can also support additional recovery: battery recycling through hydrometallurgical processes, which recover lithium, cobalt and nickel through acid leaching and selective separation, has the potential to achieve high recovery rates with lower energy intensity than traditional smelting. Pyrometallurgical routes are still relevant where there is smelting infrastructure, as in Chile and Peru, but are more energy-intensive and prone to material losses, while emerging direct recycling approaches aim to restore cathode material with minimal processing. Urban mining of e-waste can tap into growing electronic waste streams, such as portable electronics, EV batteriesand motors, and wind turbines, where valuable materials, including battery minerals, rare earths and other minerals, are often present at higher concentrations than in extracted ores.

Policy tools to support innovation

Targeted policy instruments are essential to support innovation in critical mineral production and processing in LAC, particularly when deployed as part of co-ordinated industrial and innovation strategies.

Financial tools play a central role, including direct R&D funding, co-financing through public innovation agencies and blended finance mechanisms from development banks, which help de-risk early-stage technologies and crowd in private investment.

Country experiences highlight how these instruments can translate into innovation outcomes. In Brazil, the SENAI-led lithium-ion battery project (2024-2027), supported by funding of around USD 12.5 million, combines applied research funding with industry co-investment to establish pilot production lines and develop domestic technological capabilities. The programme brings together a consortium of industrial partners, enabling knowledge transfer across the battery value chain and supporting the development and testing of locally adapted technologies.

Similarly, development finance institutions are supporting innovation by linking funding with technical assistance and capability building. The IDB, through initiatives such as LAC Minerals, provides blended finance and technical support to improve project design, environmental standards and local supplier integration. In Argentina, for example, IDB-supported financing for the Rincón DLE project is coupled with measures to strengthen local supply chains and operational capabilities, contributing to the diffusion of knowledge and innovation across the sector.

Beyond funding, a strong focus is needed on enabling firms to innovate by **improving capabilities and the broader ecosystem**. This includes investments in skills and human capital, the development of research and technology institutions and expansion of existing programmes, and policies that encourage collaboration, such as cluster initiatives and regional innovation programmes.

Finally, LAC countries can leverage **demand-side policies** and **international collaboration** to accelerate innovation uptake and diffusion. Public procurement, standards and lead market initiatives can create early demand for new technologies, while foreign direct investment, participation in global value chains and collaboration within the region can foster knowledge transfer and skills development.

From innovation to industry

Innovation could be a major source of value creation for LAC, but only if it is embedded in broader industrial, infrastructure and skills strategies. The region benefits from strong foundations: major mining companies already originate from the continent, including Chile's Codelco and Brazil's Vale, and mining technology and service providers can help directly deploy solutions in operations. This provides a platform to scale technologies that raise recovery rates, improve water and energy management, enhance safety and reduce environmental impacts. However, the scope to innovate in other parts of the value chain varies by segment. In areas where domestic capabilities are more limited, including advanced battery materials, rare earth separation, specialised equipment and some digital and automation technologies, attracting partners and firms with advanced technological expertise can be valuable to complement local innovation. Policy has a crucial role to play. Building capacity in geological services and technology centres, targeted R&D support, actions to support technology transfer and demonstration projects, investment in education and international partnerships can help strengthen innovation capabilities and enhance operational efficiency.

Annex

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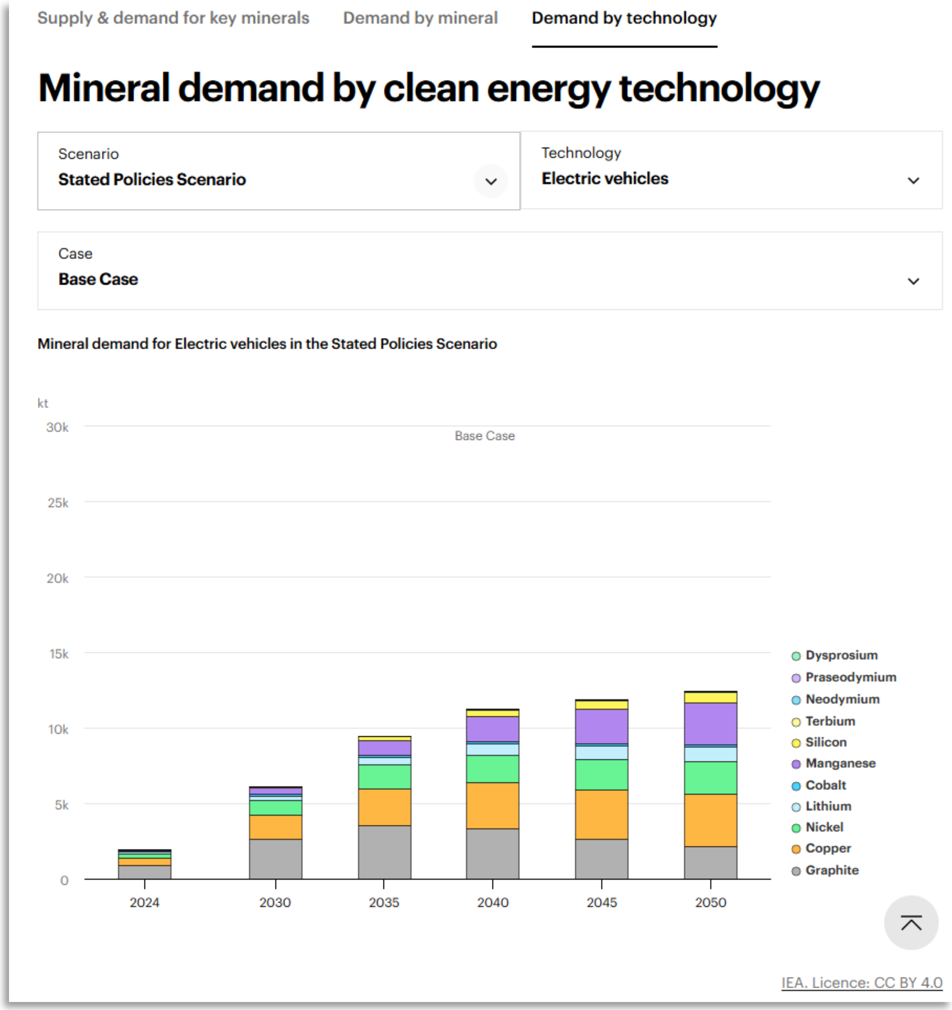
IEA Critical Minerals Data Explorer

The International Energy Agency (IEA) has integrated critical minerals into its long-term energy modelling framework. In 2023, the Critical Minerals Data Explorer, an interactive online tool that allows users to easily access the IEA's projections, was launched and has been regularly updated since then. In 2025, the Data Explorer was updated to include long-term supply projection data, as well as demand projection data for key energy minerals such as copper, lithium, nickel, cobalt, graphite and rare earth elements.

The tool provides users with access to the IEA's demand projection results under various energy scenarios and technology evolution trends (through various alternative technology cases). Users can look up total and sectoral demand for key energy minerals by scenario and technology case. Long-term supply projections for the key energy minerals are also accessible in the tool.

The numbers are regularly updated to align with the latest energy projections.

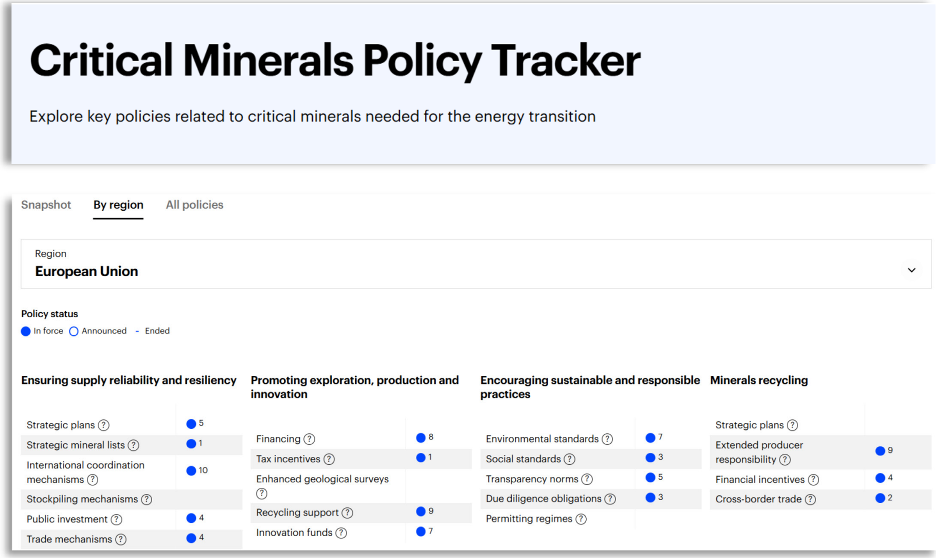


IEA Critical Minerals Policy Tracker

The IEA launched the Critical Minerals Policy Tracker in November 2022 to monitor and analyse policy developments on critical minerals. This tool, which is updated regularly, covers policies across more than 60 countries; however, active policy monitoring is conducted for a smaller subset of around 45 jurisdictions.

The data for the tracker are primarily sourced from the IEA Policies Database, which encompasses an array of government-issued policies, laws and regulations relevant to the energy sector. The methodology for data collection for the Critical Minerals Policy Tracker includes desk research and stakeholder submissions to capture policies in place within each of the focus countries and regions. Feedback from country delegates and external researchers further refines and validates the database entries.

Policies tracked by this tool are categorised into four key areas: ensuring supply reliability and resiliency; promoting exploration, production and innovation; encouraging sustainable and responsible practices; and advancing minerals recycling. Within each category, policies are further divided into four to six subcategories. This categorisation aids the IEA's systematic analysis of policy trends and differences across various countries and regions, providing stakeholders with insights into global policy approaches to managing critical mineral resources.



In 2024, the tool was expanded to include the fourth area, supporting the IEA's analysis on Recycling of Critical Minerals. Since 2025, policies concerning supply chain traceability have been integrated into the Policy Tracker with the release of The Role of Traceability in Critical Mineral Supply Chains and Critical Mineral Traceability for Energy and Economic Security.

The Critical Minerals Policy Tracker provides an overview of the evolving landscape of mineral supply chain policies and governance in the context of energy transitions.

Methodology

Scope

The critical minerals model, linked closely with the Global Energy and Climate (GEC) Model, assesses the mineral requirements for the following energy technologies:

- low-emissions power generation
  - solar photovoltaic (PV) (utility-scale and distributed)
  - wind (onshore and offshore)
  - concentrating solar power (parabolic troughs and central tower)
  - hydropower
  - geothermal
  - bioenergy for power
  - nuclear power
- electricity networks (transmission, distribution and transformer)
- electric vehicles (battery electric and plug-in hybrid electric vehicles, motors)
- battery storage (utility-scale and residential)
- hydrogen (electrolysers and fuel cells).

All of these energy technologies require metals and alloys, which are produced by processing mineral-containing ores. Ores – the raw, economically viable rocks that are mined – are beneficiated to liberate and concentrate the minerals of interest. Those minerals are further processed to extract the metals or alloys of interest. Processed metals and alloys are then used in end-use applications.

While this analysis covers the entire mineral and metal value chain from mining to processing operations, we use "minerals" as a representative term for the sake of simplicity.

We focus specifically on the use of minerals in energy technologies, given that they generally require considerably more minerals than their fossil fuel counterparts. Our model also focuses on the requirements for building a plant (or making equipment), and not on operational requirements (e.g. uranium consumption in nuclear plants).

Our model considers a wide range of minerals used in energy technologies. They include copper, major battery metals (lithium, nickel, cobalt, manganese and graphite), rare earth elements, arsenic, boron, cadmium, chromium, gallium, germanium, hafnium, indium, iridium, lead, magnesium, molybdenum, niobium, platinum group metals, selenium, silicon, silver, tantalum, tellurium, tin, titanium, tungsten, vanadium and zinc.

Steel and aluminium are widely used across many energy technologies, but we have excluded them from the scope of this analysis. Steel does not have substantial security implications, and the energy sector is not a major driver of growth in steel demand. Aluminium demand is assessed for electricity networks only, as the outlook for copper is inherently linked with aluminium use in grid lines, but it is not included in the aggregate demand projections.

For the six focus minerals – copper, lithium, nickel, cobalt, graphite and rare earth elements – we model total demand including uses in energy applications and other segments. Consumption outside the energy sector has been estimated using historical consumption by end-use applications, relevant activity drivers (e.g. gross domestic product [GDP], industry value added and steel production) and material intensities.

Demand

For each of the energy technologies, we estimate overall mineral demand using five main variables:

- technology deployment trends under different scenarios
- sub-technology shares within each technology area
- mineral intensity of each sub-technology
- mineral intensity improvements
- material efficiency measures (recycling, reuse and behavioural change).

Energy deployment trends under the Current Policies Scenario (CPS) and the Stated Policies Scenario (STEPS) are taken from the projections in the World Energy Outlook 2025, adjusted using the latest information in the Global EV Outlook 2026 and other sources. The High Demand Scenario (HDS) reflects a higher-demand case, in which stronger deployment of key energy technologies and more material-intensive pathways lead to increased demand for critical minerals.

Mineral intensity assumptions are developed and continuously refined through extensive literature reviews and expert and industry consultations, including with IEA Technology Collaboration Programmes. The pace of mineral intensity improvements varies by scenario, with the STEPS generally seeing minimal improvement over time compared with the modest improvement (around 10% in the longer term) assumed in the HDS. In areas that may particularly benefit from economies of scale or technology improvement (e.g. silicon and silver use in solar PV, platinum loading in fuel cells, rare earth elements use in wind turbines and copper in buildings), specific improvement rates have been applied based on a review of the underlying drivers.

Supply

Supply projections for the six key energy minerals are built using data from the pipeline of operating and announced mining and refining projects by country. These projections are divided into a base and a high-production case, with categorisation assessed according to their probability of coming online based on various factors such as the status of financing, permitting and feasibility studies.

The base case includes production from existing assets and those under construction, along with projects that have a high chance of moving ahead as they have obtained all necessary permits, secured financing and/or established offtake contracts. The high-production case additionally considers projects at a reasonably advanced stage of development that are seeking financing and/or permits.

Primary supply requirements have been assessed by deducting projected secondary supply from projected total demand. Secondary production is estimated with two parameters: the average recycling rate and the lifetime of each end-use sector. The recycling rate is the combination of the end-of-life collection rate (the amount of a certain product being collected for recycling) and the yield rate (the amount of material a recycling process can recover). For emerging technologies such as lithium-ion batteries, we assume collection rates increase at a faster pace. The yield rate is assumed to vary according to the technical limitations of extracting each mineral using currently available recycling methods. Reuse rates are much lower than collection rates for recycling, as the use of second-life batteries (in grid applications) faces many technical and regulatory obstacles. Losses from manufacturing processes are also taken into account. For primary supply requirements for mined materials, a certain loss ratio during refining processes is assumed.

We acknowledge the use of data on mining and refining projects from various professional information sources, including S&P Global Market Intelligence, Wood Mackenzie and Benchmark Mineral Intelligence.

Key projection results

Copper demand

	Historical		Current Policies			Stated Policies			High Demand		
Unit: kt Cu	**2021**	**2025**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Clean energy	5 654	8 003	10 232	11 822	12 174	10 725	13 073	13 559	12 302	15 668	16 572
Electricity networks	4 189	4 544	5 637	6 693	6 430	5 713	6 631	6 316	6 002	7 181	6 815
Electric vehicles	264	794	1 623	2 359	2 391	1 763	3 046	3 476	2 017	4 143	4 750
Solar PV	707	1 970	2 044	1 755	2 099	2 222	2 219	2 300	2 803	2 626	2 758
Other	493	695	927	1 015	1 253	1 066	1 177	1 466	1 480	1 719	2 249
Other uses	19 296	19 772	20 560	21 757	23 714	20 605	21 911	24 014	19 665	20 051	21 495
Total demand	24 950	27 775	30 792	33 580	35 888	31 370	34 984	37 572	31 967	35 719	38 066
Share of clean energy	23%	29%	33%	35%	34%	34%	37%	36%	38%	44%	44%

Notes: kt = kilotonnes. Demand is based on refined copper and excludes the direct use of scrap. Demand for electric vehicles includes both electric vehicle battery and electric vehicle motor demand.

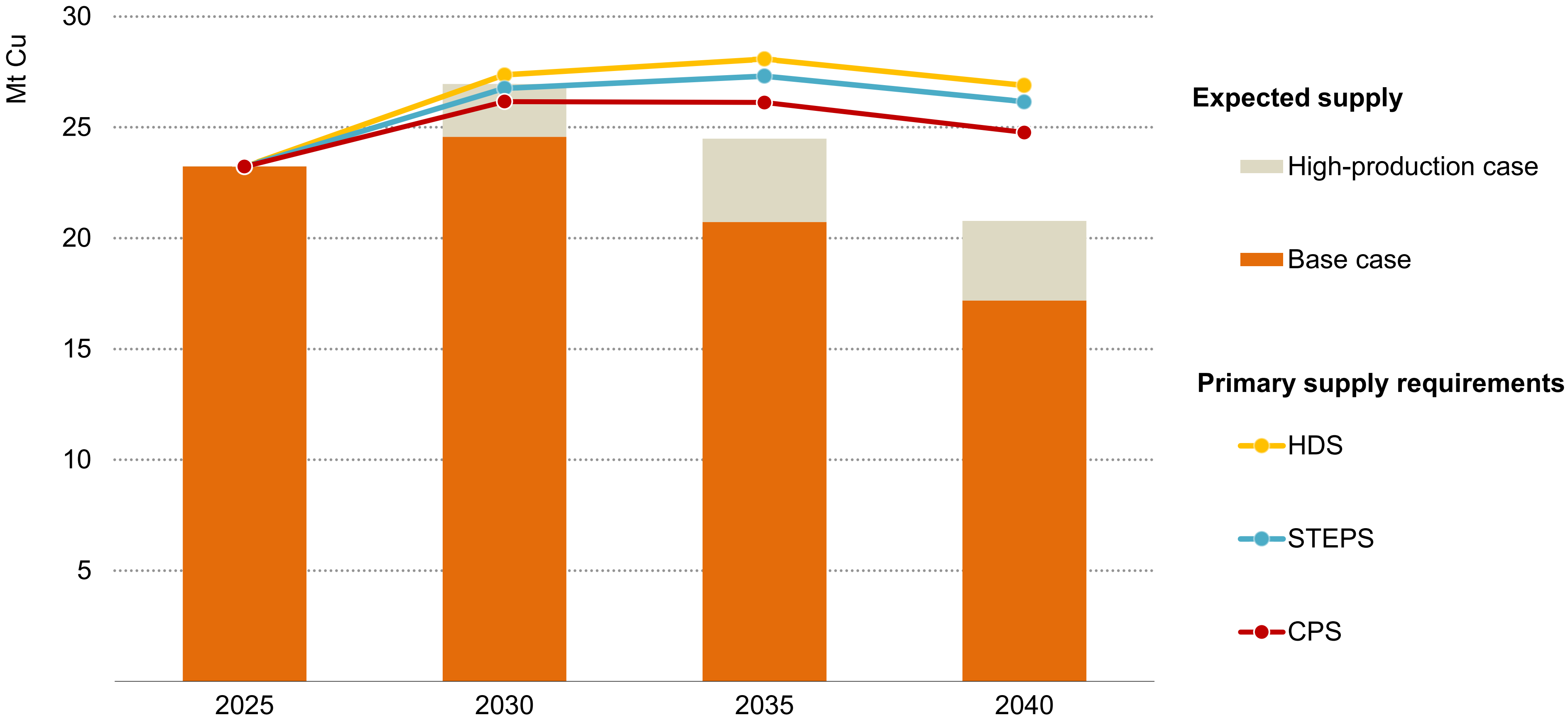
Copper supply

Unit: kt Cu	Mining					Refining			
	Historical		Base case			Historical		Base case	
	2021	2025	2030	2040		2021	2025	2030	2040
Chile	5 672	5 485	5 369	4 165	China	10 378	13 069	17 121	17 221
DRC	2 019	3 338	4 212	2 696	DRC	2 019	3 338	4 212	2 696
Peru	2 284	2 726	2 712	1 859	Chile	2 282	1 741	1 846	1 359
China	1 823	1 838	2 040	1 852	Japan	1 514	1 431	1 624	1 624
Russia	867	1 145	1 244	1 343	Russia	954	990	1 110	1 105
United States	1 262	1 101	1 196	632	India	490	646	1 500	1 500
Rest of world	7 530	7 594	7 798	4 636	Rest of world	7 328	6 740	8 970	8 205
World	21 457	23 227	24 571	17 183	World	24 965	27 955	36 383	33 710
Top 3 share	46%	50%	50%	51%	Top 3 share	57%	62%	61%	62%

Notes: kt = kilotonnes. DRC = Democratic Republic of the Congo.

Copper supply-demand balance

Mined copper supply from existing and announced projects and primary supply requirements by scenario



Notes: HDS = High Demand Scenario; STEPS = Stated Policies Scenario; CPS = Current Policies Scenario. Based on mined output. Primary supply requirements are calculated as the “total demand net of secondary supply”, also accounting for losses during refining operations. See Introduction section for definitions of the base and high-production cases.

Lithium demand

	Historical		Current Policies			Stated Policies			High Demand		
Unit: kt Li	**2021**	**2025**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Clean energy	67	203	368	652	708	368	836	1 002	470	1 131	1 381
Electric vehicles	63	171	333	594	636	333	765	911	416	1 037	1 260
Battery storage	5	32	35	57	72	35	71	90	54	94	121
Other uses	36	72	70	96	120	70	96	120	70	96	120
Total demand	103	275	438	748	828	438	932	1 122	540	1 227	1 501
Share of clean energy	65%	74%	84%	87%	85%	84%	90%	89%	87%	92%	92%

Note: kt = kilotonnes.

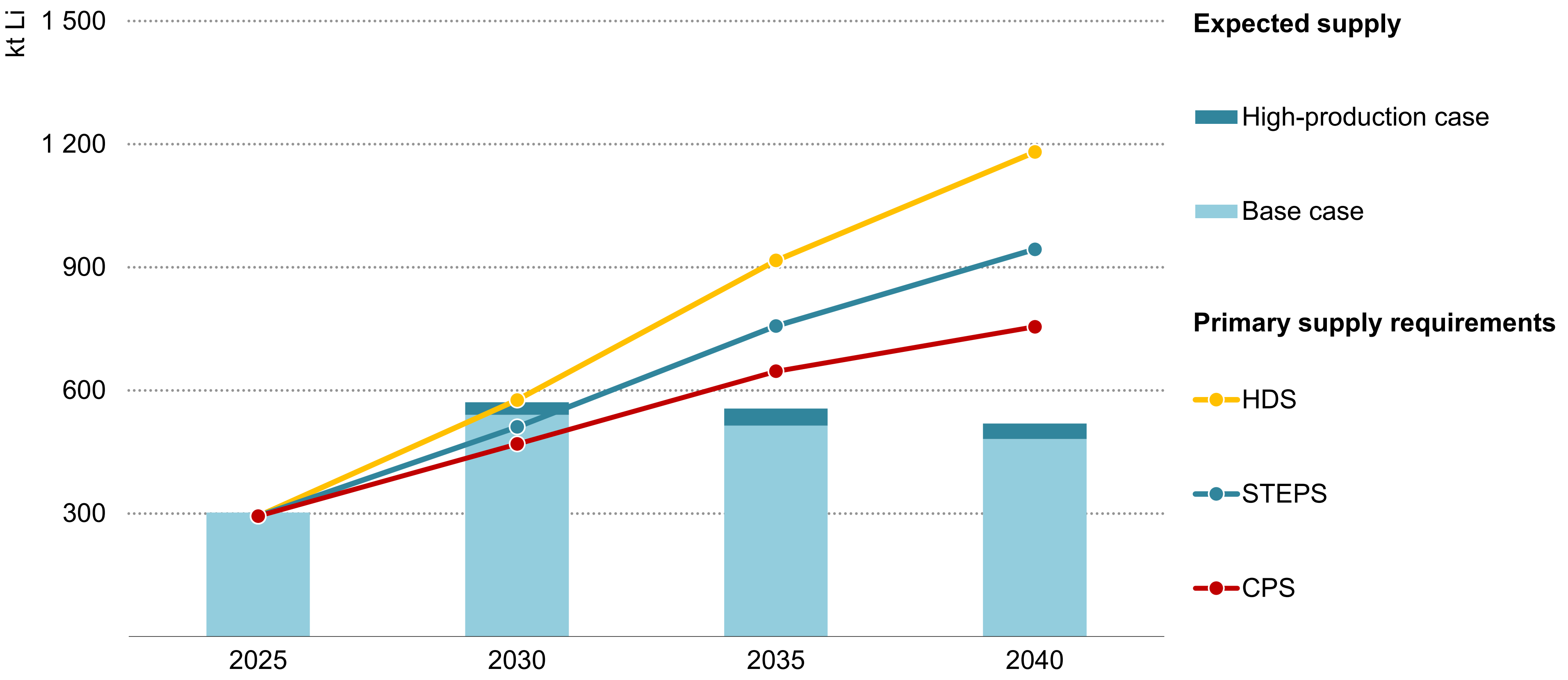
Lithium supply

Unit: kt Li	Raw materials				Chemicals				
	Historical		Base case			Historical		Base case	
	2021	2025	2030	2040		2021	2025	2030	2040
Australia	50	104	143	120	**China**	70	235	369	374
China	17	70	162	150	**Chile**	25	52	57	59
Chile	28	52	57	59	**Argentina**	7	16	51	54
Zimbabwe	2	28	27	27	**Australia**	0	6	16	26
Argentina	6	19	51	54	**Germany**	0	3	6	7
Canada	0	7	24	22	**United States**	1	1	19	20
Rest of world	4	23	77	50	**Rest of world**	0	5	25	28
World	107	302	540	482	**World**	103	319	544	568
Top 3 share	89%	75%	67%	68%	**Top 3 share**	99%	95%	88%	86%

Notes: kt = kilotonnes. Raw materials cover the extraction of lithium from hard-rock ore, as well as from clays and brines. Lithium chemicals cover the first production of lithium carbonate, hydroxide, sulphates and chlorides, and exclude reprocessing.

Lithium supply-demand balance

Mined lithium supply from existing and announced projects and primary supply requirements by scenario



Notes: HDS = High Demand Scenario; STEPS = Stated Policies Scenario; CPS = Current Policies Scenario. Based on raw material output covering the extraction of lithium from hard-rock ore, clays and brines. Primary supply requirements are calculated as the “total demand net of secondary supply”, also accounting for losses during refining operations. See the Introduction section for definitions of the base and high-production cases.

Nickel demand

	Historical		Current Policies			Stated Policies			High Demand		
Unit: kt Ni	**2021**	**2025**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Clean energy	308	625	1 276	1 932	2 051	1 409	2 403	2 763	1 698	3 253	3 963
Electric vehicles	222	439	909	1 449	1 448	989	1 851	2 054	1 119	2 500	2 839
Battery storage	9	28	59	160	305	71	199	382	92	264	512
Other	77	159	308	323	297	348	353	326	486	488	611
Other uses	2 536	2 906	3 055	3 429	3 746	3 055	3 429	3 746	3 100	3 270	3 375
Total demand	2 845	3 532	4 331	5 361	5 797	4 464	5 832	6 509	4 799	6 523	7 338
Share of clean energy	11%	18%	29%	36%	35%	32%	41%	42%	35%	50%	54%

Note: kt = kilotonnes.

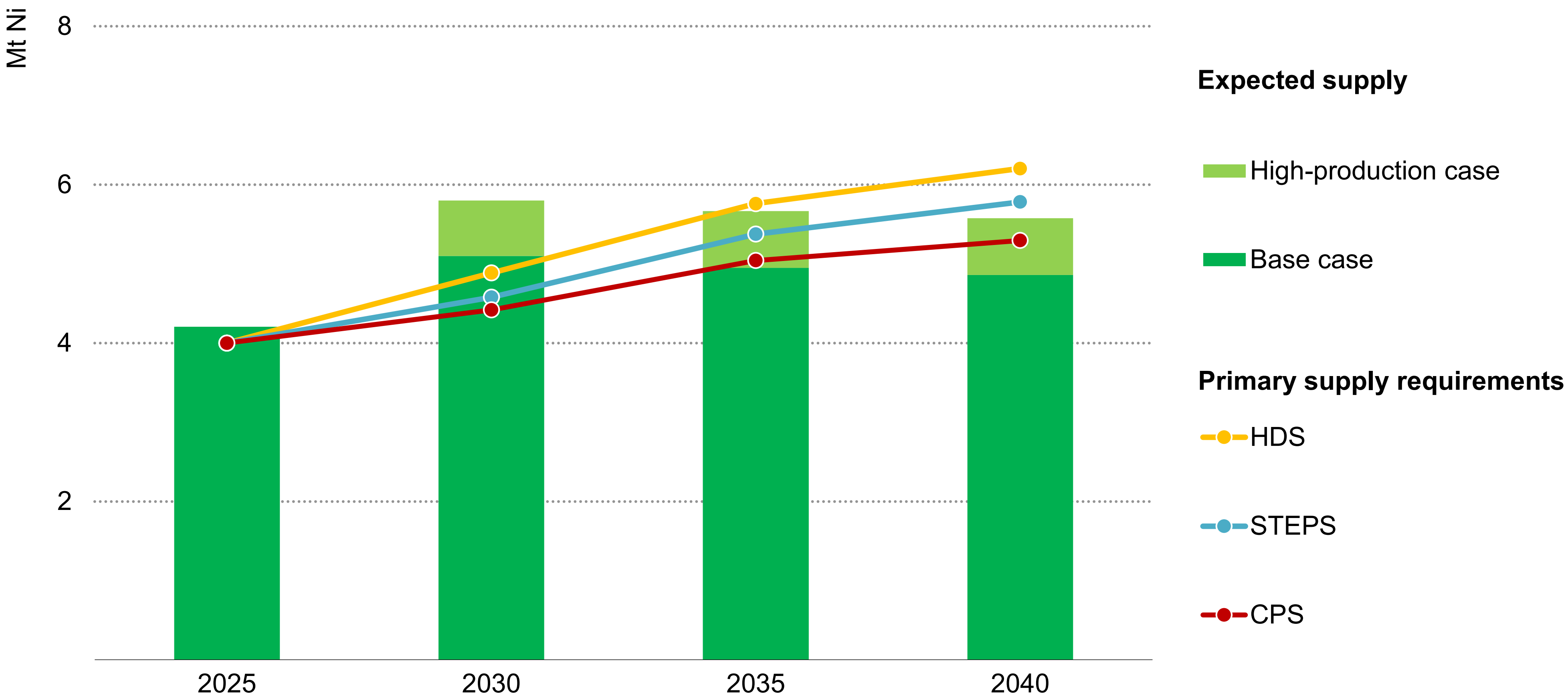
Nickel supply

	Mining					Refining			
	Historical		Base case			Historical		Base case	
Unit: kt Ni	2021	2025	2030	2040		2021	2025	2030	2040
Indonesia	1 105	2 637	3 567	3 568	Indonesia	907	1 681	2 080	2 081
Philippines	476	482	308	308	China	746	1 160	1 194	1 194
Russia	205	192	218	218	Canada	113	125	134	90
China	108	147	161	152	Russia	121	123	142	142
New Caledonia	186	138	207	207	Japan	128	108	107	107
Canada	134	138	147	52	Norway	91	100	92	92
Brazil	76	85	82	82	Brazil	61	64	73	65
Rest of world	480	388	408	271	Rest of world	541	367	409	387
World	2 770	4 207	5 098	4 858	World	2 709	3 729	4 231	4 159
Top 3 share	65%	79%	80%	84%	Top 3 share	66%	80%	81%	82%

Notes: kt = kilotonnes. Nickel refining includes nickel that is processed into a metal, oxide, nickel pig iron, ferronickel, or sulphate and excludes outputs from intermediate production steps.

Nickel supply-demand balance

Expected mined nickel supply from existing and announced projects and primary supply requirements by scenario



Notes: HDS = High Demand Scenario; STEPS = Stated Policies Scenario; CPS = Current Policies Scenario. Based on mined output. Primary supply requirements are calculated as the “total demand net of secondary supply”, also accounting for losses during refining operations. See Introduction section for definitions of the base and high-production cases.

Cobalt demand

	Historical		Current Policies			Stated Policies			High Demand		
Unit: kt Co	**2021**	**2025**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Clean energy	52	90	123	109	118	134	139	167	153	190	233
Electric vehicles	50	84	119	109	118	130	139	167	147	190	233
Battery storage	2	6	4	0	0	5	0	0	6	0	0
Other uses	135	169	165	197	225	171	204	234	165	195	222
Total demand	187	259	287	306	343	305	343	401	318	385	455
Share of clean energy	28%	35%	43%	36%	34%	44%	41%	42%	48%	49%	51%

Note: kt = kilotonnes.

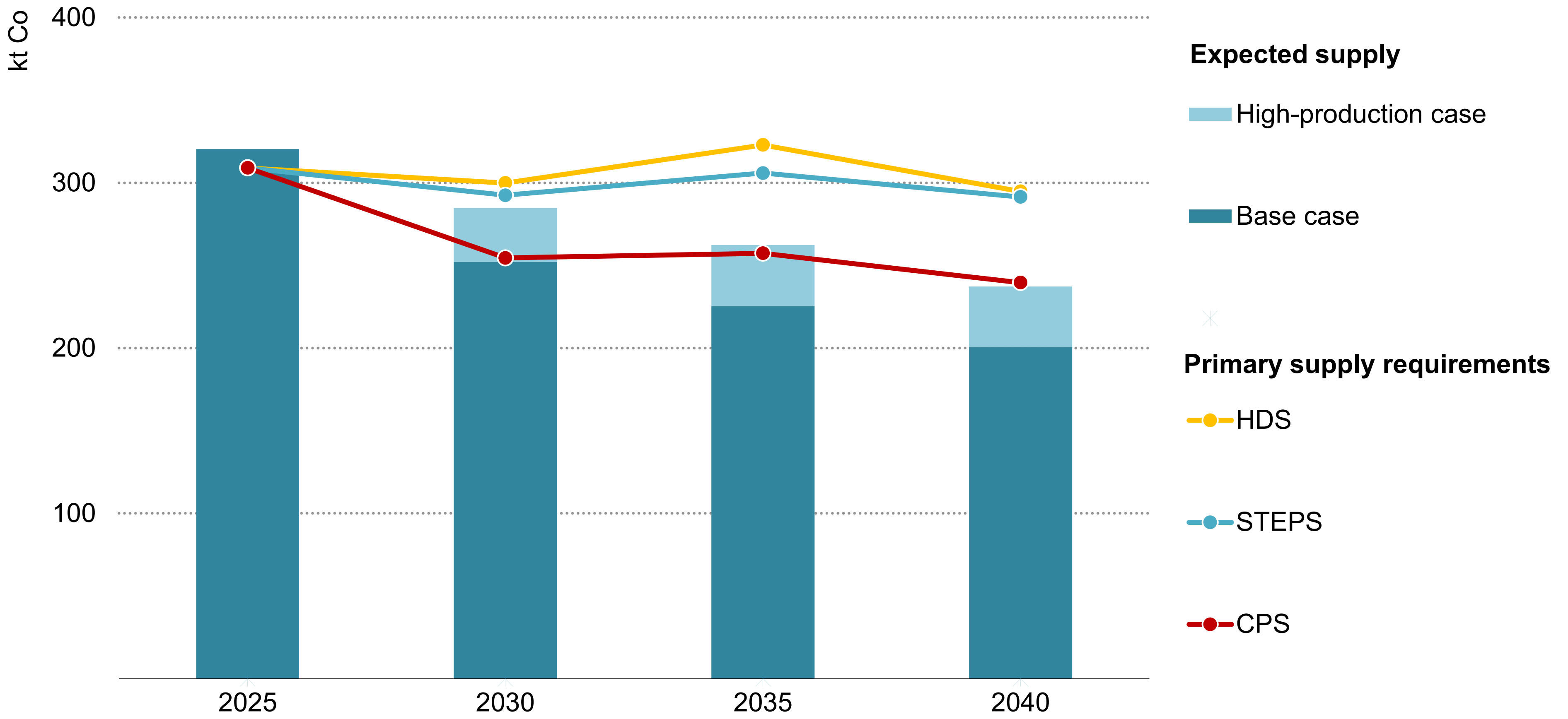
Cobalt supply

Unit: kt Co	Mining					Refining			
	Historical		Base case			Historical		Base case	
	2021	2025	2030	2040		2021	2025	2030	2040
DRC	122	210	121	88	China	132	180	217	260
Indonesia	4	48	69	67	Finland	14	20	20	20
Russia	6	8	8	8	Japan	5	6	7	7
China	7	7	7	7	Indonesia	0	6	17	17
Australia	8	4	5	4	Canada	4	6	6	2
Zambia	4	4	7	6	Norway	4	3	3	3
Rest of world	35	39	34	21	Rest of world	19	17	26	27
World	186	320	252	200	World	177	238	295	335
Top 3 share	73%	83%	79%	81%	Top 3 share	85%	87%	86%	89%

Notes: kt = kilotonnes. DRC = Democratic Republic of the Congo.

Cobalt supply-demand balance

Expected mined cobalt supply from existing and announced projects and primary supply requirements by scenario



Notes: HDS = High Demand Scenario; STEPS = Stated Policies Scenario; CPS = Current Policies Scenario. Based on mined output. Primary supply requirements are calculated as the “total demand net of secondary supply”, also accounting for losses during refining operations. See Introduction section for definitions of the base and high-production cases. The export quota is assumed to remain in place both in the base case and the high-production case.

Graphite demand

	Historical		Current Policies			Stated Policies			High Demand		
Unit: kt	**2021**	**2025**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Clean energy	849	2 491	4 227	4 519	2 649	4 675	5 809	3 687	5 408	7 871	5 079
Electric vehicles	786	2 087	3 804	3 776	1 871	4 162	4 884	2 711	4 747	6 644	3 774
Battery storage	62	404	424	743	778	513	925	976	661	1 227	1 305
Other uses	3 391	3 287	3 906	5 009	5 961	3 975	5 138	6 170	4 031	5 383	6 444
Total demand	4 240	5 779	8 133	9 529	8 610	8 650	10 947	9 856	9 438	13 254	11 523
Share of clean energy	20%	43%	52%	47%	31%	54%	53%	37%	57%	59%	44%

Notes: kt = kilotonnes. Demand covers raw natural graphite and synthetic graphite.

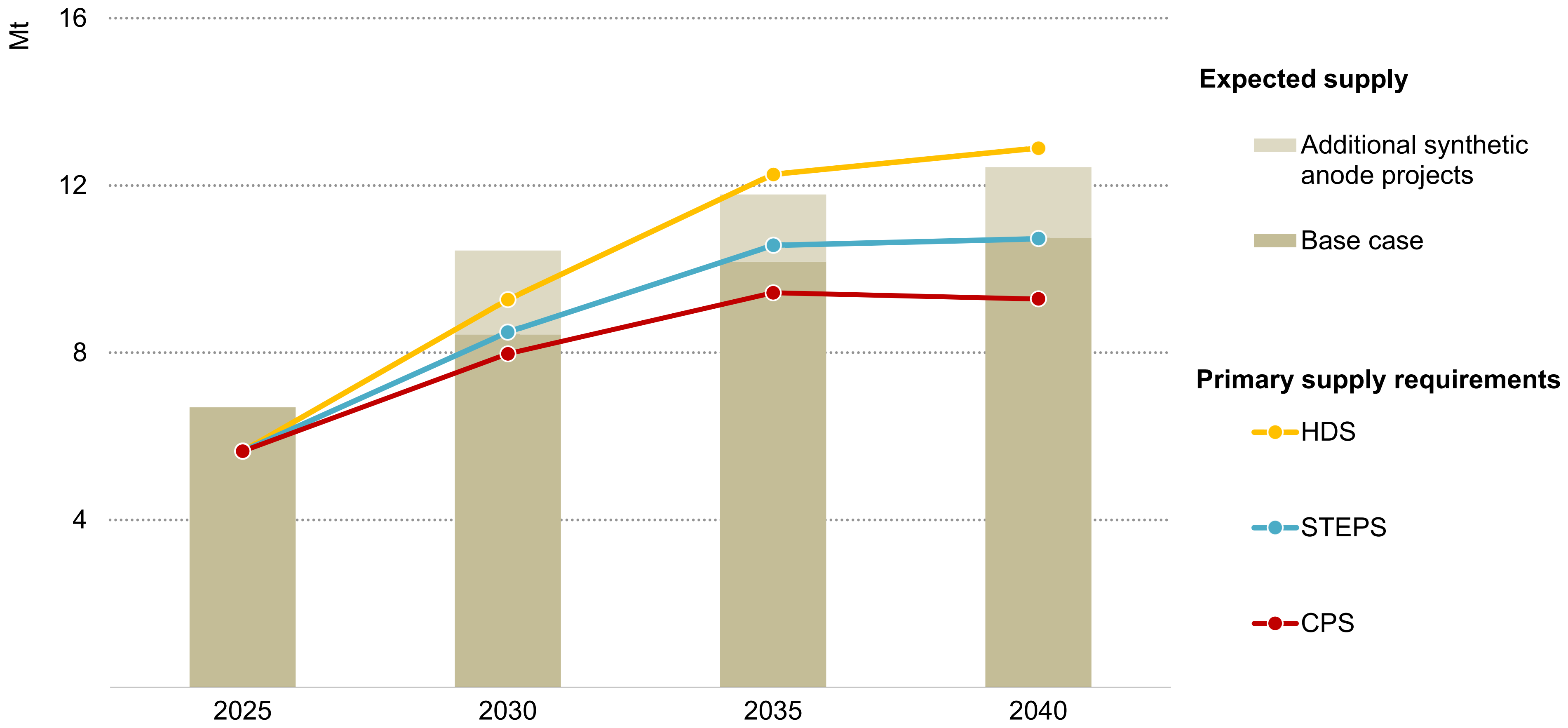
Graphite supply

Unit: kt	Mining (natural graphite) Historical 2021	Mining (natural graphite) Historical 2025	Mining (natural graphite) Base case 2030	Mining (natural graphite) Base case 2040		Refined battery-grade supply Historical 2021	Refined battery-grade supply Historical 2025	Refined battery-grade supply Base case 2030	Refined battery-grade supply Base case 2040
China	1 234	1 432	1 239	1 337	China	638	2 139	3 026	4 039
Madagascar	82	70	170	165	Japan	41	68	149	165
Mozambique	77	67	259	368	Indonesia	0	32	93	103
Tanzania	0	62	263	283	United States	0	13	15	17
Brazil	67	64	99	84	Korea	0	5	10	11
Russia	28	28	30	49	Germany	0	5	10	10
Rest of world	51	51	154	174	Rest of world	4	3	53	121
World	1 540	1 774	2 214	2 460	World	683	2 266	3 356	4 467
Top 3 share	90%	88%	80%	81%	Top 3 share	100%	99%	97%	96%

Notes: kt = kilotonnes. Refined battery-grade supply includes spherical graphite made from natural flake graphite and synthetic anode production.

Graphite supply-demand balance

Expected graphite supply from existing and announced projects and primary supply requirements by scenario



Notes: Mt = million tonnes; HDS = High Demand Scenario; STEPS = Stated Policies Scenario; CPS = Current Policies Scenario. Primary supply requirements are calculated as the “total demand net of secondary supply” and include raw natural graphite and synthetic graphite. See Introduction section for definitions of the base and high-production cases.

Rare earth elements demand

	Historical		Current Policies			Stated Policies			High Demand		
Unit: kt REE	**2021**	**2025**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Clean energy	11	21	33	36	40	37	44	56	48	64	80
Electric vehicles	3	11	20	25	26	21	33	41	24	46	54
Wind	8	10	13	10	13	16	11	15	24	18	27
Other uses	64	72	79	95	111	79	95	111	79	95	112
Total demand	75	93	112	131	151	116	140	167	127	160	192
Share of clean energy	15%	22%	30%	27%	26%	32%	32%	34%	38%	40%	42%

Notes: kt = kilotonnes. REE = rare earth elements. Rare earth elements refer only to four magnet rare earths: neodymium, praseodymium, dysprosium and terbium.

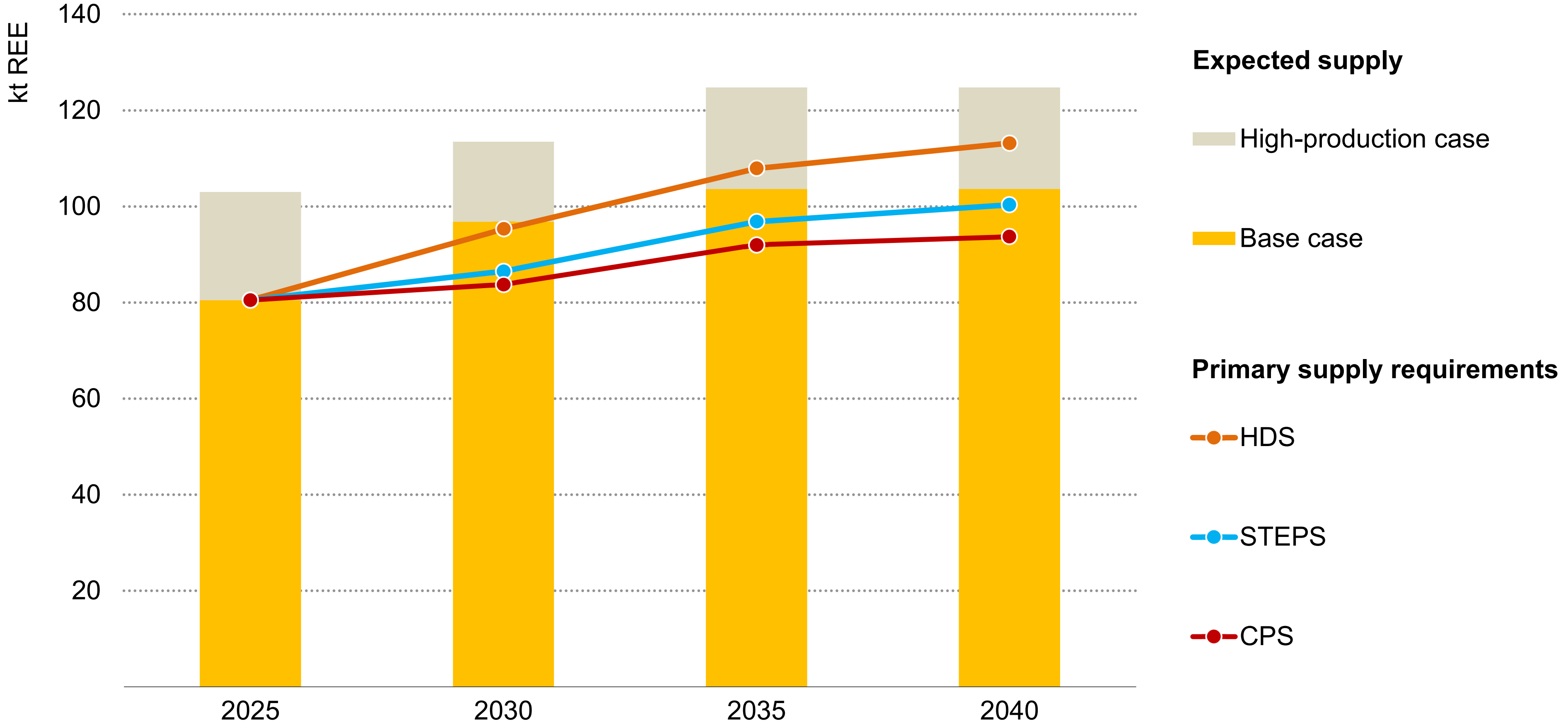
Rare earth elements supply

	Mining				Refining				
	Historical		Base case			Historical		Base case	
Unit: kt REE	2021	2025	2030	2040		2021	2025	2030	2040
China	32	47	51	57	China	53	75	81	86
Myanmar	8	13	11	11	United States	0	5	9	11
United States	6	7	9	9	Malaysia	4	5	10	10
Australia	4	4	11	12	France	0	1	1	1
Lao PDR	0	4	8	8	Viet Nam	1	1	1	1
Rest of world	7	5	6	6	Rest of world	2	3	8	9
World	57	80	97	104	World	60	89	111	118
Top 3 share	81%	85%	76%	77%	Top 3 share	97%	94%	91%	91%

Notes: kt = kilotonnes. Lao PDR = Lao People's Democratic Republic. Rare earth elements refer only to four magnet rare earths: neodymium, praseodymium, dysprosium and terbium.

Rare earth elements supply-demand balance

Expected mined magnet rare earth elements supply from existing and announced projects and primary supply requirements by scenario



Notes: HDS = High Demand Scenario; STEPS = Stated Policies Scenario; CPS = Current Policies Scenario. REE = rare earth elements. The figures are for magnet rare earths only. Primary supply requirements are the demand net of reuse and recycling.

List of mining companies assessed for investment analysis and sustainability performance tracking

24 major mining companies in the mining sector by category

Category	Company
Battery metals	Albemarle
	Ganfeng Lithium
	IGO
	Mineral Resources
	Norilsk Nickel
	PLS Group Limited
	SQM
	Tianqi Lithium
	Zhejiang Huayou
Copper players	CMOC Group Limited
	Codelco
	Eramet
	First Quantum Minerals
	KGHM
	Southern Copper

	South32
	Zijin Mining Group Co. Ltd.
Diversified majors	Anglo American
	BHP
	Freeport-McMoRan
	Glencore
	Rio Tinto
	Teck Resources
	Vale

Theoretical by-product production from primary production

Roots of by-products

Primary product	By-product	Recovery stage	Process	Theoretical production		Typical content/grade (indicative)
Copper	Molybdenum	Mining	Flotation during beneficiation; molybdenum concentrate separated from copper concentrate	10-1 000	t from Mt of ore	0.001-0.1% in 1 t of ore
	Rhenium	Smelting	Roasting	0.1-0.6	t from Mt of ore	0.1-0.6 g per t of ore
	Gold	Refining	Anode slimes from copper electro-refining	0.1-1	t from Mt of ore	0.1-1 g per t of ore
	Silver	Refining	Anode slimes from copper electro-refining	0.1-20	t from Mt of ore	0.1-20 g per t of ore
	Selenium	Refining	Anode slimes from electro-refining	50	t from kt of anode slime	5% in anode slimes
	Tellurium	Refining	Anode slimes from electro-refining	20	t from kt of anode slime	2% in anode slimes
	Cobalt	Refining	Acid leach solutions in copper hydrometallurgy	1 00-5 000	t from Mt of ore	0.01-0.5% in 1 t of ore

Roots of by-products (continued)

Primary product	By-product	Recovery stage	Process	Theoretical production		Typical content/grade (indicative)
Zinc	Indium	Refining	Leach residues and solvent extraction	40-270	t from Mt of concentrate	0.004-0.027% in 1 t of concentrate
	Germanium	Refining	Roast-leach-electrowinning	30	t from Mt of ore	0.003% in 1 t of ore
	Gallium	Refining	Leach residues and solvent extraction	10-500	t from Mt of ore	0.001-0.05% in 1 t of ore
Lead	Silver	Refining	Hydrometallurgy process during lead refining	500	t from Mt of concentrate	Hundreds g per 1t of concentrate
	Bismuth	Refining	Roasting dross and reduction	~200	t from Mt of concentrate	-0.02% in 1 t of concentrate
	Antimony	Refining	Roasting dross and reduction	4 000	t from Mt of concentrate	0.4% in 1 t of concentrate
Nickel	Cobalt	Refining	Precipitation and electrolytic	1 000-2 000	t from Mt of ore	0.1-0.2% in 1 t of ore
	Platinum group metals	Refining	Anode slimes from copper electrolytic refining	Palladium ~9 and platinum ~2	t from Mt of ore	Palladium ~9 g and platinum ~2 g per t of ore
Aluminium	Gallium	Refining	Solvent extraction and electrowinning	10-100	t from Mt of ore	0.001-0.01% in 1 t of ore

Abbreviations and acronyms

AI	artificial intelligence
AlNiCo	aluminium-nickel-cobalt alloy magnet
ARECOMS	Regulatory and Control Authority for Strategic Mineral Substances
AUD	Australian dollar
BEV	battery electric vehicle
BWR	boiling water reactor
CAM	cathode active material
CAPEX	capital expenditure
CME	Chicago Mercantile Exchange
Co	cobalt
CPS	Current Policies Scenario
CSAM	Central and South America
c-Si	crystalline silicon
Cu	copper
DLE	direct lithium extraction
DRC	Democratic Republic of the Congo
ECLAC	Economic Commission for Latin America and the Caribbean
EV	electric vehicle
GHG	greenhouse gas
HDS	High Demand Scenario
HPAL	high-pressure acid leaching
HPM	high-purity manganese sulphate
HREE	heavy rare earth element
IEA	International Energy Agency
ICE	internal combustion engine
IDB	Inter-American Development Bank
LAC	Latin America and the Caribbean
Lao PDR	Lao People's Democratic Republic
LEC	liquid-encapsulated Czochralski
LEU	low-enriched uranium
LEU+	low-enriched uranium plus
Li	lithium
LFP	lithium iron phosphate
LME	London Metal Exchange
LNG	liquefied natural gas
LWGR	light water graphite reactor
MOCVD	metal-organic chemical vapour deposition
MoU	memorandum of understanding
MREE	magnet rare earth element
NdFeB	neodymium-iron-boron
Ni	nickel
NMC	lithium nickel manganese cobalt oxide
OECD	Organisation for Economic Co-operation and Development
OEM	original equipment manufacturer
OPEX	operating expenditure
PHEV	plug-in hybrid electric vehicle
PHWR	pressurised heavy water reactor
PPA	purified phosphoric acid
Pu	plutonium
PUREX	plutonium uranium reduction extraction

PV	photovoltaic
PWR	pressurised water reactor
R&D	research and development
RD&I	research, development and innovation
REE	rare earth element
RepU	reprocessed uranium
RIGI	Incentive Regime for Large Investments
RoW	rest of world
SHFE	Shanghai Futures Exchange
Si-Gr	silicon-doped graphite
SmCo	samarium-cobalt
SMR	small modular reactor
STEPS	Stated Policies Scenario
SWU	separative work unit
SX/EW	solvent extraction and electrowinning
TC	treatment charge
TC/RC	treatment and refining charge
TOPCon	tunnel oxide passivated contact
TRISO	tri-structural isotropic
U	uranium
U_3O_8	triuranium octoxide
UF_4	uranium tetrafluoride
UF_6	uranium hexafluoride
UO_2	uranium oxide
US	United States
USD	US dollar
VAT	value added tax
VGF	vertical gradient freeze
VVER	water-water energetic reactor
YSZ	yttria-stabilised zirconia

Units of measure

g	gramme
GW	gigawatt
GWh	gigawatt-hour
kg	kilogramme
kt	kilotonne
kWh	kilowatt-hour
m^3	cubic metre
Mt	million tonnes
MW	megawatt
toz	troy ounce

See the IEA glossary for a further explanation of many of the terms used in this report.

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