Critical raw materials for the energy transition – how to achieve the targets?

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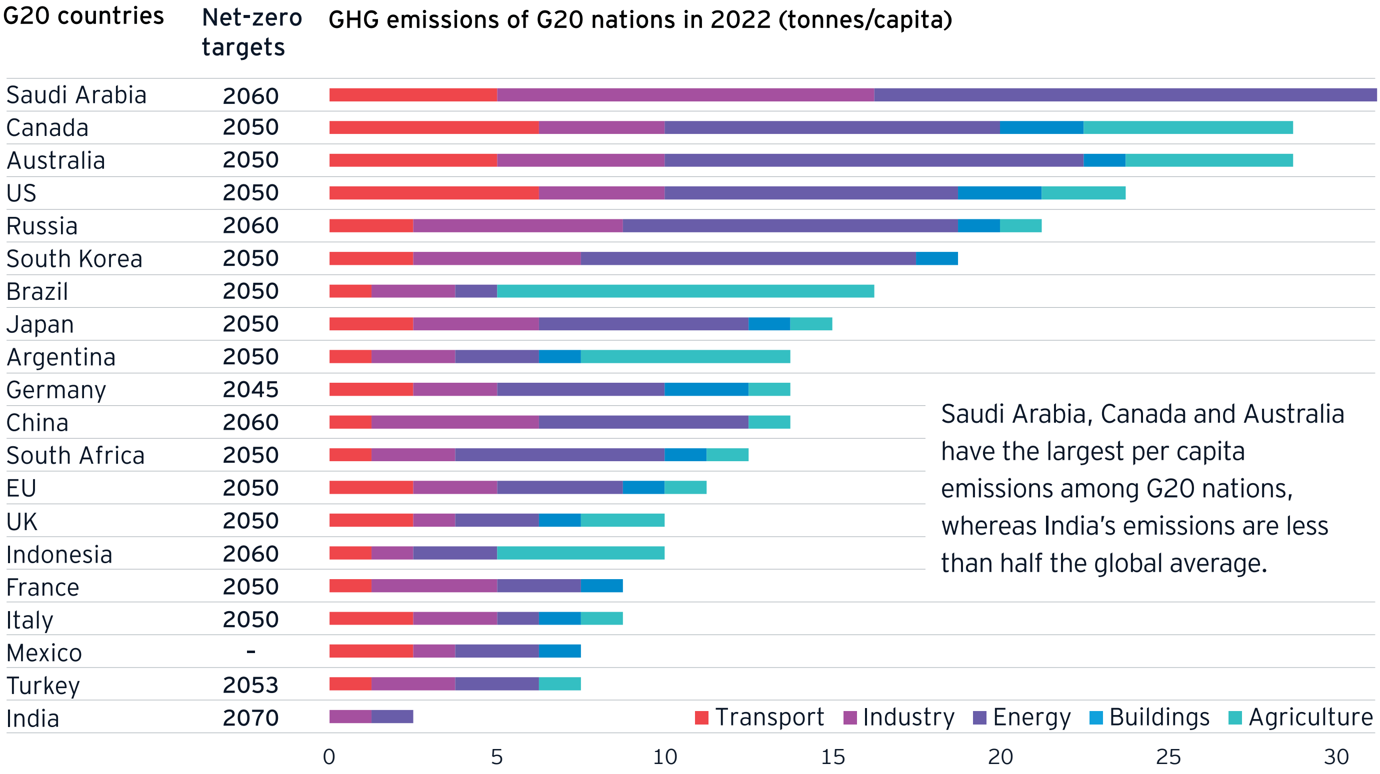
Introduction

Global awareness of climate change has existed for decades. However, worsening climate-related disasters have become impossible to ignore, and climate has become a central concern for communities across the globe. The dire forecasts for a warming world have led to growing calls for climate action.

National net-zero commitments went mainstream over the last decade and following the COP 26 climate conference in Glasgow, well over 100 governments set a decarbonization target. These commitments cover 88% of global emissions and 90% of global GDP (vs. 61% and 68% respectively in December 2020).[1] Most nations plan to reach net zero by 2050.

Net-zero targets in G20 countries



Saudi Arabia, Canada and Australia have the largest per capita emissions among G20 nations, whereas India's emissions are less than half the global average.

Source: EY analysis of publicly available data.

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[1] https://zerotracker.net/insights/pr-net-zero-stocktake-2022 .

Nations from Central, Eastern and Southeastern Europe and Central Asia (CESA) have also set their targets. Those from the EU (Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Greece, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia and Slovenia) align with the bloc's goal of achieving net zero by 2050. The same timeline has been set by Serbia and Uzbekistan, while Turkey plans to reach net zero later, in 2053. Kazakhstan announced its intention to reach "carbon neutrality" by 2060, and Azerbaijan adopted a voluntary commitment to 40% emissions reduction by 2050.

Geopolitical crises served as a wake-up call for most importers on the degree of their fossil fuel dependence, and on the need for energy supply chain diversification, sovereignty and security.

Policy support for energy transition has strengthened worldwide. In Europe, RePowerEU is driving decarbonization investment, India is leading emerging markets on investment in renewables and Japan has announced its GX Green Transformation Roadmap.

The US is now emphatically back in the global technology race. The Inflation Reduction Act, Department of Energy loan program, Bipartisan Infrastructure Law and Investment Tax Credit for wind, solar and battery projects, have driven new US solar and wind investments during this decade, and catalyzed massive investment in battery and electric vehicle (EV) manufacturing.

However, replacing fossil fuels with clean energy sources by extension increases dependence on so-called critical raw materials (CRM), as clean energy technologies (renewable power and EVs) need more materials such as copper, lithium, nickel, cobalt, aluminum and rare earth elements than fossil-fuel-based electricity generation technologies. Because the metals and mining sectors have long lead-times and are highly capital-intensive, price fly-ups and bottlenecks could be unavoidable with demand expected to outstrip supply. Simultaneously, price volatility will create uncertainty around the large up-front capital investments needed for production.

Supply, demand, and pricing interplays will emerge across different commodities, leading to feedback loops followed by a combination of technology shifts, demand destruction and material substitution. Metals and mining companies will need to grow faster, and cleaner, than ever before. At the same time, midstream and end-user sectors will need to factor potential resource constraints and sustainability requirements into technology development and growth plans.

This report analyzes both the opportunities and challenges which lie ahead.

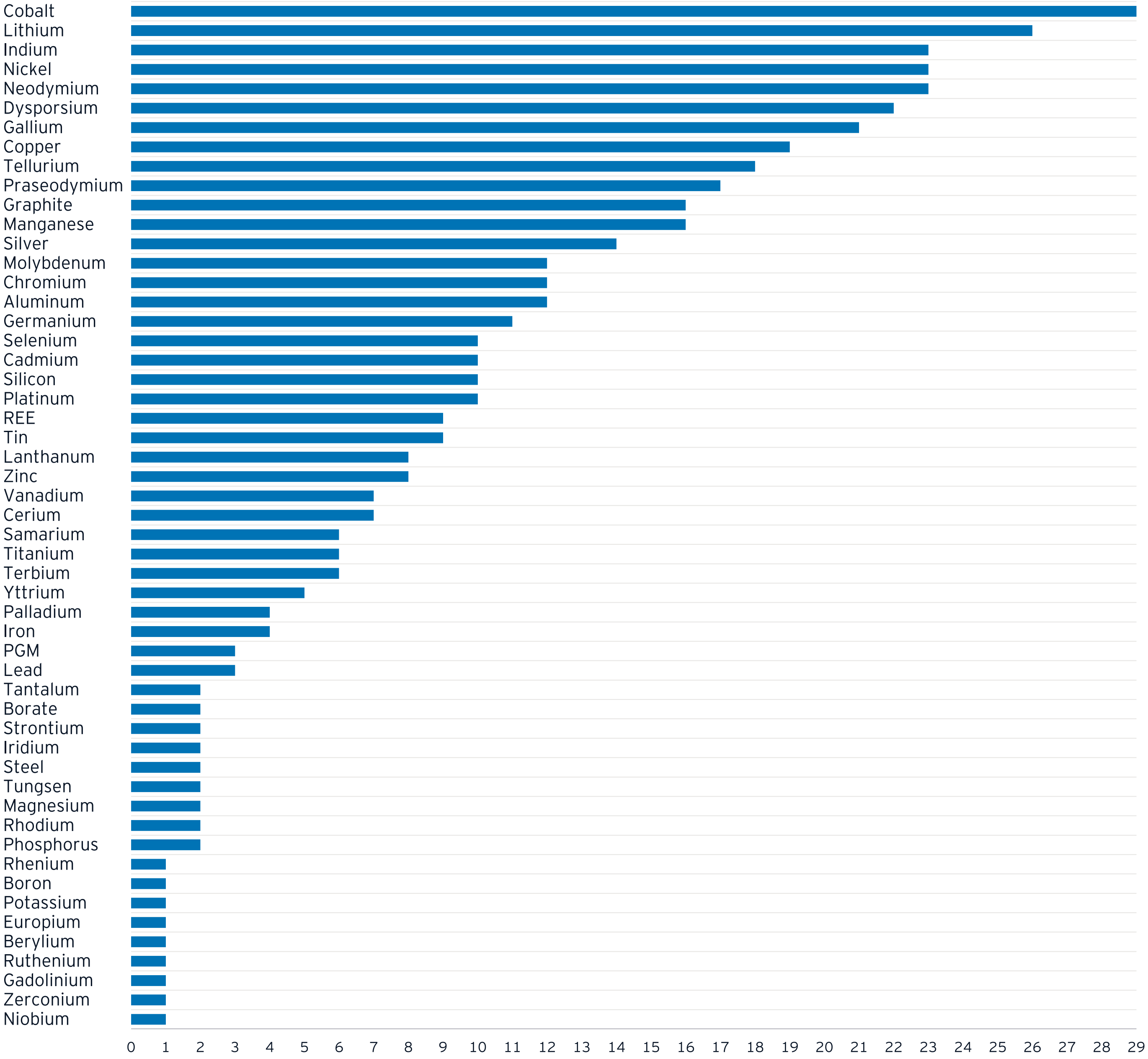
What are critical raw materials (CRMs)?

There is no unique definition of CRMs today, and the factors determining criticality depend on the specific nation. The core idea is that raw materials, or minerals, are critical if they have a role in a country's strategically important economic sectors (such as renewable energy, electric vehicles, digital, aerospace and defense technologies).

This could also include being dependent on imports of a certain mineral or being under supply risk amid scarcity and proximity of supply, complexity of mining and processing or lack of viable substitutes.

No single list of CRMs exists. The governments including those of the EU, the US[2] and China have compiled their own lists that identify materials that are critical for their economies.

Energy transition materials defined as critical by countries and regions (based on frequency of their inclusion in lists)



Note: REE – rare earth elements, PGM - platinum-group metals.
Source: IRENA, IEF, Payne Institute, NUPI.

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[2] https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf.

A comparison of critical material listings (2023)

	US	EU	China	India	Australia	Canada
Aluminum/bauxite	✓	✓	✓		✓	✓
Antimony	✓	✓	✓	✓	✓	✓
Arsenic	✓	✓				
Baryte	✓	✓				
Beryllium	✓	✓		✓	✓	
Bismuth	✓	✓		✓	✓	✓
Boron/borate		✓				
Cadmium				✓		
Cesium	✓					✓
Chromium	✓				✓	✓
Cobalt	✓	✓	✓	✓	✓	✓
Coking coal		✓				
Copper	✓	✓	✓	✓		✓
Feldspar		✓				
Fluorspar	✓	✓	✓			✓
Gallium	✓	✓		✓	✓	✓
Germanium	✓	✓		✓	✓	✓
Gold			✓			
Graphite/natural graphite	✓	✓	✓	✓	✓	✓
Hafnium	✓	✓		✓	✓	
Helium		✓				✓
Holmium	✓					
Indium	✓			✓	✓	✓
Iron ore			✓			
Lead						
Lithium	✓	✓	✓	✓	✓	✓
Lutetium	✓					
Magnesium	✓	✓			✓	✓
Manganese	✓	✓			✓	✓

	US	**EU**	**China**	**India**	**Australia**	**Canada**
Molybdenum			✓	✓		✓
Nickel	✓	✓	✓	✓		✓
Niobium	✓	✓		✓	✓	✓
PGM	✓	✓		✓	✓	✓
Phosphate rock		✓				
Phosphorus		✓	✓	✓		
Potash			✓	✓		✓
REE		✓	✓	✓	✓	✓
Rhenium				✓	✓	
Rubidium	✓					
Ruthenium	✓					
Scandium	✓	✓			✓	✓
Selenium				✓		
Silicon	✓	✓		✓	✓	
Silver						
Strontium		✓		✓		
Tantalum	✓	✓		✓	✓	✓
Tellurium	✓			✓		✓
Tin	✓		✓	✓		✓
Titanium	✓	✓		✓	✓	✓
Tungsten	✓	✓	✓	✓	✓	✓
Uranium			✓			✓
Vanadium	✓	✓		✓	✓	✓
Zinc	✓					✓
Zirconium	✓		✓	✓	✓	

Note: PGM group includes six elements (platinum, palladium, rhodium, ruthenium, iridium, and osmium). REE group includes yttrium, lanthanum, praseodymium, terbium, dysprosium, neodymium, cerium, europium, samarium, holmium, gadolinium, thulium, yetterbium, erbium, lutetium, promethium.

Source: EY CESA Energy Center analysis of official documents.

We have analyzed those metals and minerals which are crucial as inputs for energy transition in meeting climate targets. CRM inputs vary by technology.

The use of selected critical minerals

		Main use	Other Uses
Co	**COBALT**	EV batteries	Battery storage Magnets Electrolyzers
Cu	**COPPER**	Electric grids EV batteries Solar PV	Battery storage Bioenergy CSP Electrolyzers Geothermal Hydro
Dy	**DYSPROSIUM**	EV motors Wind turbines	Nuclear reactors
C	**GRAPHITE**	EV batteries	Battery storage Fuel cells Nuclear reactors
Ir	**IRIDIUM**	PEM electrolyzers	Spark plugs Electrical contacts Aerospace
Li	**LITHIUM**	EV batteries Battery storage	Nuclear reactors
Mn	**MANGANESE**	EV batteries	Battery storage CSP Electrolyzers Geothermal Hydropower Wind turbines
Nd	**NEODYMIUM**	EV motors Wind turbines	Lasers Steelmaking
Ni	**NICKEL**	Electrolyzers EV batteries Fuel cells	Battery storage Bioenergy CSP Geothermal Hydropower Solar PV
Pt	**PLATINUM**	PEM electrolyzers	Electronics Automotive

Source: Energy Minute.

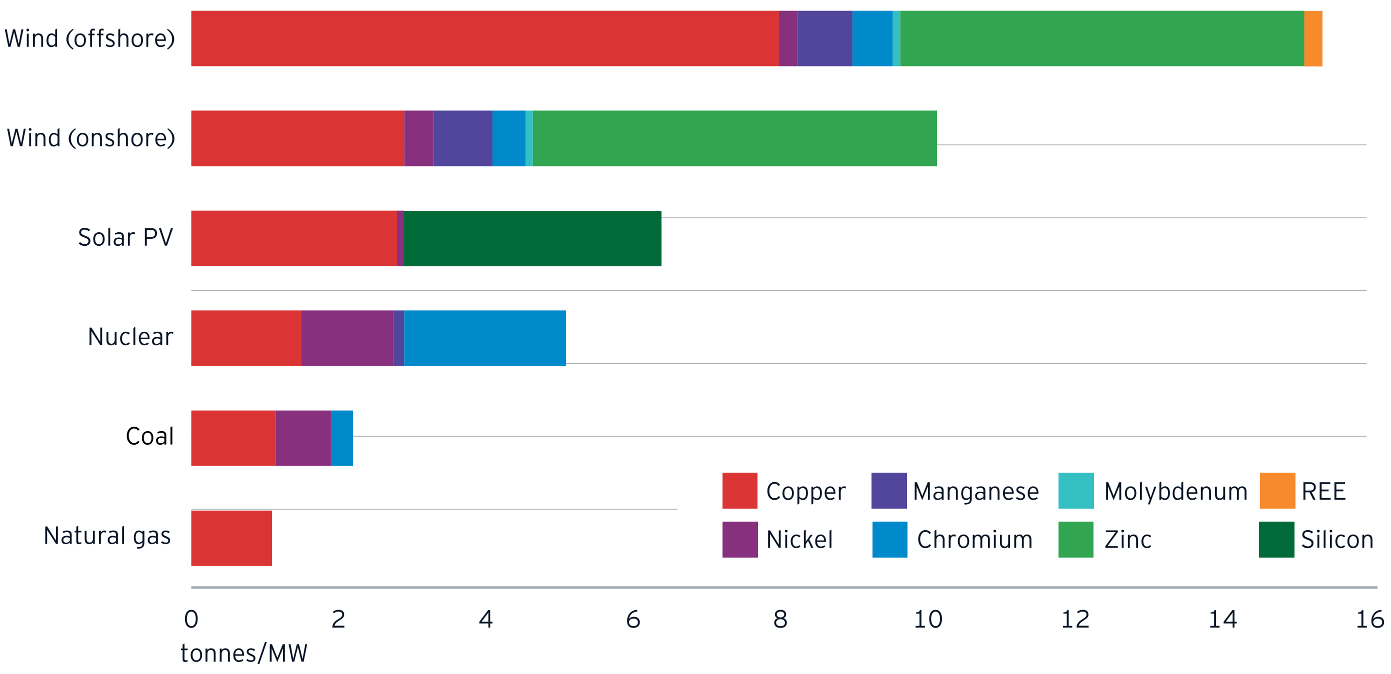
Applications in renewable energy

Solar panels use various raw materials in their manufacture, each with a specific function, including silicon, copper, aluminum, and silver. Silicon, copper, and aluminum are used to create the semiconductor material that makes up the solar cells, the wiring in the panels and the frame, respectively. Silver use is as a conductor for the electrical current generated by the solar cells. Other metals that may be used in smaller quantities include gallium, indium, and selenium.

Wind turbines use steel for the turbines (the manufacture of which, depending on the details, can involve nickel, molybdenum, titanium, manganese, vanadium or cobalt), with copper for cabling and iron for other parts. The one metal for which wind generation or electricity is the primary source of demand is zinc.

Onshore and offshore wind turbines share similarities, but they also have significant differences. Offshore wind turbines encounter harsher conditions than their onshore counterparts and thus need to be more resistant to corrosion, higher winds and extreme weather. Offshore wind farms offer greater capacity factors than their onshore counterparts, but also require greater material inputs in their foundations (steel) and in the cabling required to transmit the electricity onshore (for example, copper).

Concentration of critical materials used in selected clean energy technologies vs. traditional electricity generation methods



Source: EY analysis of IEA mineral requirements for clean energy transitions and publicly available sources.

Application in electric vehicles (EVs)

Batteries comprise two electrodes, a cathode and an anode, and an electrolyte through which they exchange ions. Depending on the composition of these three parts, they require different minerals.

Many EVs still use lead-acid batteries, which use lead and sulfuric acid, but lithium-ion batteries (LIBs) are expected to rapidly take over the market, so growth in demand for lead-acid batteries is not expected.

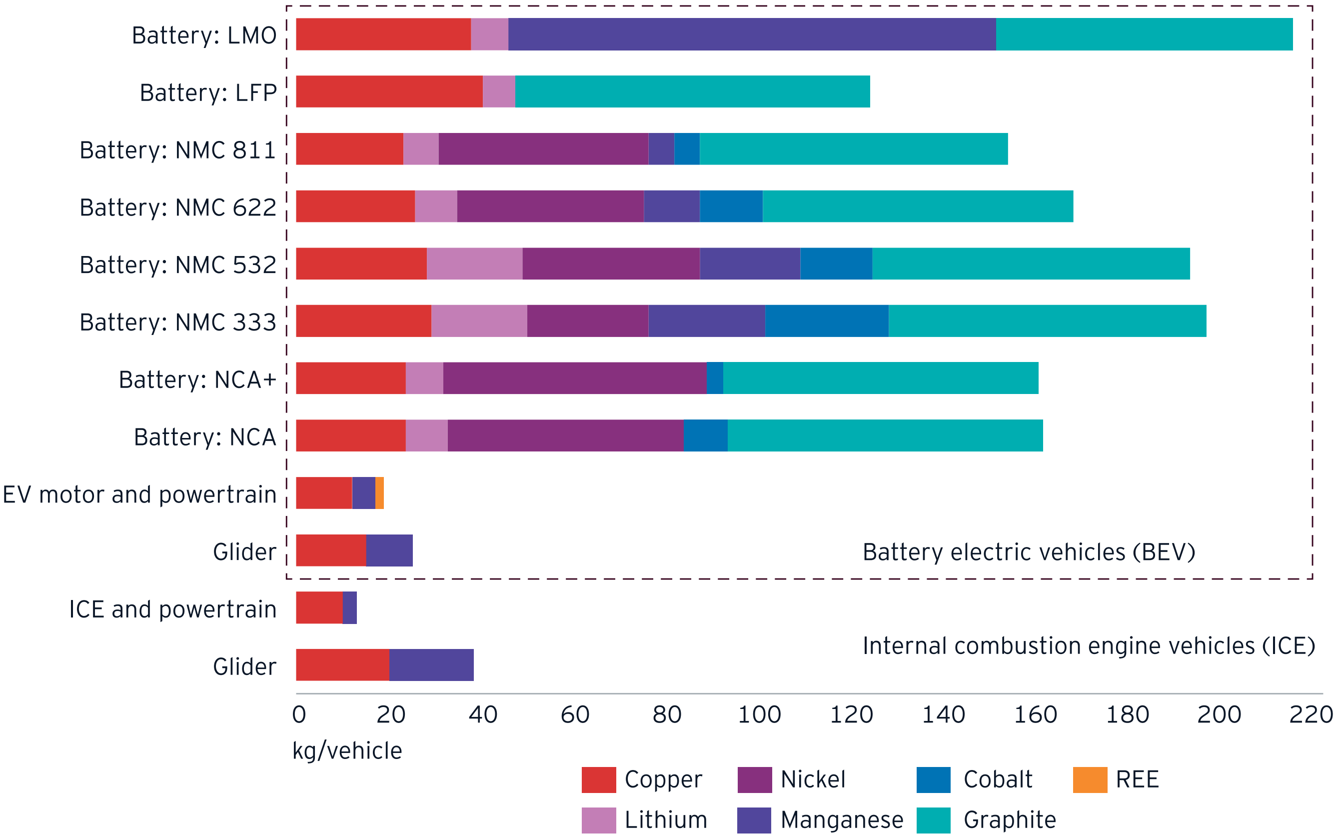
Most batteries use graphite as the anode, which means graphite will be the most sought-after mineral in energy storage. However, there is active development of zinc-air batteries that use air as the anode, sodium-ion batteries that use hard carbon as an anode and solid-state batteries that use lithium as an anode.

Cathodes vary more widely and most often use nickel, while various combinations of cobalt, lithium and manganese are also common.

Battery chemistry

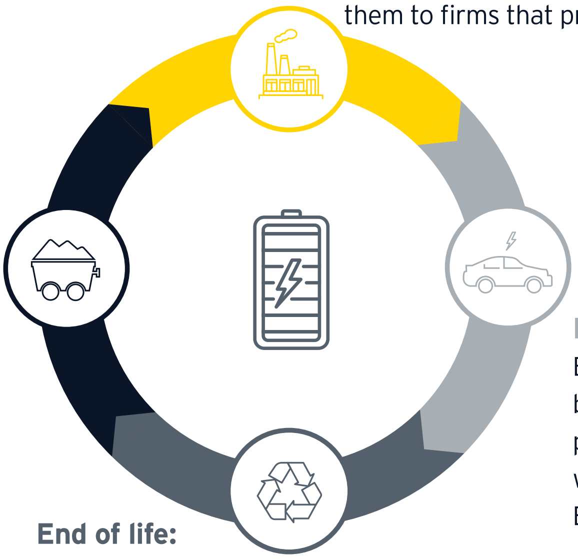
LFP:	Lithium-iron-phosphate is used more today by EV manufacturers in China than by their counterparts in Europe and North America. It has the advantages of chemical stability and less expensive battery raw materials, but the disadvantage of lower energy density.
LMFP:	Lithium-manganese-iron-phosphate is a newer type of cathode chemistry. Manganese is added to the LFP chemistry to improve energy density while retaining the LFP's advantages of safety and cost effectiveness.
LMNO:	Lithium-manganese-nickel-oxide is a type of next generation chemistry still under development. LMNO is cobalt-free and low in nickel content and has the potential to deliver high energy density and fast charging properties.
LMO:	Lithium-manganese-oxide is also a popular cathode chemistry for power tools and mild hybrid electric vehicles (MHEVs).
NCA:	Nickel-cobalt-aluminum offers high energy density, fast-charging properties and a longer life span compared with NMC chemistries. More battery players are introducing NCA cathodes.
NMC:	Nickel-manganese-cobalt is the most popular cathode chemistry used in PEV today. A series of three numbers follows the NMC designation, which represents the respective proportions of the constituent metals in the cathode (e.g., 811 is eight parts nickel to one part manganese to one part of cobalt).
NMCA:	Nickel-manganese-cobalt-aluminum is a newer cathode type with 90% nickel content and reduced cobalt content to deliver higher drive range at lower cost, and with added aluminum to improve stability and lifecycle.

Concentration of critical materials used in battery vehicles vs. internal combustion engines (ICE)



Source: EY analysis of IEA Mineral requirements for clean energy transitions and publicly available sources.

EV battery supply chain



Midstream:
Processors and refiners purify the raw materials, then use them to create cathode and anode active battery materials; commodities traders buy raw materials and sell them to firms that produce battery cells.

Upstream:
Mines extract raw materials.

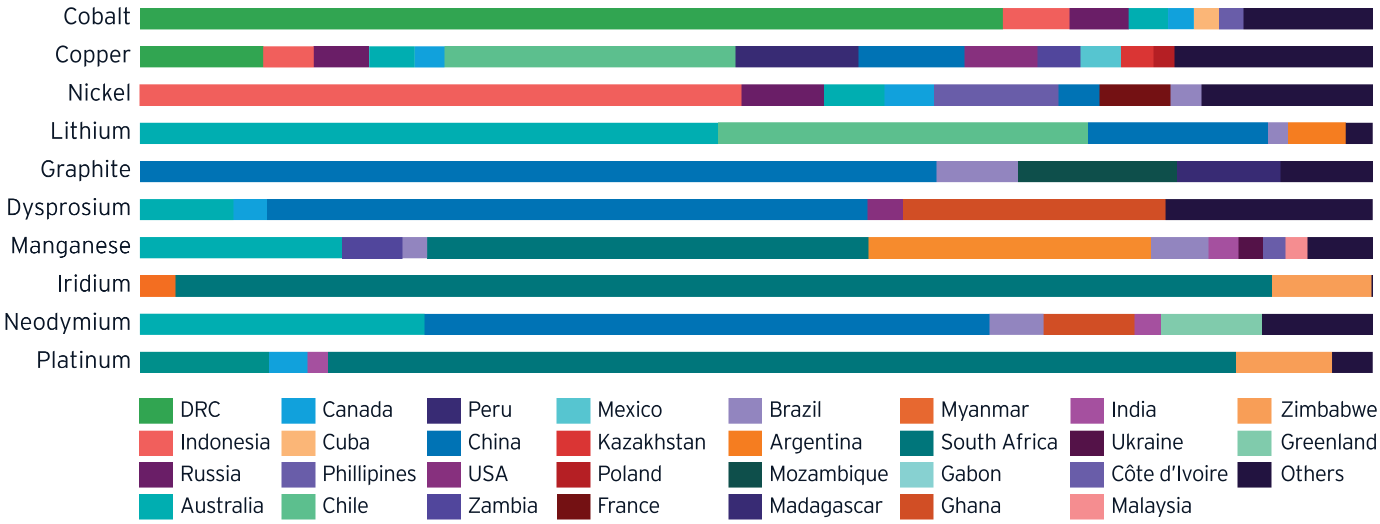
Downstream:
Battery manufacturers assemble the battery cells into modules and then pack and sell them to automakers, who place the finished batteries in EVs.

End of life:
When batteries no longer serve their original purpose, they can be reused or recycled.

The existing CRM supply chain is highly concentrated and risky

The mining of CRMs is highly concentrated in Asia-Pacific, Latin America and Africa. For instance, cobalt mining in the Democratic Republic of Congo (DRC) represents 70% of global supply, more than 60% of natural graphite comes from China, South Africa produces around 70% of the world's platinum and Indonesia and Australia mine almost 50% of the global supply of nickel and lithium. However, it is notable that China also has a significant presence in Africa's mining industry.

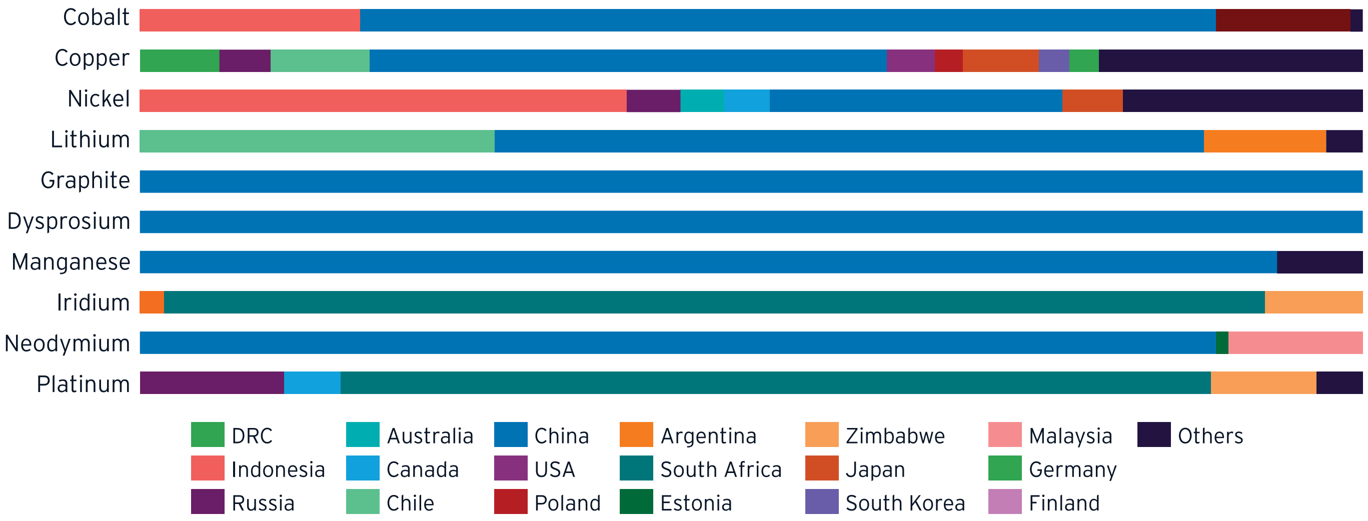
Key mining countries for selected minerals



Source: IRENA – Geopolitics of the energy transition: Critical Materials (2023).

Mineral processing is even more concentrated. The dominant player here is China, globally supplying 100% of the refined natural graphite and dysprosium (a rare earth element), 90% of the manganese, 70% of the cobalt, 60% of the lithium and approximately 40% of the copper.

Key processing countries for selected minerals



Source: IRENA – Geopolitics of the energy transition: Critical Materials (2023).

Today's highly concentrated overall supply chain makes the system vulnerable to geopolitical risks and consequently, the global market may face supply disruptions associated with geopolitical and ESG aspects. These could affect importers and end users of minerals in addition to the whole economy.

Areas which may create risks to CRM supply

External shocks

- Natural disasters
- Pandemics
- Economic shocks (local and global)
- Physical climate risks in mineral supply chain

ESG

Environmental

- Carbon emissions
- Use of natural resources
- Clean energy and technologies involvement
- Biodiversity loss
- Waste and pollution
- Water management
- Circularity
- Mine closure
- Green production

Social

- Human rights
- Labor relations and working conditions
- Indigenous trust and reconciliation
- Employee's health, safety and wellbeing
- Diversity and inclusion
- Social equity
- Ethical supply chains

Governance

- Corruption and bribery (including licensing and revenue collection)
- Compliance with environmental and social standards
- Presence and quality of sustainability management systems
- Presence and quality of risk management systems
- Improper revenue management to support economic growth and industrialization

Geopolitical issues

Political instability and social unrest

- Violence
- Corruption and bribery
- Labor strikes

Growing state control over mineral resources

- Tax disputes
- Expropriation
- Foreign investment screening

Mineral cartels

- Coordination of output
- Pricing
- Market allocation

Market manipulation

Source: EY CESA Energy Center analysis.

The critical mineral sector operates in a shifting environment in which many factors may influence its development, including different regulatory regimes, complex ESG-related issues and potential disruptions to supply chains and trade flows. Companies active in the sector should consider these factors in their business and operational planning to mitigate multifaceted potential risks. The table above lists the areas on which they should focus.

Interconnected external shocks to global CRM supply chains stem from natural disasters or the results of human action, either intentional, such as trade disputes, or unintentional, such as power outages. The events of recent years are illustrative of these geopolitical risks — in the form disturbance through shocks such as the COVID-19 pandemic, political tensions and energy crises.

Moreover, there are local risks of **political instability and social unrest** that may affect the supply chain. For instance, Myanmar's coup in February 2021 severely impacted the mining sector, causing an 80% decline in export earnings from minerals for this major producer of rare earth minerals.[3]

Careful management of social factors is critical for the mining sector and includes improving labor conditions to support employee health, safety and wellbeing, careful management of human rights as well as protection and compliance with labor law in certain countries.

A recent survey states that 54% of energy transition minerals are located on or near Indigenous peoples' land.[4] The proportion varies by mineral, applying to over 80% of lithium projects and more than half of those for nickel, copper and zinc. Building trust with communities is key to attaining and retaining licenses to operate. Therefore, it is crucial for miners to collaborate closely with communities to understand their expectations and concerns, working together for mutually beneficial outcomes, which can extend the life of mines.

The threat of **climate change** could potentially multiply threats to geopolitical stability, with the metals and mining sector responsible for 10% of global greenhouse gas emissions. Moreover, critical material extraction can exacerbate water stress and, as a result, disruption to food security. The highest risk is associated with platinum, followed by molybdenum and graphite.[5] Moreover, metal mining has expanded into biodiverse ecosystems. The impacts of mining, currently the fourth largest driver of deforestation, are increasing significantly, affecting up to one third of the world's forest ecosystems, when considering indirect impacts.[6]

In addition to ESG issues, there are geopolitical risks associated with security of supply and the actions of mineral-rich nations' governments.

The world is experiencing **increasing state control** over mineral resources to enhance the benefits from extraction or address its adverse impacts (i.e., to optimize resource revenue). This has been observed in Australia, Canada, Chile, Mongolia, Namibia, Peru, South Africa and Zambia, accomplished through a tax regime strengthening royalty renegotiation, creation of state-owned mineral companies, nationalization of critical material industries and restrictions on foreign investments, all of which can impact global supply.

Governments can also implement **export restrictions on raw materials**, the economic impact of which can be sizable. This effort differs from state control, as it serves the broader goal of encouraging processing and attracting downstream industries. According to the OECD's calculations, such actions have increased fivefold over the last decade.[7] About a tenth of the global value of exports of raw materials, such as lithium, cobalt and rare earths, needed for EVs and renewable energy, has faced at least once such type of measure. China, India, Argentina, Russia, Vietnam and Kazakhstan were the top six countries in terms of number of new export restrictions during 2009-2020. Restrictions grew more rapidly on upstream segments, such as ores. Among resource-rich countries, Indonesia, Namibia and

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[3] https://www.frontiermyanmar.net/en/collapse-in-minerals-exports-robs-junta-of-key-revenue/.

[4] https://www.nature.com/articles/s41893-022-00994-6#:~:text=Across%20the%20sample%20of%205%2C097,the%20purposes%20of%20conservation19.

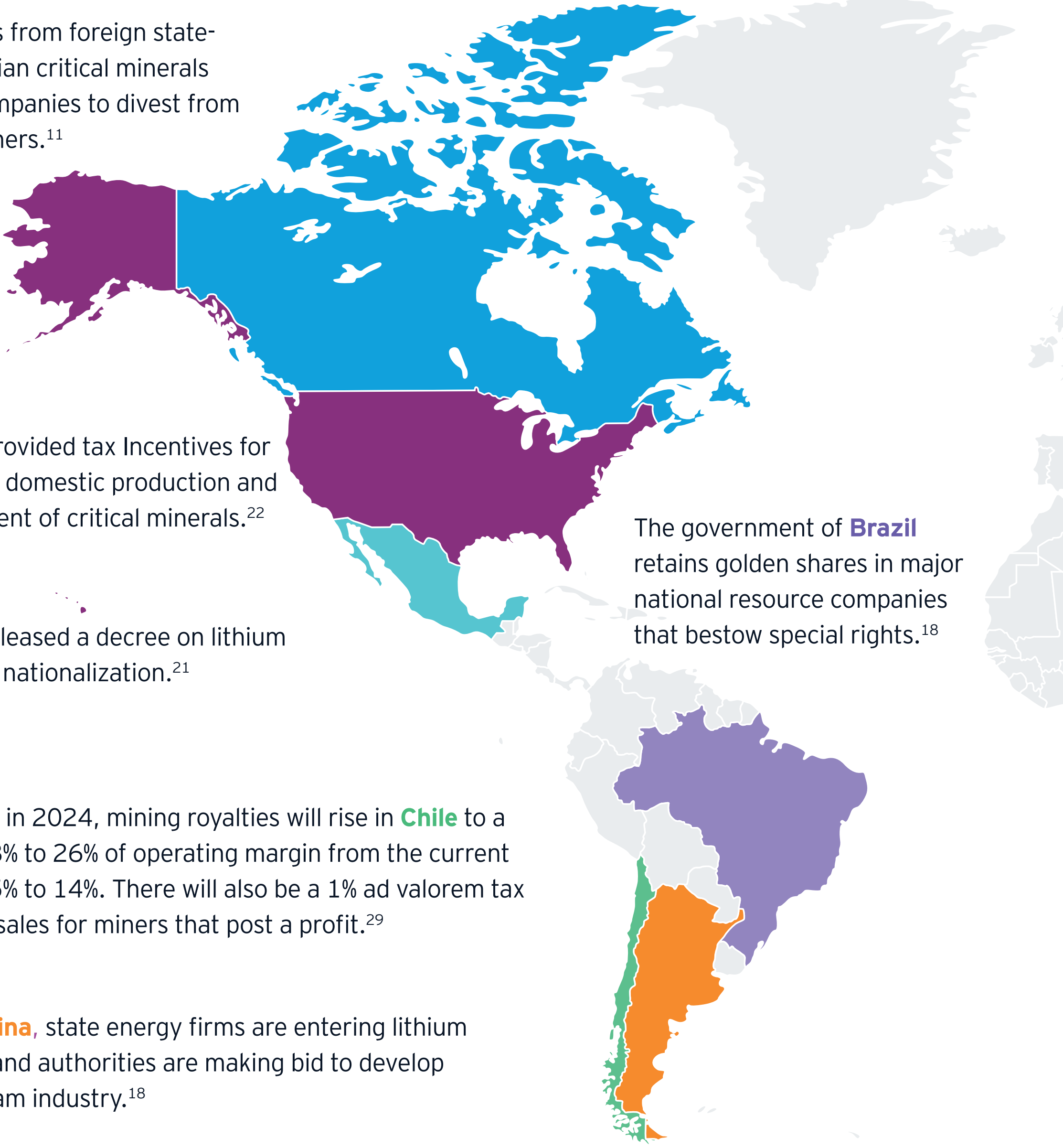
[5] https://www.nature.com/articles/s41893-022-00994-6.

[6] https://wwf.panda.org/wwf_news/?8455466/Mining-impacts-affect-up-to-13-of-global-forest-ecosystems-and-tipped-to-rise-with-increased-demand-for-metals.

[7] https://www.reuters.com/markets/commodities/export-restrictions-mount-critical-materials-says-oecd-2023-04-11/.

Zimbabwe have introduced measures to ban the export of unprocessed mineral ore.[8,9] Globally, export restrictions on critical raw materials have seen a fivefold increase since 2009.[10]

The mining sector is seeing a wave of resource nationalism and policy changes



Canada limited the investments from foreign state-owned companies in the Canadian critical minerals sector and ordered Chinese companies to divest from Canada based critical metal miners.[11]

The US provided tax Incentives for scaling up domestic production and procurement of critical minerals.[22]

Mexico released a decree on lithium resources nationalization.[21]

The government of **Brazil** retains golden shares in major national resource companies that bestow special rights.[18]

Beginning in 2024, mining royalties will rise in **Chile** to a range of 8% to 26% of operating margin from the current range of 5% to 14%. There will also be a 1% ad valorem tax based on sales for miners that post a profit.[29]

In **Argentina**, state energy firms are entering lithium business and authorities are making bid to develop downstream industry.[18]

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[8] https://asiatimes.com/2022/02/indonesia-bans-mineral-exports-to-move-up-value-chain/.

[9] https://hsfnotes.com/africa/2023/08/10/beware-pitfalls-of-resource-nationalism-lessons-from-indonesia/.

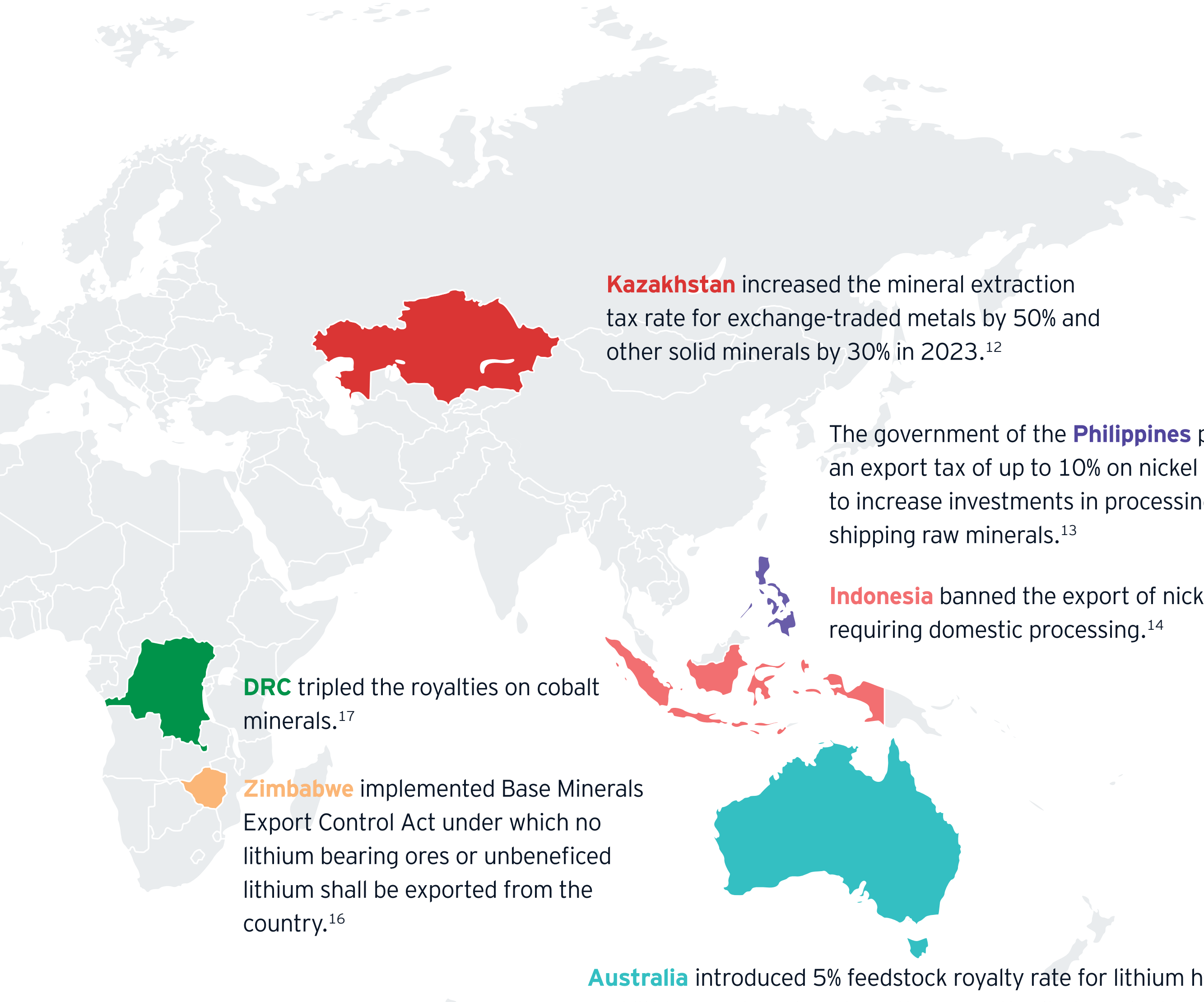
[10] https://www.oecd-forum.org/posts/raw-materials-for-the-green-transition-what-is-the-role-for-international-trade.

[11] https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/canada-gets-tough-on-chinese-state-owned-investments-in-critical-minerals-73369076.

[12] https://kgd.gov.kz/en/news/tax-rates-mineral-extraction-changed-kazakhstan-1-131064#:~:text=As%20of%20January%201%2C%20 2023,%2C%20copper%2C%20zinc%2C%20uranium)%3B.

[13] https://www.reuters.com/article/philippines-mining-nickel-idUKL4N34G0SG#:~:text=MANILA%2C%20Jan%2031%20(Reuters),House%20of%20 Representatives%20was%2010%25.

[14] https://ec.europa.eu/commission/presscorner/detail/en/ip_22_7314.



Kazakhstan increased the mineral extraction tax rate for exchange-traded metals by 50% and other solid minerals by 30% in 2023.[12]

The government of the **Philippines** plans to put an export tax of up to 10% on nickel ore exports to increase investments in processing instead of shipping raw minerals.[13]

Indonesia banned the export of nickel ore, requiring domestic processing.[14]

DRC tripled the royalties on cobalt minerals.[17]

Zimbabwe implemented Base Minerals Export Control Act under which no lithium bearing ores or unbeneficed lithium shall be exported from the country.[16]

Australia introduced 5% feedstock royalty rate for lithium hydroxide and lithium carbonate, where those are the first products sold, and feedstock is spodumene to encourage downstream processing and manufacturing.[15]

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[15] https://www.australianmining.com.au/western-australia-plots-lithium-royalty-regime/.

[16] https://www.veritaszim.net/sites/veritas_d/files/SI%202022-213%20Base%20Minerals%20Export%20Control%20%28Lithium%20Bearing%20Ores%20and%20Unbeneficiated%20Lithium%29%20Order%2C%202022.pdf.

[17] https://www.mining.com/web/congo-triples-levy-cobalt-strategic-minerals-decree/.

[18] https://insights.issgovernance.com/posts/the-race-for-critical-minerals/.

[19] https://www.miningweekly.com/print-version/lithium-nationalism-is-taking-root-in-region-with-most-resources-2021-06-29.

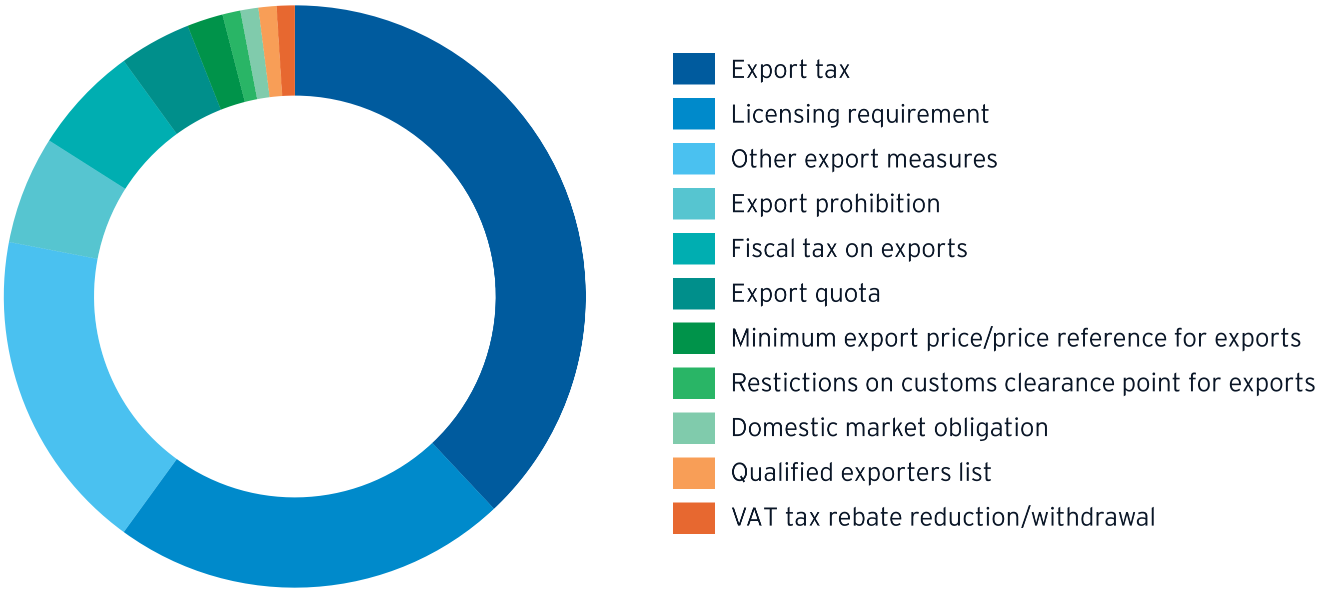
[20] https://www.reuters.com/markets/commodities/chile-miners-facing-higher-taxes-seek-faster-permits-lower-energy-costs-2023-07-13/.

[21] https://www.electrive.com/2023/02/20/mexico-signs-decree-to-nationalise-lithium-deposits/.

[22] https://kleinmanenergy.upenn.edu/news-insights/impacts-of-the-inflation-reduction-act-on-rare-earth-elements/.

The growing trend of export restrictions on critical materials has triggered a series of trade conflicts. Notably, it is not possible to link the disputes solely to energy transition, given that the materials involved have wider applications beyond the energy sector, such as steelmaking or the chemical industry.

Global increase in export restrictions by type of measures, 2009–20



Source: OECD Database on Export Restrictions on Industrial Raw Materials.

Another risk to the existing concentrated supply chain is the creation of **mineral cartels** with more power than oil's Organization of the Petroleum Exporting Countries (OPEC) with 15 member countries. If OPEC's share is 38% of global oil production,[23] the share of the top three critical mineral mining nations is much higher (for instance, 44% for copper, 66% for nickel, 80% for cobalt, 85% for graphite and 92% for lithium).[24]

Indonesia, the world's largest nickel miner, has already announced its idea of establishing an OPEC-style organization for certain battery metals, including nickel, cobalt and manganese.[25]

Argentina, Bolivia and Chile, collectively known as the "lithium triangle" with around 65% of global lithium reserves,[26] have been discussing an alliance concept since July 2022. Moreover, Bolivia has proposed designing a joint Latin American lithium policy.[27]

Considering all the above, it is important to diversify and build more self-sufficient regional supply chains (both mining and processing facilities) to avoid new dependencies, such as those associated with fossil fuels. Chinese companies have already been ensuring future control by striking new deals for minerals globally to secure raw mineral inputs.

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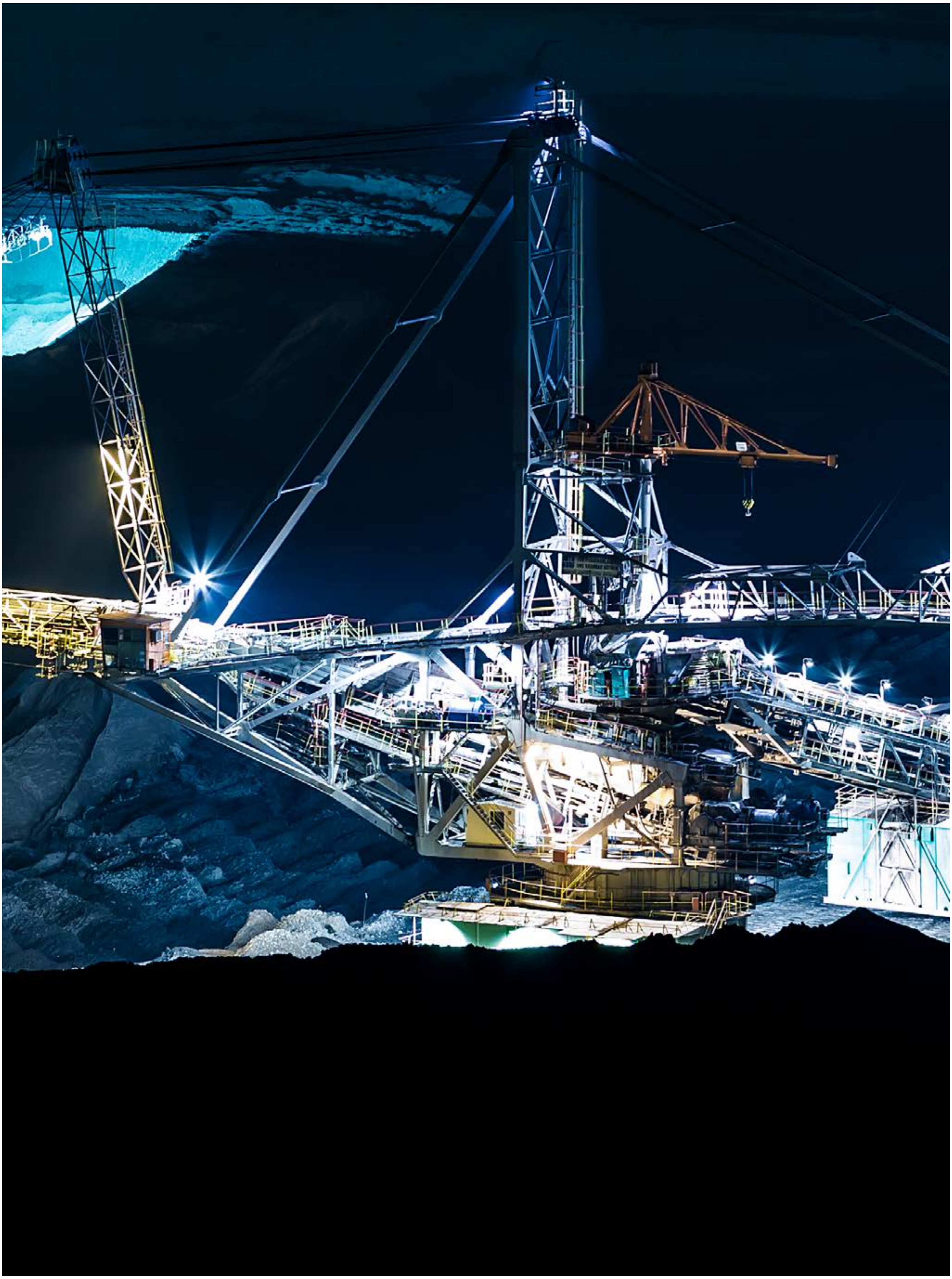
[23] https://www.statista.com/topics/1830/opec/#:~:text=OPEC's%20role%20in%20the%20world's,of%20global%20crude%20oil%20reserve.

[24] EY CESA Energy Center analysis based on IRENA report.

[25] https://www.ft.com/content/0990f663-19ae-4744-828f-1bd659697468.

[26] https://dialogochino.net/en/extractive-industries/57203-latin-america-discusses-regional-strategies-for-lithium-production/.

[27] https://www.reuters.com/world/americas/bolivia-president-calls-joint-latin-america-lithium-policy-2023-03-24/.



Mineral shortages could stem from growing competition between industrial applications and the energy transition

Market demand for critical materials in the 2020s has originated from non-energy transition uses, except for lithium (only 20% of demand came from industries outside EVs, energy storage and other Li-ion battery use in 2022[28]).

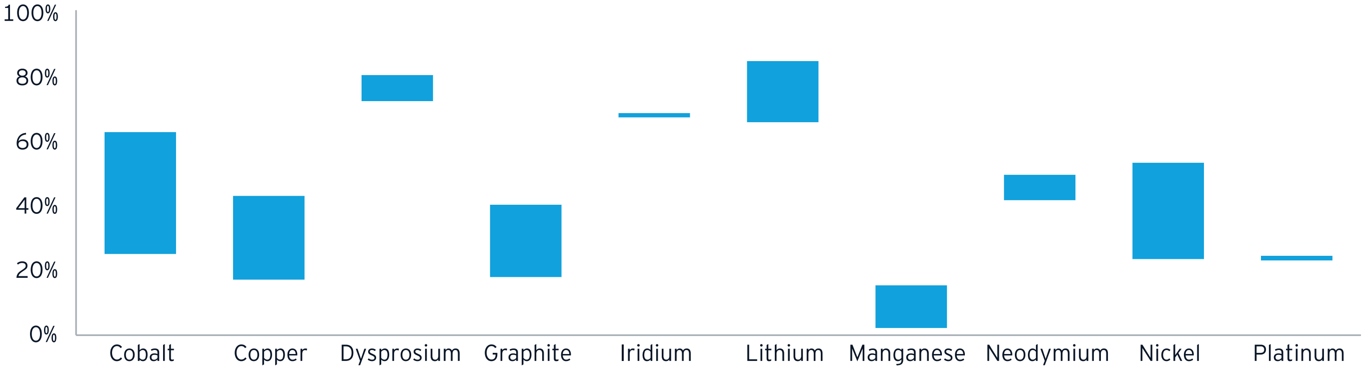
For example, roughly 90% of nickel was used in iron and steel production, while 10% was associated with clean energy technologies.[29] The energy sector represented roughly 32%[30] and 33%[31] of total demand for copper and cobalt, respectively.[32] However, compared with the mid-2010s, clean energy technologies are currently becoming the fastest-growing segment of demand.

Energy transition technologies increasingly require critical materials and may exceed the demand from non-energy uses in some cases. Experts worldwide project that the share of this promising segment will increase to 36% for copper,[33] 26% to 38% for nickel,[34] 48% to 56% for cobalt,[35] and 95% to 99% for lithium[36] by 2030.

Considering the use of most minerals and metals in current industrial applications, we expect that global competition for resources will become fierce in the coming decade. Thus, dependence on critical raw materials may soon replace today's dependence on oil.

The calculations may differ due to the specifics of each methodology. Nevertheless, forecasters warn of the risk of supply deficit for specific critical materials. If we compare the supply of materials with the demand expected in 2030, we can see that the range of disparity for most minerals is wide, including 17% to 43% for copper, 66% to 84% for lithium, 23% to 53% for nickel and 25% to 63% for cobalt.

Estimated disparity between current supply and anticipated demand for selected critical minerals in 2030



Note: The comparison of the mine production of selected material in 2022 with the demand expected in 2030.

Sources: IRENA, USGS, Fastmarkets, S&P Capital IQ, Eurometaux, BNamericas, IHS Markit, Minerals Council of Australia, Systemiq, Benchmark Minerals, government of Canada, Euro Manganese, WSJ, Mining.com, QYResearch, Nickel Asia and other open sources.

To avoid a demand-supply gap for materials with a high disparity level, increasing mining and processing capacities is essential. Additionally, bridging the gap requires an improvement in material recovery from tailings and recycling technologies. Such advancements require government investment in infrastructure, the design of enabling legal frameworks, including mandates through public policy, as well as research and innovation in recycling technologies.

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[28] Battery Materials Analytics, Argus, April 2023.

[29] Fastmarkets, 2023.

[30] BNamericas, 2022, Eurometaux, 2022, IHS Markit, 2022, Minerals Council of Australia, 2022, S&P Global IQ, 2022, Systemiq, 2023, IRENA, 2023.

[31] Fastmarkets, 2023.

[32] https://www.iea.org/data-and-statistics/charts/total-demand-for-selected-minerals-by-end-use-in-the-net-zero-scenario-2021-2050.

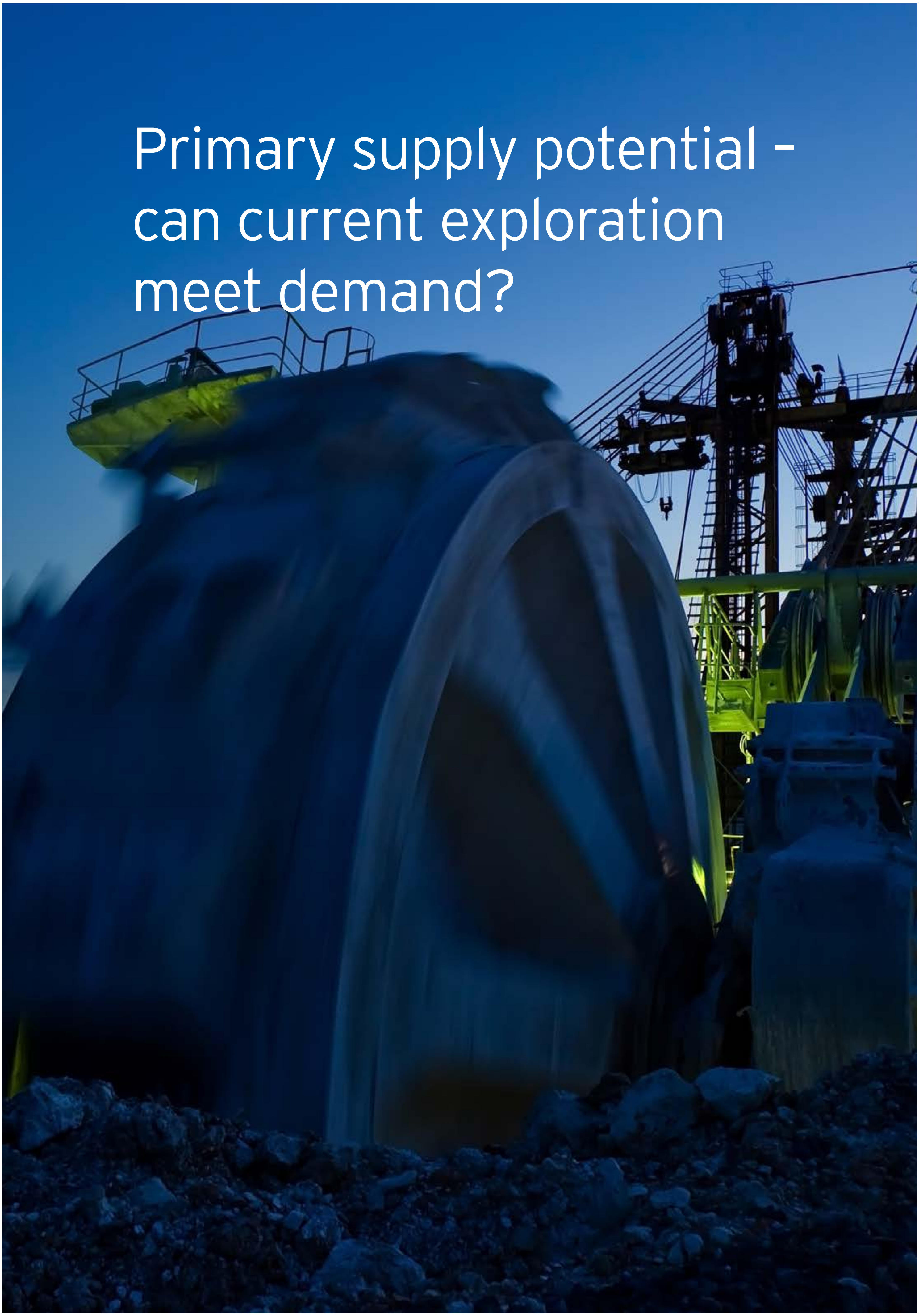
[33] BNamericas, 2022, Eurometaux, 2022, IHS Markit, 2022, Minerals Council of Australia, 2022, S&P Global IQ, 2022, Systemiq, 2023, IRENA, 2023.

[34] Eurometaux, 2022, IRENA, 2023.

[35] Eurometaux, 2022, IRENA, 2023.

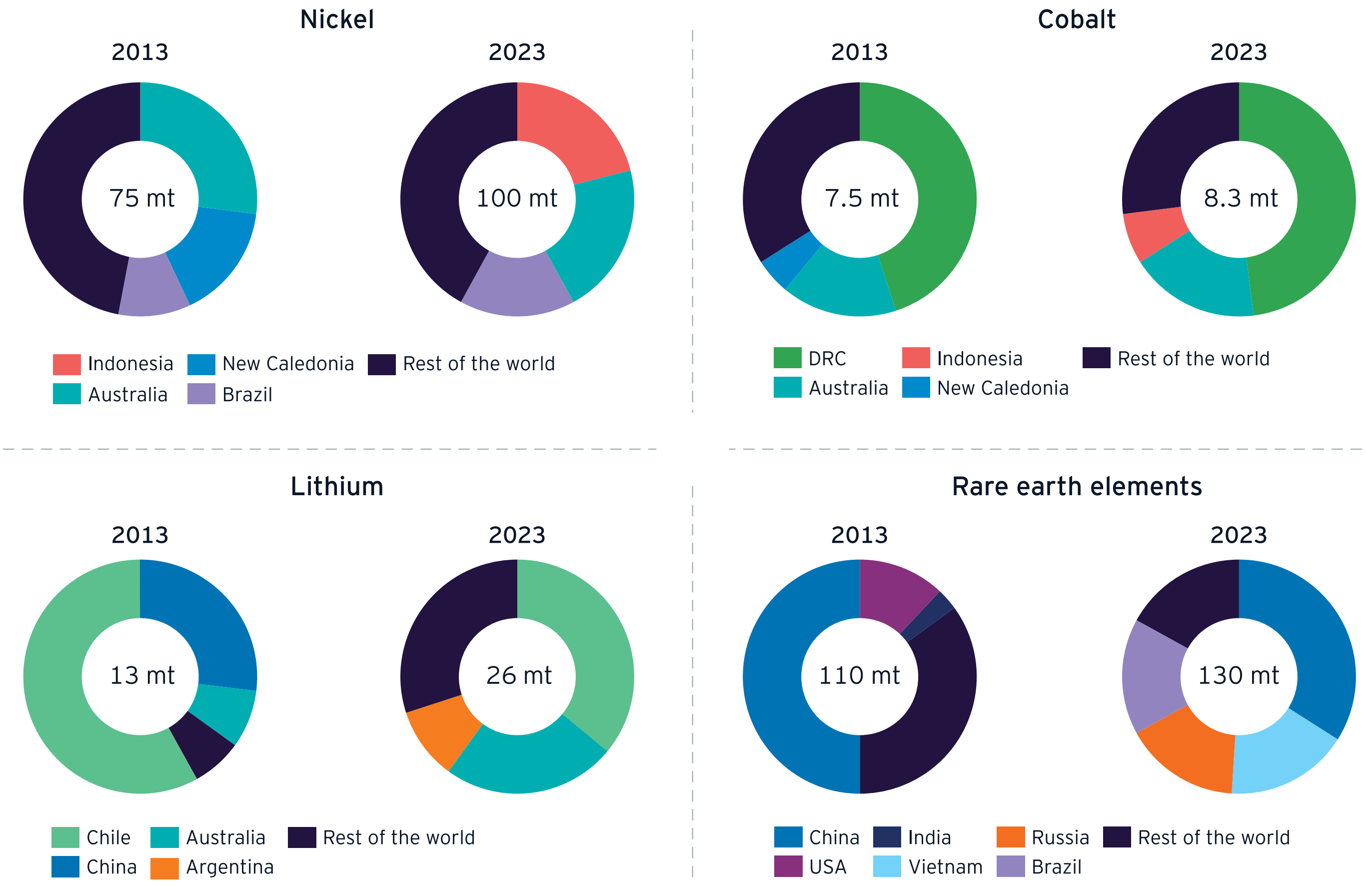
[36] Eurometaux, 2022, IRENA, 2023.

Primary supply potential - can current exploration meet demand?



There is no scarcity of geological reserves and there are enough minerals in the ground to support energy transition. Distribution of global critical mineral reserves is more even than current mineral production. This opens opportunities to diversify supply considering that a substantial portion of the world, especially developing countries, remains unexplored.

Top countries' share of global CRM reserves in 2013 vs. 2023



Sources: US Geological Survey.

There is growing recognition across importing nations of the need for policy interventions to ensure adequate and sustainable mineral supplies. Countries and regions have developed their own initiatives, such as the EU's Critical Raw Materials (CRM) Act, the US Inflation Reduction Act, Australia's Critical Minerals Strategy and Canada's Critical Minerals Strategy.

The IEA's Critical Minerals Policy Tracker identified 200 policies and regulations in 25 countries and regions (including both major producers and consumers of critical minerals), with over 100 of these enacted in the past few years.[37] These interventions have implications for trade and investment.

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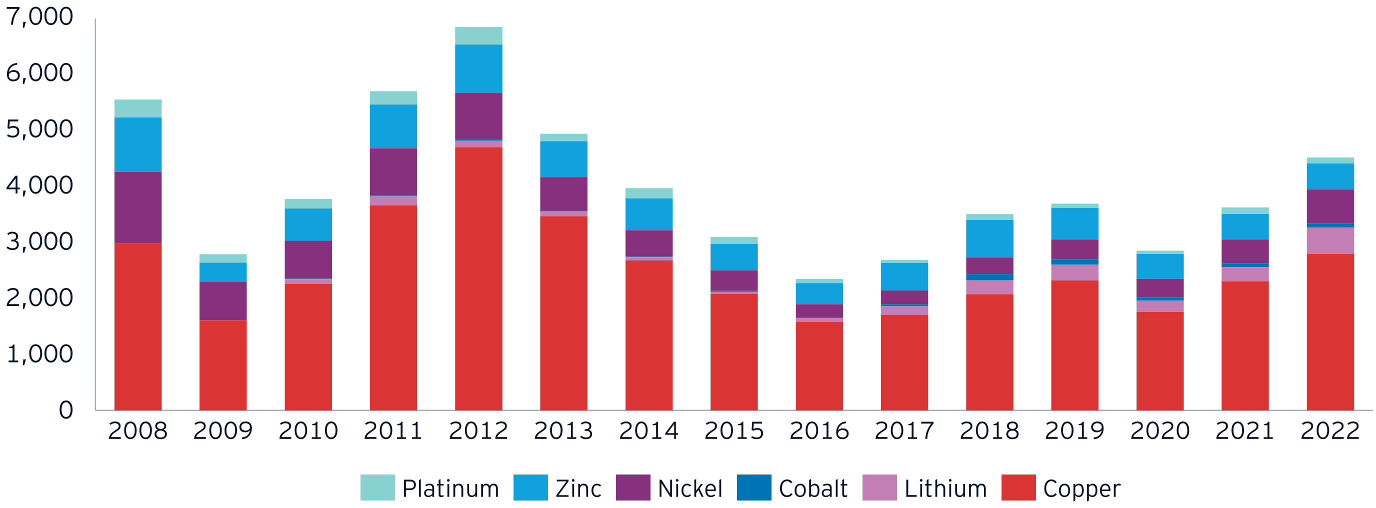
[37] https://www.iea.org/reports/critical-minerals-policy-tracker/key-findings.

Exploration spending (the funds allocated to identifying potential mineral deposits in an area) are also increasing – cumulative expenses on copper, lithium, cobalt, nickel, zinc and platinum gained 25% on an annual basis in 2022.[38] The compounded average growth rate for these minerals was 11% between 2017 and 2022, while in a wider period from 2010 it was lower (2%). Last year copper (21% y-o-y), lithium (88% y-o-y) and nickel (45% y-o-y) drove expansion, while zinc and cobalt's growth was insignificant (1% and 2% respectively). Palladium's exploration budget experienced a reduction by 6% y-o-y in 2022.

A large majority of the exploration budget for selected minerals comes from OECD countries, dominated by Australia, Canada, Chile and the US, which have increased their exploration budgets for nickel, cobalt, lithium and copper in the past 10 years.

Exploration budget for selected critical minerals, US$ million



Source: EY CESA Energy Center's analysis of S&P Global Intelligence (August 2023).

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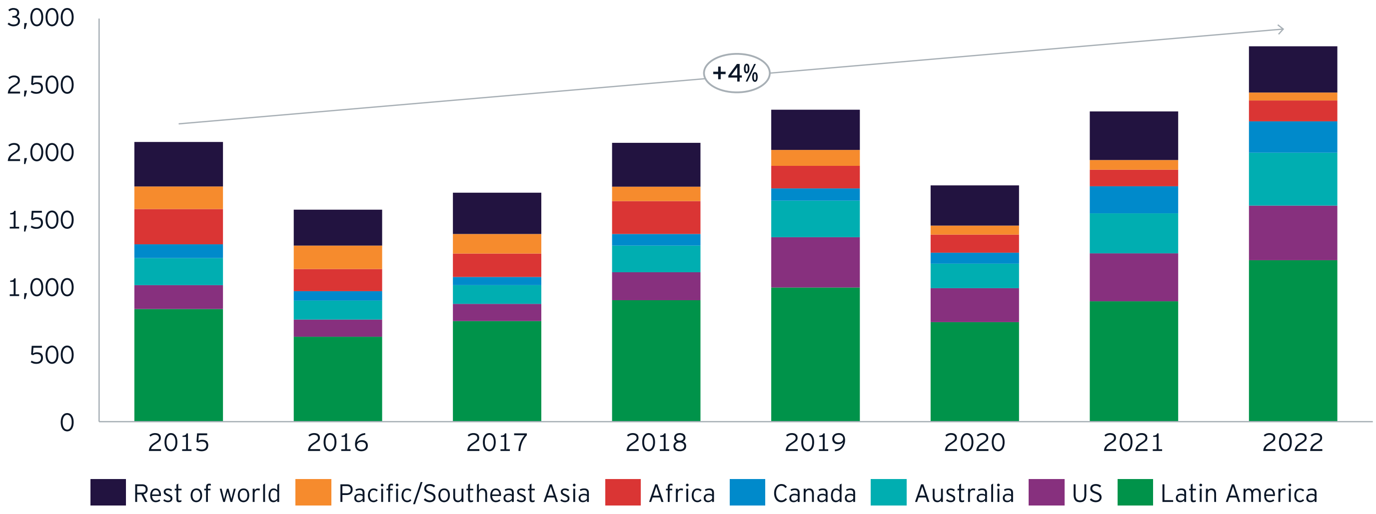
[38] EY CESA Energy Center's analysis of S&P Global Intelligence (August 2023).

Total exploration budgets for **copper** (also known as "red metal") increased 21% globally in 2022, the highest level since 2014.[39] Latin America led the way in absolute values last year (34% more than in 2021). Australia, the US and Canada followed, which expanded their exploration budgets by 33%, 14% and 16%, respectively. Notably, spending in Latin America was 16% higher than these in 2022. In 2017, the gap between them was almost 130%. Among other nations, the DRC and Ecuador increased their budget for copper and fresh players in the market are Cuba,[40] Afghanistan,[41] Cyprus[42] and Tanzania.[43] There are promising new frontiers, such as Ecuador and Argentina, where mining is still at an early stage and progressing slowly. Notably, Iran and Russia possess significant reserves, but their access to investment remains limited.

Last year saw two large copper mines commence operations in Peru and Serbia.[44] Chile expects its deposits to follow this year, while two other major projects, in Russia and in Mongolia, are currently under construction.

However, fatter exploration budgets over recent years have not led to a meaningful increase in the number of recent major discoveries. While copper reserves and resources increased by 50 million tonnes compared with the previous year's analysis, the increase came from assets largely discovered in the 1990s.[45]

Copper exploration budget by country and region, US$ million



Source: EY CESA Energy Center's analysis of S&P Global Intelligence (August 2023).

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[39] https://www.spglobal.com/marketintelligence/en/news-insights/research/copper-by-the-numbers-exploration-development-operations.

[40] https://mining.com.au/antilles-gold-confirms-high-grade-copper-from-el-pilar-gold-copper-oxide-deposit-cuba/.

[41] https://thechinaproject.com/2023/06/28/the-fortune-of-copper-under-an-ancient-buddhist-site-in-afghanistan-that-china-is-supposed-to-mine/.

[42] https://cyprus-mail.com/2021/10/14/cyprus-to-get-first-new-copper-mine-in-decades/#:~:text=Venus%20Minerals%20and%20Hellenic%20Copper,village%20in%20the%20Nicosia%20district.

[43] https://www.lse.co.uk/news/in-brief-marula-mining-buys-licenses-in-tanzania-copper-project-9gtspb3qgncd31l.html.

[44] https://www.mining.com/chart-copper-exploration-budgets-jump-but-major-discoveries-elusive/#:~:text=According%20to%20a%20report%20by,the%20highest%20level%20since%202014.

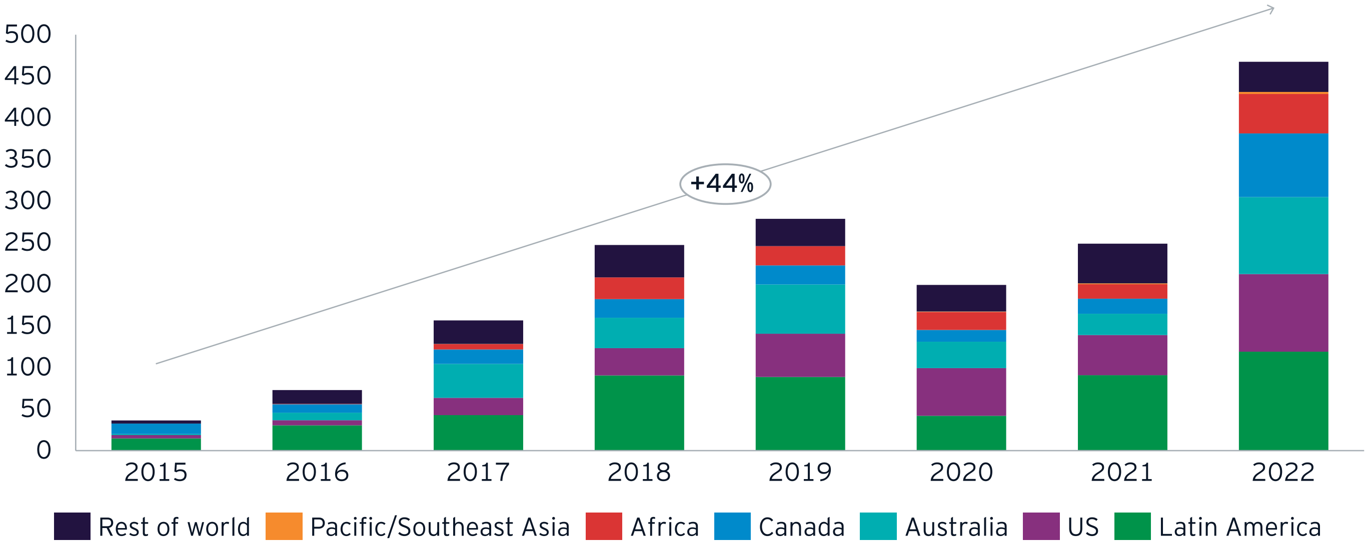
[45] https://www.mining.com/chart-copper-exploration-budgets-jump-but-major-discoveries-elusive/.

The **lithium** (so-called white gold) exploration budget increased by 88% in 2022 after years of remaining flat.[46] Canada and Australia contributed 57% of the global exploration budget growth (mostly thanks to hard-rock lithium plays), while the US, Africa and Latin America represented 21%, 14% and 13% growth, respectively. Latin America remained the leader in absolute values last year. However, there was a 24% decrease in values in the rest of the world. In recent years, Peru, Germany and Zimbabwe have increased their budgets for lithium. Cote-d'Ivoire,[47] India,[48] Morocco,[49] Sweden[50] and the UK[51] are among the new market players.

Nickel was subject to a 45% growth in exploration expenditures in 2022 (a 10-year high), with Canada leading the race (over 90% increase y-o-y), where high-grade sulfide resources, proximity to existing infrastructure and access to low-emissions electricity create attractive investment opportunities. Australia followed with 38% growth and a 33% share of the global nickel exploration budget. China and Vietnam also increased their budgets for nickel.

The DRC is the main producer of **cobalt** (also known as the blue metal), as a by-product of larger nickel and copper mining operations. While exploration budgets for cobalt have been stable in Africa (DRC, Morocco and Zambia) since 2019, they have fallen twice in Australia. In 2022, the global value of the budget added only 1% compared with the previous year. In comparison with 2019, it was 29% lower.

Lithium exploration budget by country and region, US$ million



Source: EY CESA Energy Center's analysis of S&P Global Intelligence (August 2023).

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[46] https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/battery-next-ev-makers-use-model-t-playbook-due-to-metal-supply-fears-75880328#:~:text=Exploration%20budgets%20for%20lithium%20alone,years%20of%20remaining%20relatively%20flat.

[47] https://issafrica.org/iss-today/cote-divoires-mines-risk-degrading-its-fragile-environment#:~:text=A%20consortium%20of%20two%20companies,in%20the%20northern%20Boundiali%20region.

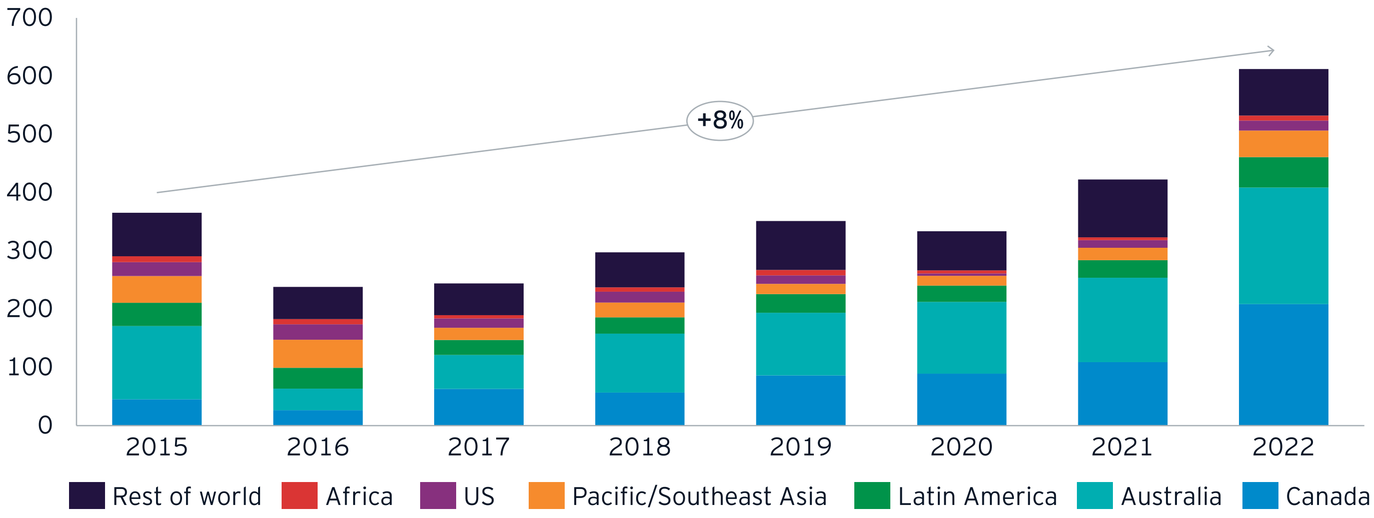
[48] https://www.telegraph.co.uk/global-health/climate-and-people/lithium-mining-india-precious-metal-batteries-carbon/.

[49] https://www.atalayar.com/en/articulo/economy-and-business/major-lithium-deposit-discovered-morocco/20220519161714156503.html.

[50] https://www.cnbc.com/2023/01/13/sweden-mining-company-lkap-finds-big-deposit-of-rare-earth-metals.html.

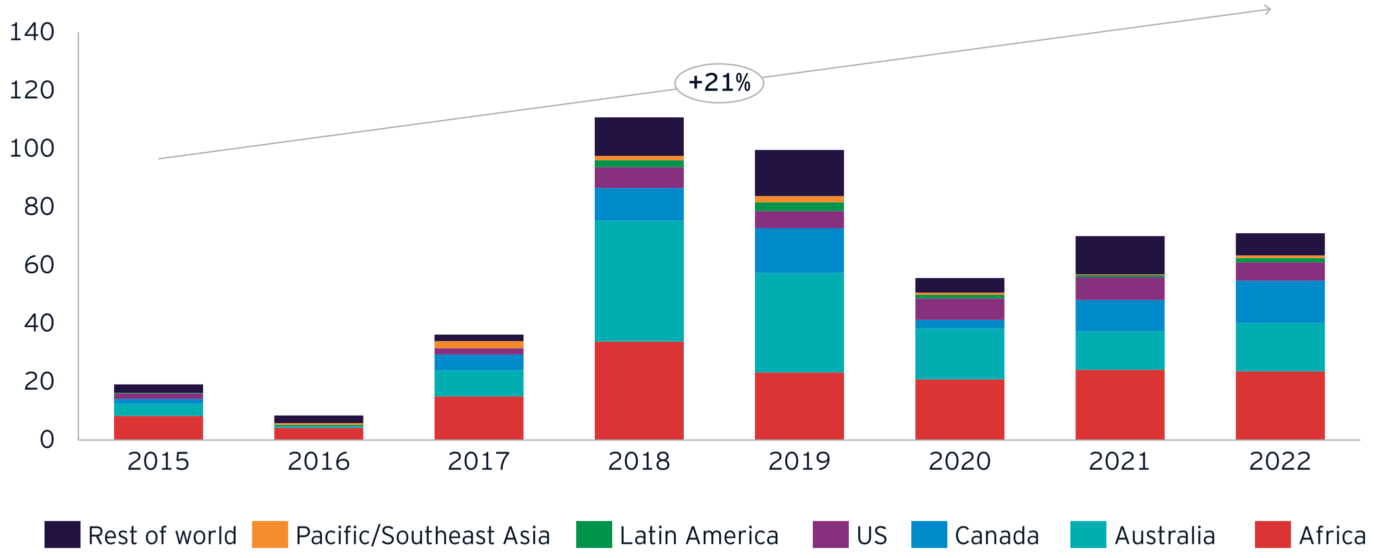
[51] https://www.bbc.co.uk/news/uk-england-cornwall-66051126.

Nickel exploration budget by country and region, US$ million



Source: EY CESA Energy Center's analysis of S&P Global Intelligence (August 2023).

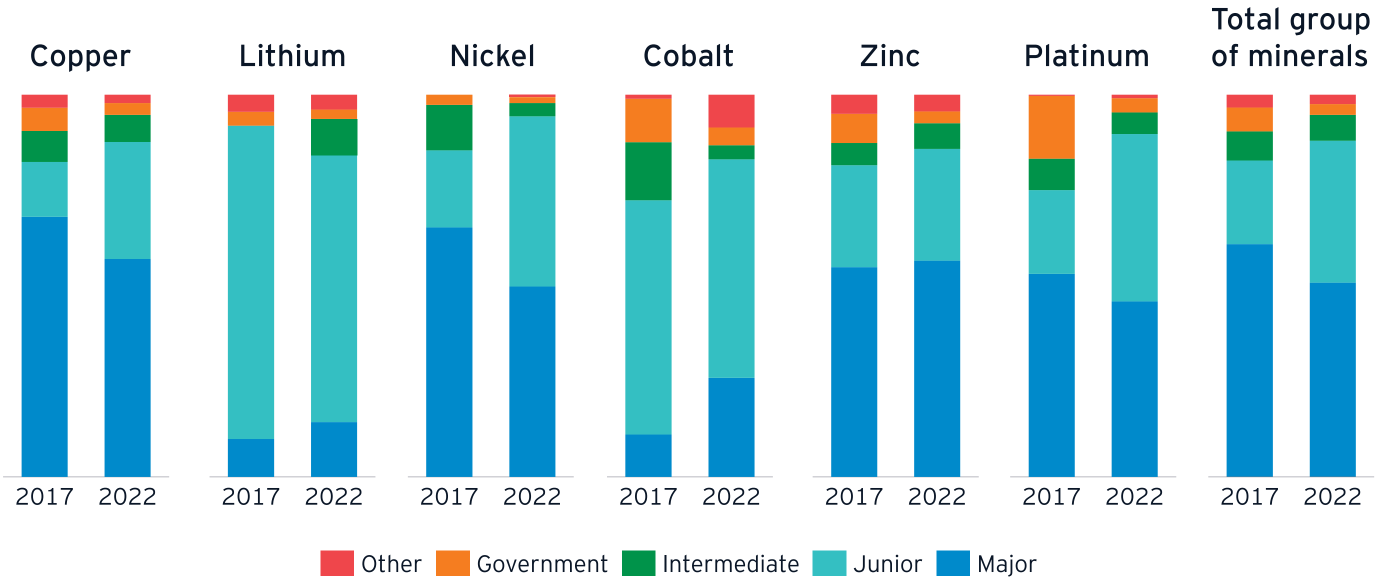
Cobalt exploration budget by country and region, US$ million



Source: EY CESA Energy Center's analysis of S&P Global Intelligence (August 2023).

Junior companies generating annual revenues under US$50 million represented 37% of overall exploration budgets for all the minerals listed above in 2022 (vs. 22% in 2017). The majors hold 51% of budgets, while governments hold only 3%. For comparison, their share decreased by 10 p.p. and 3 p.p., respectively, between 2017 and 2022. Notably, the largest share of the majors in budgets were in copper, zinc and nickel exploration last year (57%, 57% and 50%), while the most junior's portion was in lithium exploration (70%).[52]

Exploration budget by company type, 2017 vs. 2022



Source: EY CESA Energy Center's analysis of S&P Global Intelligence (August 2023).

The less good news is that the critical minerals sector needs to do more if it is to match the level of demand required to achieve net-zero emissions by 2050. The industry needs at least 384 new mines for graphite, lithium, nickel and cobalt, based on average mine sizes of each, by 2035.[53]

Overall investments in the critical minerals value chain needs to increase cumulatively from US$200 billion to an anticipated US$405 billion between 2022 and 2030 to meet expanded demand.[54]

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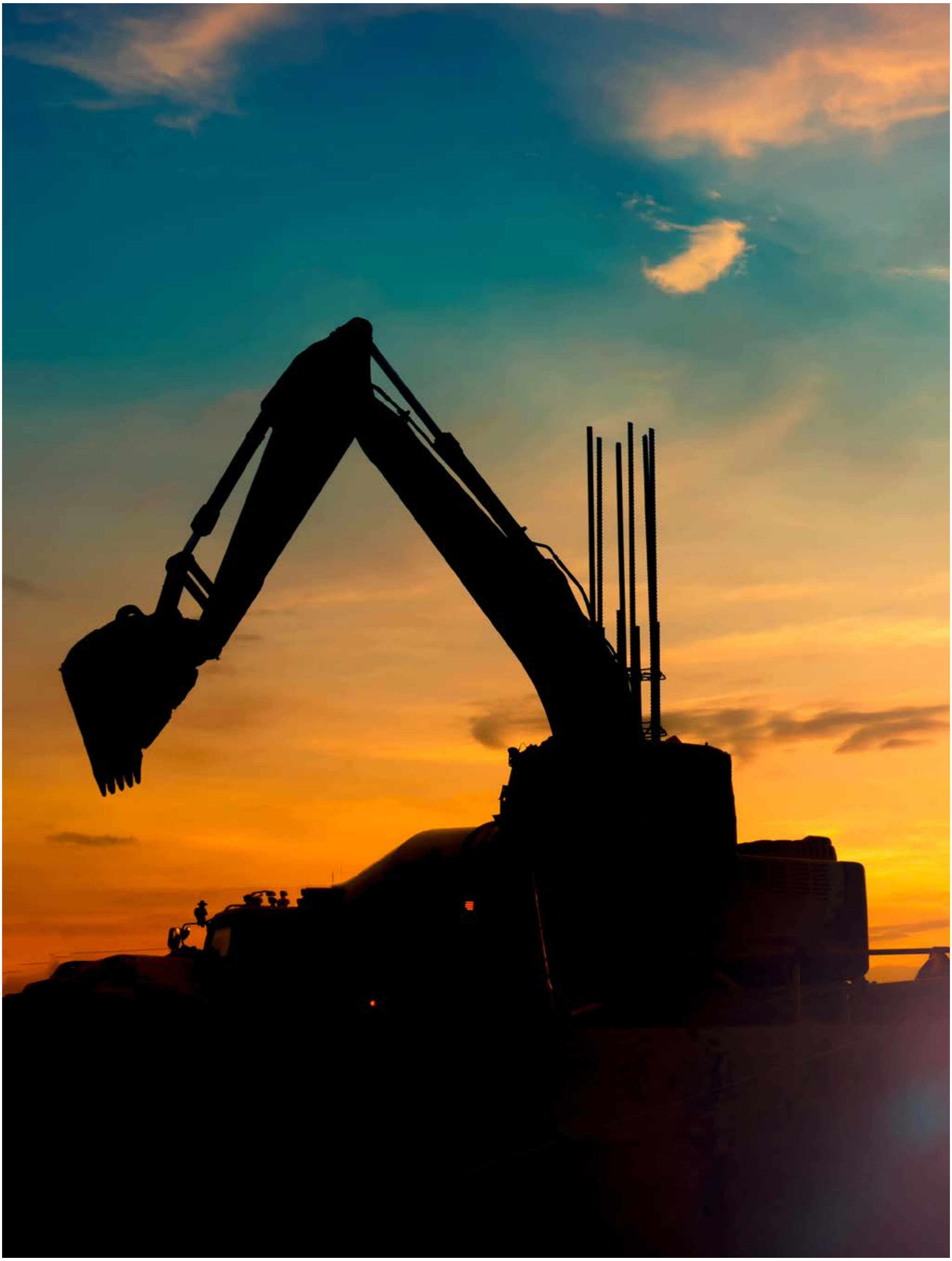
[52] EY CESA Energy Center's analysis of S&P Global Intelligence (August 2023).

[53] https://source.benchmarkminerals.com/article/more-than-300-new-mines-required-to-meet-battery-demand-by-2035.

[54] EY calculations based on Energy Technology Perspectives 2023 by IEA.



Sustainable mining is complex, requiring considerable time and effort

However, we should remember that not all exploration projects result in a new mine. For example, there were only four copper deposit discoveries between 2015 and May 2022 in contrast to 193 discoveries during 1990 to 2007 and 31 discoveries between 2008 and 2014.[55]

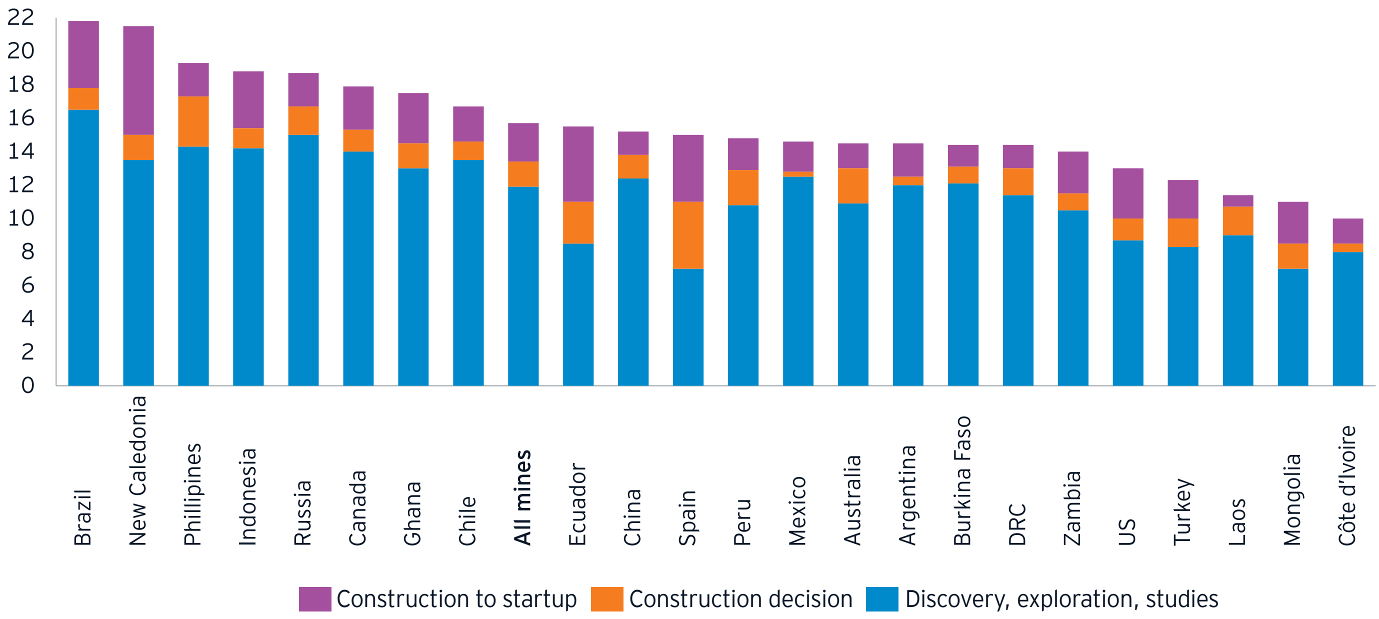
Even if exploration projects result in a new mine, it takes years from discovery to opening the mine. The time varies from 10 to 30 years based on several factors.

The average lead time from discovery to commercial production for 127 precious and base metals mines[56] that began production between 2002 and 2023 and were discovered from 1980 onward was between 15 and 16 years.[57]

There are shorter lead times for mines in Africa compared with other regions with more strict regulations (especially in licensing). The upward effect on the average lead time is driven by countries such as Canada, Russia and Chile. For instance, mining projects in Canada are subject to federal and provincial requirements. Each province has its own permissions regime specific to mining, regulating construction, operation, closure and reclamation. There is a growing consensus that Canada needs to optimize the process to reduce the lead time of mines to support the development of the domestic supply chain for critical minerals, coinciding with US green energy spending plans.

The US is outperforming Canada and Australia in lead time. Nevertheless, over recent decades lead times for new mining projects there have extended dramatically. If in 1956 copper mines in the US took as long as three to four years to construct and deliver product (including permissions and administration), today the permission process alone can take between seven and ten years. As a result, there is a strong push to change current laws surrounding permissions for new mines to meet the goal of boosting independence in critical minerals in the US.

Global average lead time from discovery to production (years)



Note: Covers 127 mines and includes countries with at least two mines (as of April 2023).

Source: EY CESA Energy Center's analysis of S&P Global Intelligence.

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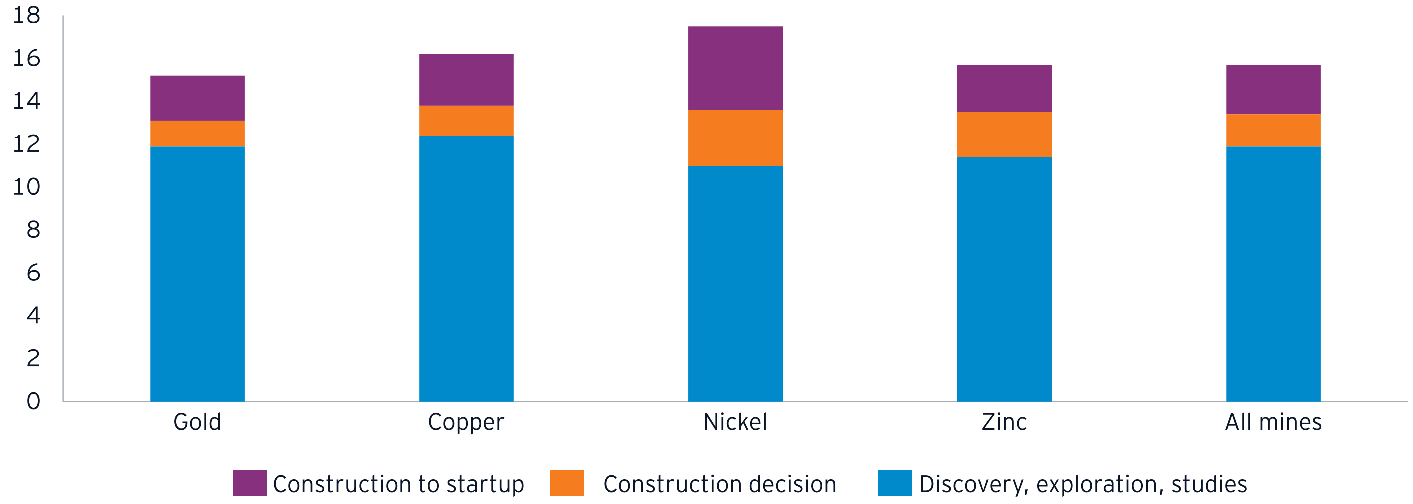
[55] https://www.spglobal.com/marketintelligence/en/news-insights/research/copper-discoveries-declining-trend-continues.

[56] 127 mines include gold, copper, nickel, silver and zinc mines.

[57] https://www.spglobal.com/marketintelligence/en/news-insights/research/discovery-to-production-averages-15-7-years-for-127-mines.

Global average lead time from discovery to production (years)



Note: Covers 127 mines and includes 70 gold, 34 copper, 13 nickel and 9 zinc mines (as of April 2023).

Source: EY CESA Energy Center's analysis of S&P Global Intelligence.

If gold deposits are less complex, copper development over the past few decades has focused on deeper, low-grade porphyry deposits, which require intensive exploration to define and substantial infrastructure to bring into production. Mining of larger volumes of rock secures the same amount of copper, as grades are deteriorating. Currently operating copper mines have an average grade of 0.53%, while projects under development now have an average grade of 0.39% or lower.[58] Thus, estimates of the average lead time for copper are 16 years (vs. 15 years for gold).

Nickel mines have the longest average lead time among the commodity group at 17 to 18 years, with a range of 11 to 29 years. Those mines with longer lead times have faced challenges of funding, changes of ownership and protests by local communities and experienced delays. Notably, nickel mines discovered in the 1980s and 1990s increased their average lead time during a time of lower nickel prices and potentially face tighter access to capital.

However, despite the longer cumulative lead time, exploration and study times for mines are notably shorter (11 years on average compared with 12 years for gold and slightly more for copper). Longer times to reach a construction decision after the end of feasibility studies and a longer construction phase increased the average time to nickel production.

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[58] https://stockhead.com.au/resources/how-do-drilling-results-make-the-grade-copper-and-zinc/ .

Considering that most cobalt production is as a by-product of large-scale copper and nickel mines (except the mines in Morocco and some Canadian arsenide ores), its lead time from resource discovery to production is in the range of copper and nickel. Lithium deposit lead time is in the range of between 5 and 10 years.[59]

It should also notable that open pit mines require slightly more lead time than underground mines (five months), attributed to the permissions and studies phase. However, the construction time for open pit mines is slightly shorter than for underground mines due to less complex infrastructure.

On the other hand, it takes only 24 months to build a battery plant[60] or up to five years[61] from concept to operation. This creates a gap between elastic demand and inelastic supply.

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[59] https://tdk-ventures.com/why-we-invested-in-novalith/.

[60] https://tdk-ventures.com/why-we-invested-in-novalith/.

[61] https://www.faraday.ac.uk/wp-content/uploads/2022/07/Faraday_Insights_2_update_July_2022_FINAL.pdf.

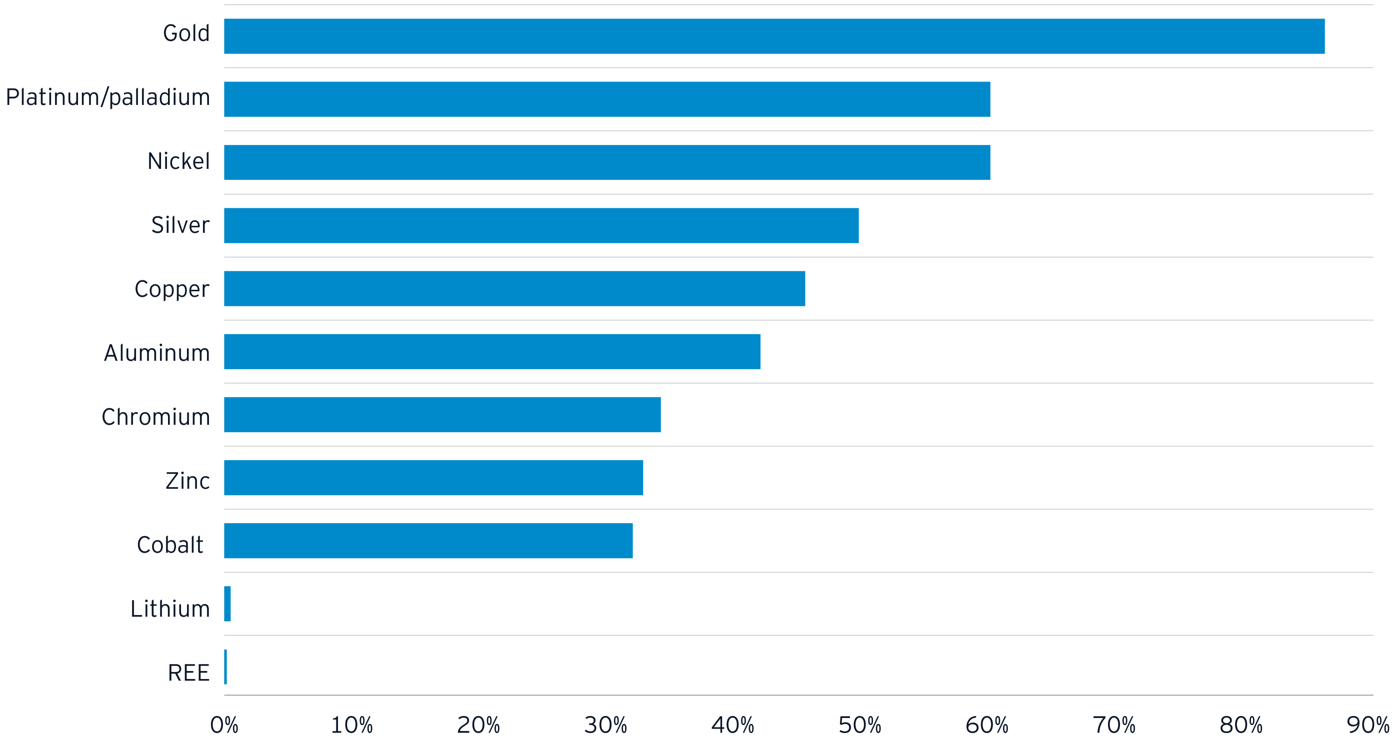
Secondary supply could narrow the deficit – is recycling a panacea?

Opposite to fossil fuels and other single-use materials, critical minerals have permanent physical properties making them indefinitely recyclable in theory.

With the limited potential contribution of the mining industry in the short term, fostering circularity and upscaling recycling capacities could be key study options.

At the end-of-life (EOL) stage, metal-based products can be reprocessed and reintroduced to the production process to make new metals of the same quality as new metals from primary sources. Recycling EOL products to recover metals is a widespread practice in commodity markets. Mature recycling industries reach end-of-life recycling rates (or the share of a recycled material in waste flows known as EOL-RR) between 30% and 60%. However, recycling of metals is still below the required scale.

Current global average recycling rates for minerals (EOL-RR)

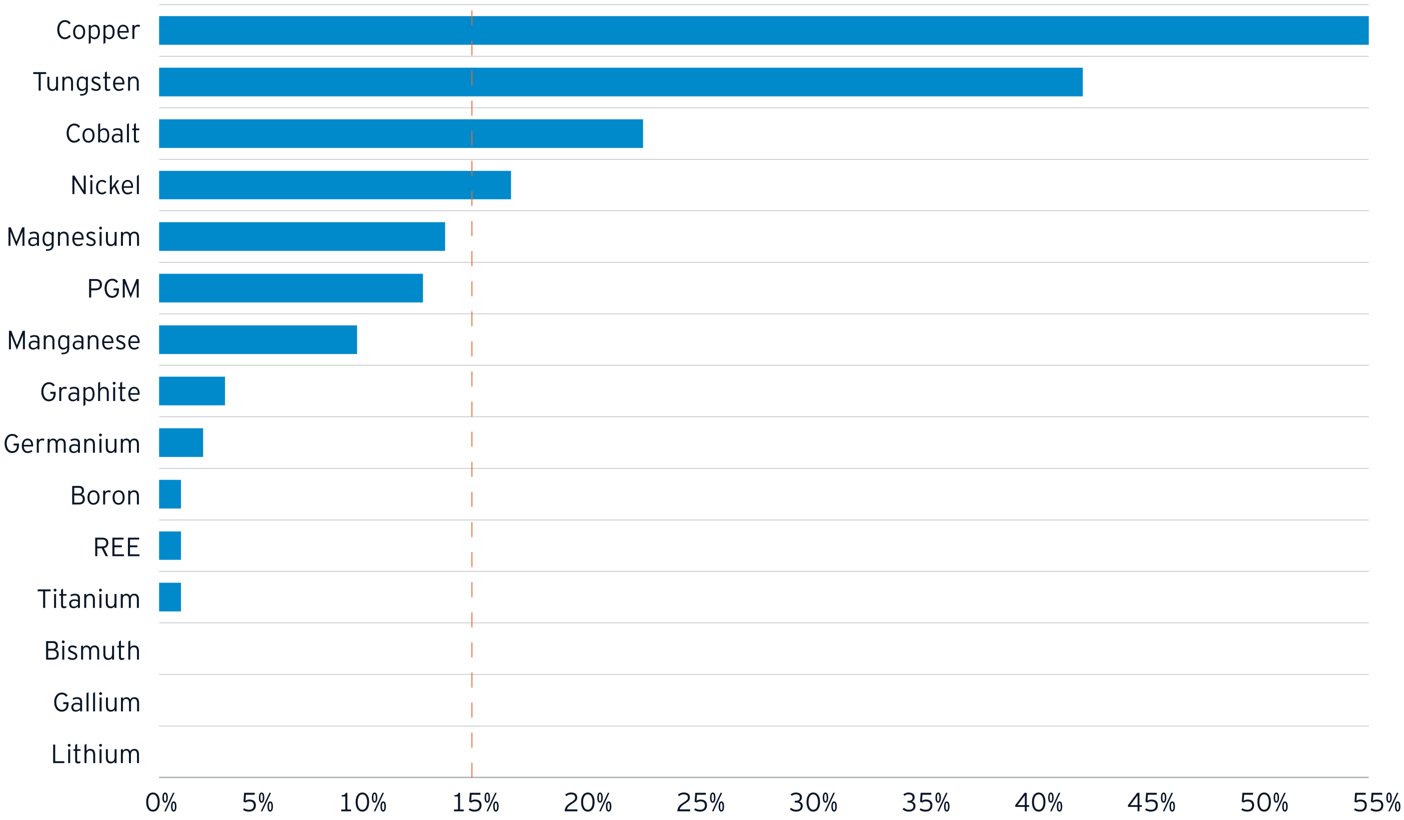


Source: IEA.

EOL-RR differs from the secondary (recycled) mineral share in total global supply (known as end-of-life recycling input rate or EOL-RIR).[62] The former is higher than the latter due to the availability of scrap. For instance, if we recycle 45% of refined copper at the end of its life for all applications globally[63] (about 60% in power grids), the recycled content of new copper supply was only 17% in 2012-21.[64]

Notably, EOL-RIR is the selected recycling indicator used as a supply risk reduction parameter in the European Commission's criticality methodology. In the EU, where recycling activities are well-established, EOR-RIR for copper is estimated at 55%, for cobalt at 22% and for nickel at 16%. The rate for lithium is close to 0%.[65]

Current EOL-RIR for strategic raw materials in the EU vs. CRM Act target



Source: European Commission.

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[62] EOL-RR (end-of-life recycling rate) – the share of copper in waste flows that is recycled. EOL-RIR (end-of-life recycling input rates) – the ratio of secondary raw materials obtained through recycling of products, which reached end-of-life, divided by the overall quantity of raw materials fed into the economy. Because of increases in material use over time and long in-use lifetime, EOL-RIR value is sensibly lower than the correspondent EOL-RR.

[63] https://eurometaux.eu/media/jmxf2qm0/metals-for-clean-energy.pdf.

[64] https://cdn.ihsmarkit.com/www/pdf/0722/The-Future-of-Copper_Full-Report_14July2022.pdf.

[65] https://www.rtlnieuws.nl/sites/default/files/content/documents/2023/07/04/Study%202023%20CRM%20Assessment%20%281%29.pdf.

Currently, **the availability of scrap is simply not enough** to meet growing demand. Only a handful of EVs and batteries have reached their end-of-life. Existing EV batteries run on a 10- to 20-year cycle.[66] The average lifespan of a solar panel is about 25 to 30 years.[67] In terms of durability, wind turbines last an average of 20 to 25 years.[68] Thus, it is going to take decades until we reach a point where there is significant secondary feedstock.

There are also various **bottlenecks throughout the recycling chain** (from product design to the collection of disposed products and the recycling process). Systematic collection of products containing CRMs is often lacking. For instance, in the case of mobile phones, it was estimated several years ago that up to 700 million unused devices across the EU were uncollected.[69] In a hypothetical scenario where all these devices are collected and recycled, approximately 15,000 tonnes of gold, silver, copper, palladium, cobalt and lithium could be recovered. The collection of waste electric and electronic equipment was only 46% within the bloc in 2020 (with significant variations across Member States), leaving large quantities of potentially valuable material out of the production cycle.[70] In the case of end-of-life EVs, roughly a third (around 3.5 million vehicles) are currently either not properly collected or exported outside the EU.[71] The issue was associated mainly with inefficient waste management systems, lack of collection infrastructure and limited economic incentives for the recycling of some CRMs.

However, like many countries, the EU is improving **policies and developing rules** to increase the use of recycled materials. The bloc set a target of at least 15% of the EU's annual raw material consumption for recycling in its CRM Act.[72] In July 2023 the EU Council adopted the EU Battery Regulation Amendment, laying out the structure to achieve sustainable battery lifecycles. According to the update, every industrial or EV battery on the EU market with a capacity of over 2 kWh will require a battery passport to be identified with a QR code from February 2027.[73] The Regulation requires many other criteria to be met to sell batteries in the EU, including the reporting of a carbon footprint declaration, recycled content percentages, as well as human rights and battery supply chain due diligence obligations throughout the battery value chain.[74]

China has also introduced a platform that traces batteries throughout their lifetime, therefore further ensuring that batteries will be collected when they reach EOL. For recycling, China sets voluntary recovery targets for lithium, cobalt, nickel and manganese. The US Environment Protection Agency plans to develop battery recycling best practices and battery labeling guidelines by 2026. However, it is critical to create a complex supportive policy environment for recycling by 2040. If more than one million EV batteries per year could reach EOL by 2030 globally, 10 years later the amount could reach about 14 million per year.[75]

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[66] https://www.newsecuritybeat.org/2023/05/critical-mineral-recycling-offer/.

[67] https://www.cnbc.com/2023/05/13/recycling-end-of-life-solar-panel-wind-turbine-is-big-waste-business.html.

[68] https://www.nationalgrid.com/stories/energy-explained/can-wind-turbine-blades-be-recycled#:~:text=There%20are%20more%20than%208%2C000,around%2020%2D25%20years).&text=They%20can%20mostly%20be%20recycled,that%20have%20already%20been%20recycled.

[69] https://circulareconomy.europa.eu/platform/sites/default/files/impact_of_ce_on_fmcg_-_mobile_phones_case_study.pdf.

[70] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Waste_statistics_-_electrical_and_electronic_equipment.

[71] https://environment.ec.europa.eu/topics/waste-and-recycling/end-life-vehicles/end-life-vehicles-regulation_en.

[72] https://ec.europa.eu/commission/presscorner/detail/en/qanda_23_1662.

[73] https://www.circularise.com/blogs/battery-regulation-eu-what-you-need-to-know-about-battery-passports.

[74] https://www.circularise.com/blogs/eu-battery-passport-regulation-requirements.

[75] The International Council of Clean Transportation.

Policy levers to scale up battery and recycling practices

Regulatory area	Policy lever	Existing policy example
Battery traceability and collection	‣ Battery removability ‣ Battery traceability mechanism ‣ Regulations that clearly define who is responsible for the battery when it reaches EOL	China's government released a set of policies that place the responsibility of collecting EV EOL batteries on manufacturers or importers.[76] In 2018, it created a Traction Battery Recycling and Traceability platform to trace batteries throughout their lifetime.[77]
Building domestic capacity for reuse and recycling	‣ Incentives and grants to support development	The US$3.1 billion in grants in the US, together with a separate US$60 million program for battery recycling, is an effort to reduce the reliance on competing nations that have an advantage over the global supply chain.[78]
Battery information	‣ Regulations for the disclosure of battery information to optimize the battery recycling process	The EU's Battery Regulation Amendment introduced labeling and information requirements for the battery's components and recycled content, an electronic "battery passport" and a QR code.[79]
Battery standards	‣ Standards for battery durability ‣ Standard for accuracy and reporting of the state-of-health metric ‣ Standards of safety when handling end-of-life batteries	The UL 1974 Standard for Evaluation for Repurposing Batteries in the US and Canada sets general safety standards for sorting and grading used EV batteries and estimating their state of health (SoH).[80]
Recycling mandates	‣ Element-specific mandates on proportion of material for recovery ‣ Element-specific mandates on recycled material for use in new manufactured batteries	The EU's Battery Regulation Amendment sets a target for lithium recovery from waste batteries of 50% by the end of 2027 and 80% by the end of 2031. The recycling efficiency target for nickel-cadmium batteries is set at 80% by the end of 2025 and 50% by the end 2025 for other waste batteries.[81]
Research and development	‣ Investments in R&D to optimize the processes	The UK aims to become a scientific knowledge leader on battery material recovery and recycling through its Critical Mineral Strategy. Various funding initiatives will support the circular economy.[82]

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[76] https://www.electrive.com/2022/01/29/battery-reuse-recycling-expands-to-scale-in-china/.

[77] https://www.upsbatterycenter.com/blog/tracking-electric-vehicle-batteries-china/.

[78] https://www.nytimes.com/2022/05/02/climate/biden-electric-car-batteries.html#:~:text=The%20%243.1%20billion%20in%20grants,a%20Department%20of%20Energy%20statement.

[79] https://www.consilium.europa.eu/en/press/press-releases/2023/07/10/council-adopts-new-regulation-on-batteries-and-waste-batteries/.

[80] https://www.ul.com/news/ul-issues-worlds-first-certification-repurposed-ev-batteries-4r-energy.

[81] https://www.consilium.europa.eu/en/press/press-releases/2023/07/10/council-adopts-new-regulation-on-batteries-and-waste-batteries/.

[82] https://www.gov.uk/government/publications/uk-critical-mineral-strategy/resilience-for-the-future-the-uks-critical-minerals-strategy#:~:text=This%20strategy%20aims%20%E2%80%93%20where%20possible,manufacturing%20sectors%20and%20national%20security.

Governments are also providing **access to funds to support new recycling facilities**. For instance, the EU awarded nearly €70 million to develop the first closed-loop Li-ion battery recycling unit (ReLieve) in Europe.[83] The US government provided a US$2 billion conditional loan to a business unit to ramp up its recycling facility to an annual capacity of 100 GWh.[84] South Korea, Japan and China are also making significant strides toward industrial mineral recycling. Notably, China has a competitive advantage in recycling capability, as recyclers have greater integration with nearby cathode production plants.

The industry is also in line with the recycling trend through increasing investments in innovation as well as **R&D** to increase recycling efficiency and partnering with the players.

Government and industry initiatives could support additional input of secondary materials to demand.

Nevertheless, the IEA predicts that by 2040, recycled quantities of copper, lithium, nickel and cobalt from spent batteries could reduce combined primary supply requirement for these minerals by about 10%.[85] Thus, recycling more critical minerals is important, but it is not going to eliminate the need for a new primary supply of metals as demand booms during energy transition. Recycling can drive sustainability, but it is not a silver bullet. We will need new mines in combination with improved recycling facilities.

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[83] https://www.eramet.com/en/eramet-obtains-european-grant-its-relieve-battery-recycling-project#:~:text=Nearly%2070%20million%20euros%3A%20this,electric%20vehicle%20battery%20recycling%20project.&text=Eramet%20set%20itself%20a%20challenge,battery%20recycling%20unit%20in%20Europe.

[84] https://www.redwoodmaterials.com/news/redwood-department-of-energy-loan/.

[85] https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/executive-summary.

Could innovation reduce CRM concentrations in clean energy technologies?

As part of the R&D blueprint, there could also be consideration of focus on funding resource efficiency and substitution of critical minerals.

Copper

For copper, the most common solution is its substitution with aluminum, especially for overhead electricity transmission lines, where the lighter metal offers significant efficiencies. This metal is the most abundant metal in the Earth's crust (a thousand times more so than copper), and it is also cheaper and easier to extract. However, aluminum has around 60% of the conductivity of copper, meaning its wires need to be 25% thicker and better insulated to fulfill the same role as the alternative.[86] Thus, the aluminum in this equivalent wire will cost and weight about half as much.

In EV motors, copper could also be replaced by aluminum as well. In this case, efficiency would fall by approximately 1%, but the motor would be lighter.[87]

Wind turbines are the number one copper problem (7-8 tonnes of material per MW[88,89]). However, substitution with aluminum in wind turbine windings is already a mature option. There are multiple advantages and disadvantages to both metals. For instance, aluminum windings have greater heat storage (2.3 times greater heat per pound when compared with copper windings), stronger corrosion resistance, less mechanical stress and more stable prices, but they require additional material and maintenance and have greater electrical connection difficulties.[90] Subsea interest in aluminum usage has been expressed by some market players. Two Norwegian companies are partnering to develop floating wind turbines involving sustainable and recyclable materials in their construction (including aluminum).[91]

Copper and aluminum may be imperfect substitutes in some respect, but they can generally be considered complementary.[92] However, it is worth remembering that aluminum requires mining and its production process is highly electro-intensive, requiring around 14 MWh per tonne of metal, about seven times more than copper smelting. The carbon footprint of primary aluminum varies depending on electricity sources. According to CRU, the global average CO_2 footprint (scope 1, 2, 3) for copper production was 4 tCO_2eq. per tonne of metal in 2020, while for aluminum it was 13 tCO_2eq.[93]

Considering the weight difference (aluminum is 30% lighter than copper[94]), substituting copper with aluminum carries no increase in carbon dioxide emissions.

Deciding to substitute a product from one material to another is not an easy choice, especially in complex supply chains. With high price ratios likely to persist, more companies are examining whether it is the time to make the switch.

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[86] https://www.shapesbyhydro.com/en/material-properties/how-we-can-substitute-aluminium-for-copper-in-the-green-transition/#:~:text=Many%20scientific%20publications%20claim%20that.

[87] https://www.shapesbyhydro.com/en/material-properties/how-we-can-substitute-aluminium-for-copper-in-the-green-transition/#:~:text=Many%20scientific%20publications%20claim%20that,aluminium%20in%20almost%20all%20applications.

[88] https://www.woodmac.com/press-releases/global-wind-turbine-fleet-to-consume-over-5.5mt-of-copper-by-2028/.

[89] https://iea.blob.core.windows.net/assets/ffd2a83b-8c30-4e9d-980a-52b6d9a86fdc/TheRoleofCriticalMineralsinCleanEnergyTransitions.pdf.

[90] https://sncmfg.com/aluminum-vs-copper-wire-windings-in-transformers/.

[91] https://www.offshore-mag.com/renewable-energy/article/14287948/world-wide-wind-hydro-to-use-aluminum-in-offshore-floating-wind-turbines.

[92] https://www.researchgate.net/profile/Marek-Vochozka/publication/363731730_Copper_and_Aluminium_as_Economically_Imperfect_Substitutes_Production_and_Price_Development/links/63dfde3e62d2a24f9202b692/Copper-and-Aluminium-as-Economically-Imperfect-Substitutes-Production-and-Price-Development.pdf.

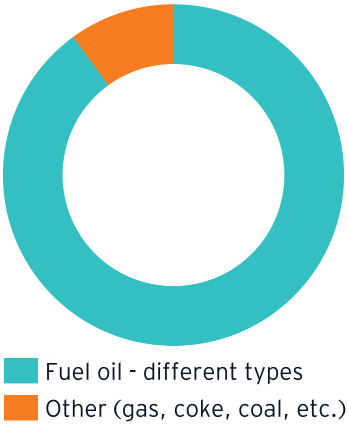
[93] https://www.crugroup.com/knowledge-and-insights/insights/2021/cru-explains-copper-aluminium-smelting-emissions/.

[94] https://www.wilsonpowersolutions.co.uk/app/uploads/WPS_Aluminium-v-Copper_white-paper_-2021.pdf.

Average global CO_2 footprint: copper vs. aluminum

COPPER

Scope 1 by fuel type



Scope 2

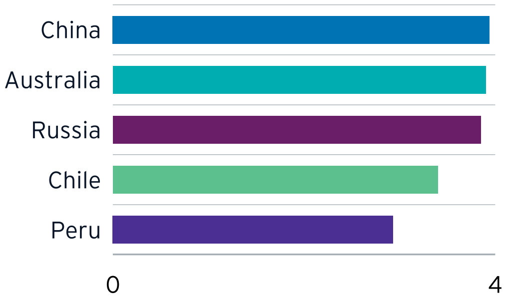
- Smelter
- Oxygen plant
- Acid plant

Average ~2 MWh per tonne of the metal

Scope 3

Copper concentrate emissions

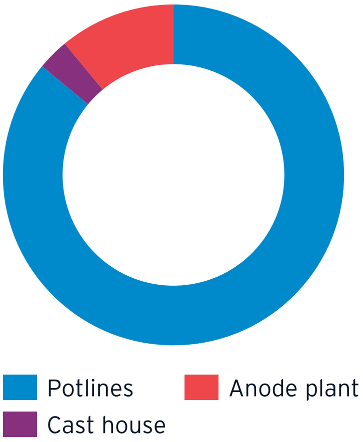
Top 5 producing countries, t CO_2eq/t Cu (2020)



Summary: Global footprint: ~ 4 t CO_2eq/t Cu

ALUMINUM

Scope 1 by fuel type



Scope 2

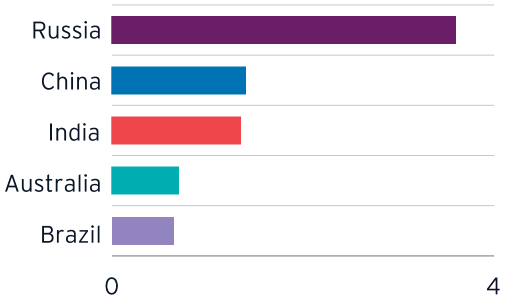
- Potlines
- Cast house
- Anode plant

Average ~14 MWh per tonne of the metal

Scope 3

Alumina emissions

Top 5 producing countries, t CO_2eq/t Al (2020)



Summary: Global footprint: ~ 13 t CO_2eq/t Al

Substitution: for 1 tonne of Cu use ~0.5 tonnes of Al_1

Source: CRU.

Battery minerals

Recent technologies with advanced chemical compositions could support battery manufacturers in ensuring the long-term supply of metals.

In 2022, NMC remained the dominant battery chemistry (60%), followed by LFP (30%) and NCA (10%).[95] While nickel-based batteries remain the dominant battery chemistry, there has been a resurgence in LFP battery chemistry over the last few years, mostly driven by the increasing uptake of LFP in EVs in China. At the global level, nickel-based batteries will probably maintain a majority share during this decade.

Nickel and cobalt cathode demand from EVs fell sharply from 93% in 2020 to around 68% in 2022. Nickel content delivers higher energy density and a longer driving range, while cobalt ensures the stability and longevity of the cell. Despite the reduction in the share, nickel-based batteries will continue to evolve. They remain the choice for manufacturers operating in markets with high expectation of performance and driving range.[96]

However, OEMs are also interested in nickel and cobalt use diversification by means of other minerals because of their excessive cost, scarcity and sustainability issues. Scope 1 and 2 emissions from mining and processing (primary production) are estimated at 10 kg CO_2 per kg of Class 1 nickel (sulfide) and at almost 17 kg CO_2 per kg of cobalt sulfate. On the other side, emissions for lithium carbonate are five kg CO_2,[97] but they differ depending on the method of extraction.

Pros and cons of alternatives to Li-ion batteries

Sodium-ion batteries	+ Cheaper and abundant + Compatible with current charging infrastructure + Redox potential similar to Li − Weight- 3X heavier − Low energy density − Still in early research and development phase
Magnesium-ion batteries	+ More stable, can be used as anode + Abundant + Redox potential allows high battery cell voltage + Metallic Mg anodes form a passivated layer of insoluble salts + Slow kinetics and volume expansions
Zinc-ion batteries	+ Relatively easy dissolution & deposition + Zn anode more stable than Mg + Safer than lead-acid + Low redox potential + Anodes suffer from dendrite formation + Electrolyte corrosion might damage the cell
Aluminum-ion batteries	+ Low cost and high abundance + A potential high charge storing capacity + Environmental friendly + Lower voltage production than Li-ion + Early stage of R&D + Works at high temperature
Metal-sulphur batteries	+ Potential of achieving high theoretical capacity and energy density + Sulphur is cheap and abundant source + Capacity fading due to sulphide dissolution & polysulphide shutting + Early stage lab testing; not a proven technology

Source: EY analysis of publicly available information.

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[95] https://www.iea.org/reports/global-ev-outlook-2023/trends-in-batteries.

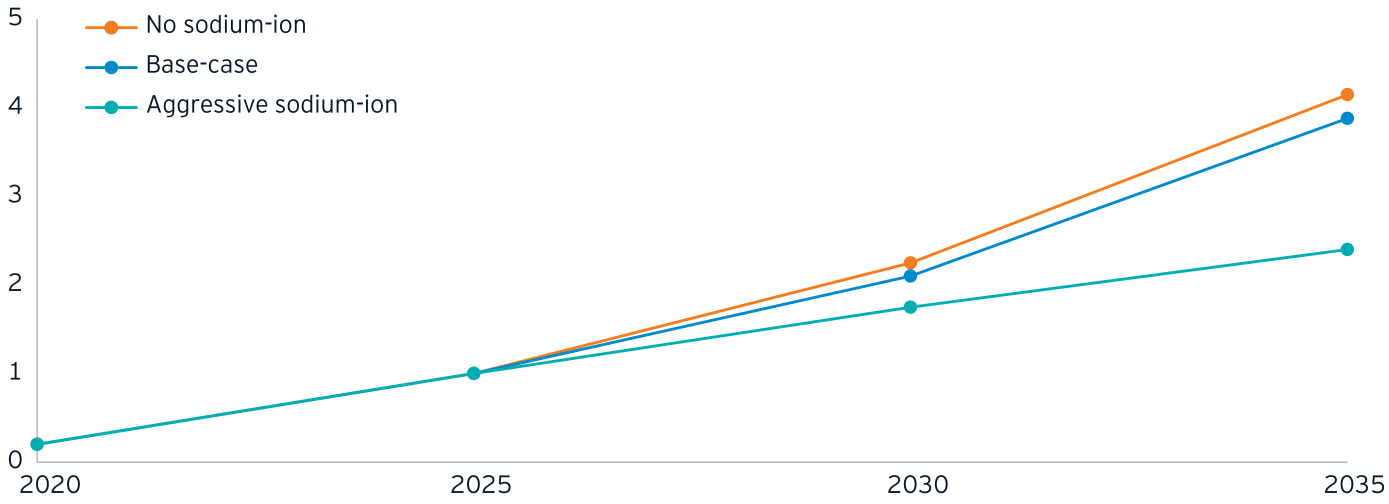
[96] https://www.crugroup.com/knowledge-and-insights/insights/2023/navigating-the-rapidly-evolving-ev-battery-chemistry-mix/#:~:text=Nickel%20and%20cobalt%20containing%20cathodes,for%20performance%20and%20driving%20range.

[97] https://www.iea.org/data-and-statistics/charts/average-ghg-emissions-intensity-for-production-of-selected-commodities.

New cobalt-free chemistry is under development, such as lithium manganese iron phosphate (LMFP) and lithium nickel manganese oxide (LNMO), which should become more commonplace from 2025 onward. The LMFP, coming to the market in 2023, contains an excellent stabilizer – manganese (Mn) – at low cost. Its addition, together with higher operating voltage, translates to up to 25% increase in energy density.[98] LNMO batteries have a higher nominal operating voltage, offer rapid charging, and could further disrupt the market. They require 55% less nickel, 40% less lithium and no cobalt. Theoretically, the latest technology offers the best of both NMC (high energy density) and LFP (cheap raw materials).[99] Lithium-manganese-rich (LMR) batteries are also within the high-manganese category, but their path to production is still unclear, although they have the potential to make a presence in the European battery supply chain.

There are also other emerging battery alternatives, including sodium-ion (Na-ion) battery, which completely preclude the need for critical minerals and use one of the most abundant and widespread resources on Earth. Currently, there are 30 Na-ion battery manufacturing plants operating, planned or under construction for a combined capacity of over 100 GWh (vs. around 1,500 GWh of current manufacturing capacity of Li-ion batteries), and almost all of them are in China. Notably, the estimated cost of the latest Na-ion battery developed by China is 30% less than an LFP battery.[100]

Impact of sodium-ion battery uptake scenarios on lithium demand (million tonnes)



Source: BloombergNEF, EY CESA Energy Center.

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[98] https://pushevs.com/2020/12/11/vspc-develops-cobalt-free-lfmp-battery-cell/.

[99] https://www.crugroup.com/knowledge-and-insights/insights/2023/navigating-the-rapidly-evolving-ev-battery-chemistry-mix/#:~:text=Nickel%20and%20cobalt%20containing%20cathodes,for%20performance%20and%20driving%20range.

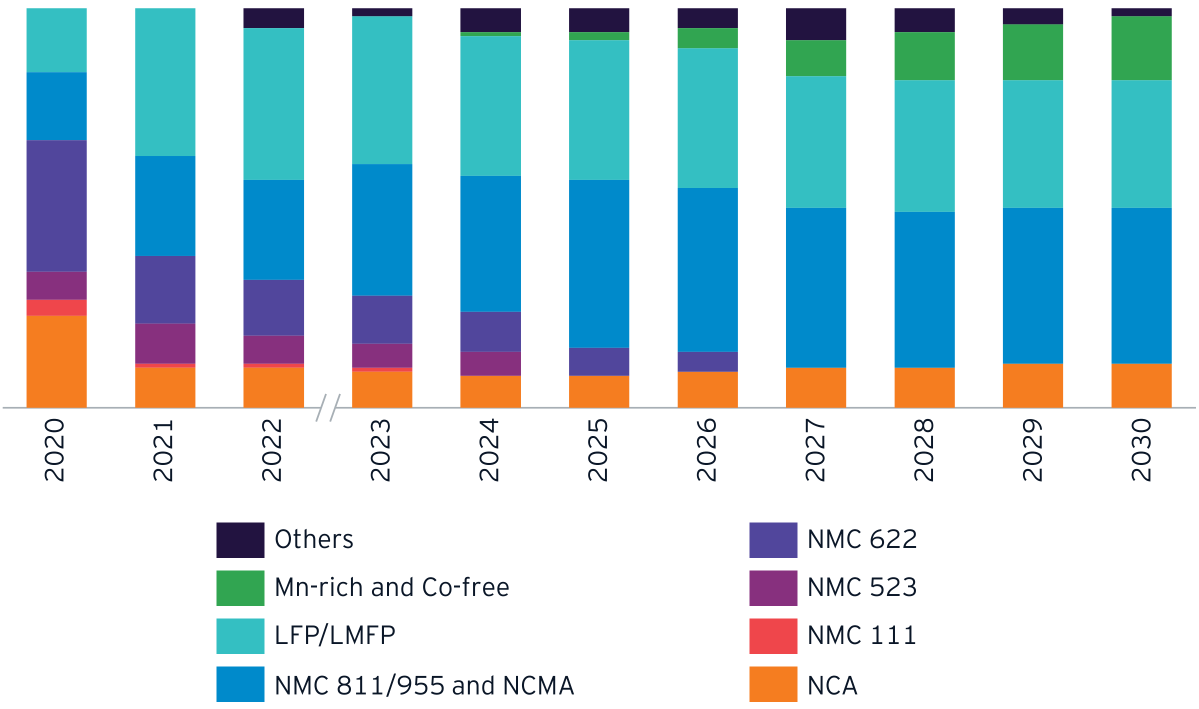
[100] https://www.ing.com/Newsroom/News/Tightening-supply-shakes-up-battery-metal-dynamics.htm#:~:text=Na%2Dion%20batteries%20also%20completely,less%20than%20an%20LFP%20battery.

BloombergNEF (BNEF) considers a base case scenario in which sodium-ion cells displace lithium demand by 7% by 2035, compared with a no sodium-ion scenario.[101] If protracted lithium shortages emerge, the switch could be much more aggressive. In an extreme scenario, substitution for sodium in the mass car market could reduce overall lithium demand by 37% by 2035.[102] BNEF anticipates sodium-ion deployment in cars will begin to take off in 2025, with over 15GWh set for deployment that year.

BNEF expects that sodium-ion's energy density in 2025 will be comparable with that of lithium ferro-phosphate in the early 2020s when it took a significant share of global battery demand. However, such an option has a lower yield than conventional lithium-ion technologies.[103] The IEA assumes that Na-ion's density is between 75 Wh/kg and 160 Wh/kg compared with 120 Wh/kg to 260 Wh/kg for Li-ion.[104]

Bottlenecks and supply chain challenges in raw material markets are driving further changes in battery chemistries, and the raw materials they need. However, technology changes and substitution are the key uncertainties for battery metals. Thus, we need to be careful to avoid unrealistically bullish forecasts.

Cathode chemistry mix forecasts for EV batteries



Source: IEA.

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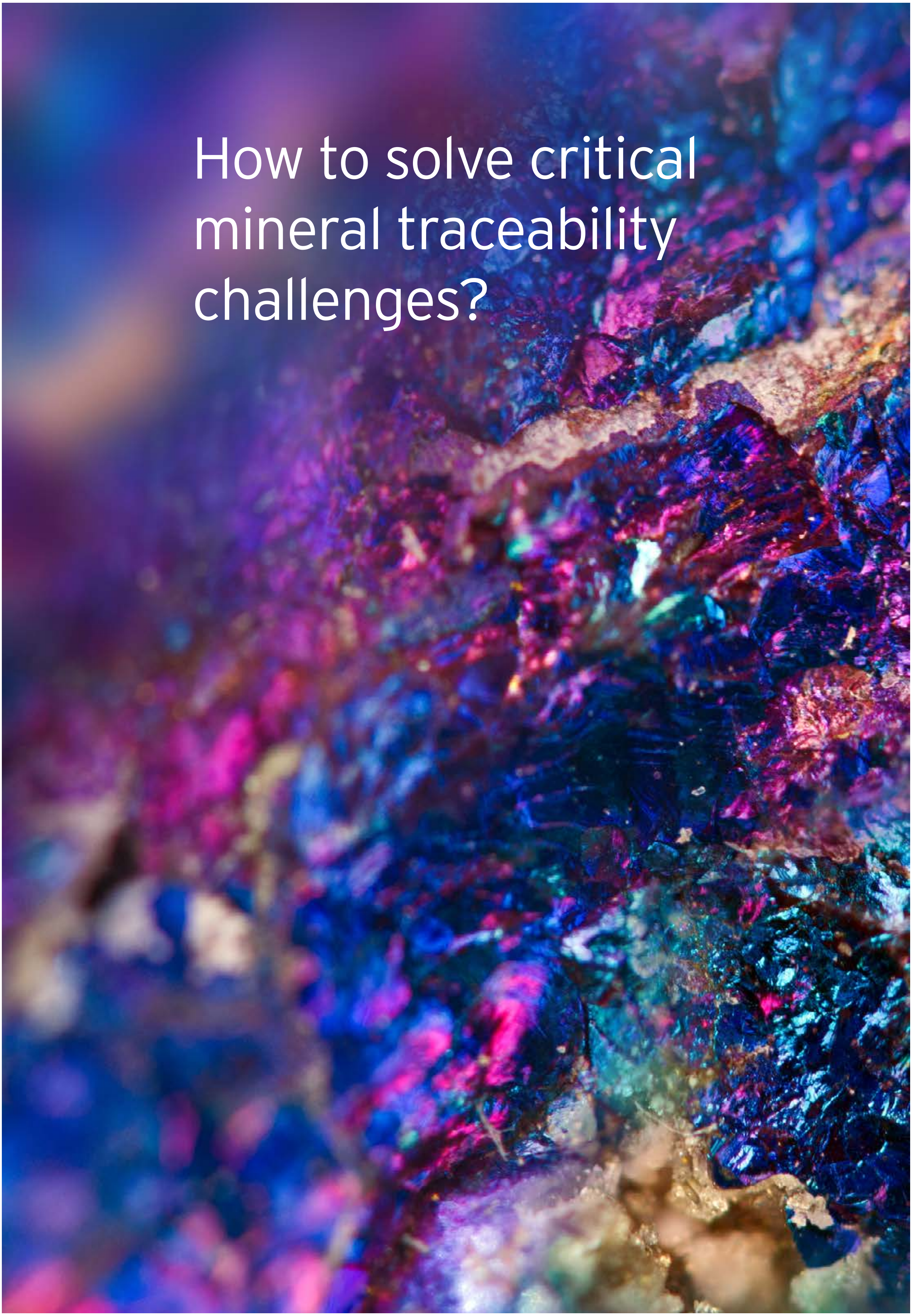
[101] https://assets.bbhub.io/professional/sites/24/2431510_BNEFElectricVehicleOutlook2023_ExecSummary.pdf.

[102] https://www.bloomberg.com/news/articles/2023-06-08/lithium-shortages-could-hand-salt-a-starring-role-in-ev-shift.

[103] https://english.elpais.com/economy-and-business/2023-03-08/global-demand-for-batteries-is-depleting-the-supply-of-raw-materials.html.

[104] https://www.iea.org/reports/global-ev-outlook-2023/trends-in-batteries.



How to solve critical mineral traceability challenges?

The lack of an industry certification standard makes it difficult to compare performance from one mine to another. Moreover, some companies may illegally mine the minerals and sell them into the supply chain without any trail.

Environmental Product Declaration (EPD) is a major step in providing evidence-based sustainability information related to critical minerals. It supports customers in their decision to select sustainable materials that meet certain criteria.

EPD provides objective, comparable, and third-party verified data on the environmental performance of its products throughout their lifecycle. A list of metrics to incorporate into EPD includes GWP (climate-related) and other significant environmental impacts such as PM, SOx, NOx, VOC, PCB, solid waste, water and wastewater and H2S.

By issuing an EPD in line with international standards (ISO 14025:2006 for labeling, ISO 14040 and ISO 14044 for assessment principles) sectoral companies are demonstrating their commitment to sustainability and providing customers with credible and transparent information about their portfolios' environmental performance. EPDs also allow companies to identify environmental hotspots in the lifecycles of their products, help them to take optimum resource decisions and demonstrate the sustainability of products. Therefore, companies often use EPDs for commercial purposes.

Notably, product manufacturers normally provide EPDs, which an independent expert must verify. An EPD normally has a validity of five years.

With **digital instruments** (blockchain and tokens), importers no longer need to ask their suppliers, who must in turn ask their own suppliers, for paper documentation of the origin of critical minerals. The paper process is labor intensive, time consuming, and sometimes not sufficient to satisfy import requirements.

In July 2021, the Australian government awarded AU$3 million (US$2.2 million) under the Blockchain Pilot Grants program to create a "digital certification" for critical minerals throughout the supply chain[105] – from extraction to processing to export to global markets. Similarly, one of Canada's leading diversified mining companies, together with the developer of innovative enterprise solutions, announced a pilot to use blockchain technology to trace responsibly produced germanium from the mine to the customer in 2022. Blockchain technology will embed data, including information on responsible ESG practices along the supply chain, such as greenhouse gas emissions, product certifications and responsible production assessments.[106]

An EU Horizon-funded case – the MaDiTraCe project – aims to develop and evaluate digital, geochemical and artificial fingerprinting approaches for CRM traceability and integrate them with a generic certification scheme. It will enhance the reliable supply of these CRMs and support compliance with current and future regulations.[107]

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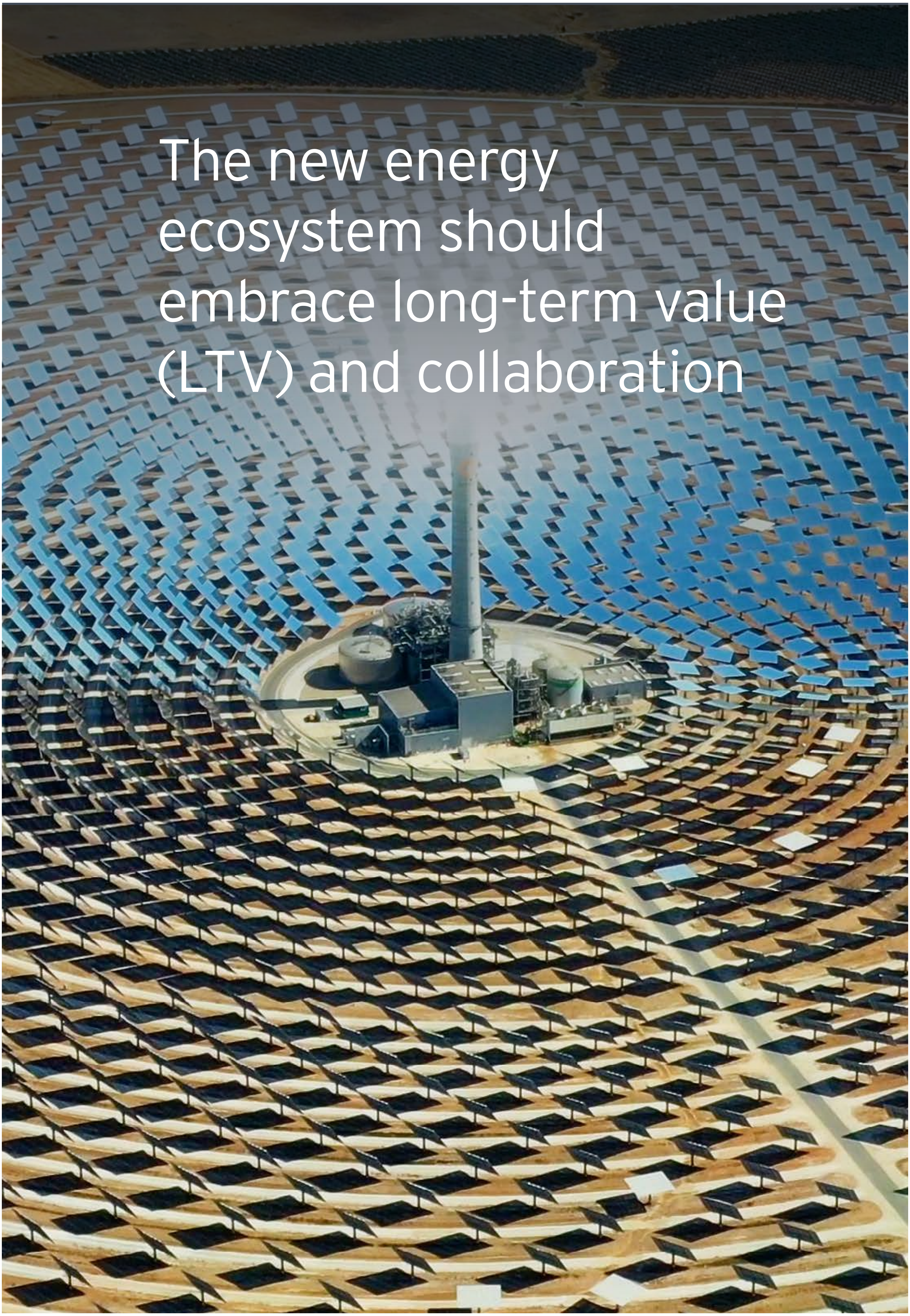
[105] https://siliconangle.com/2021/07/13/australian-government-awards-4-2m-blockchain-pilot-programs/.

[106] https://www.teck.com/news/news-releases/2022/teck-and-dlt-partner-to-pilot-traceability-for-critical-minerals-with-blockchain.

[107] https://www.maditrace.eu/.

The new energy ecosystem should embrace long-term value (LTV) and collaboration



A coordinated, successful strategy to build more diverse and resilient critical mineral supply chains would need to take a comprehensive view of where the most pressing needs are today, where demand is heading, and include technological solutions to make the supply chain more resilient, efficient and cost-effective. Such a strategy would require the public and private sectors in the form of "business-investor-government" to work together on new investments, innovative approaches to regulation and new forms of international cooperation.

Among the most visible areas of cooperation, it is worth highlighting:

- Green electricity demand coverage – green power purchase agreements (PPAs) and dedicated renewable energy portfolio) to support supply decarbonization
- Closing loop related partnerships to develop business models for secondary material collection and continuous delivery
- Logistics innovations and "just in time" concept introduction
- Materials passport position standardization (e.g., Re-Source platform[108])

Through the sharing of risks, each side receives its own benefits and further long-term value.

Companies benefit from carbon bill reductions, portfolio diversification, access to external financing, the ability to market low-carbon feedstocks and additional revenue. For instance, so-called green premiums could support the suppliers of verified low and zero-carbon critical minerals, which are dependent on the transition scenario and market tightness. The pricing agencies have already launched the tracking of premiums to the LME cash-settlement price for aluminum. The Platts low-carbon aluminum price (LCAP) applies to primary metal with a maximum emission of 4 tonnes of CO_2 per tonne of aluminum at the smelter. It only includes aluminum in this assessment which has had its smelter Scope 1 and 2 emissions certified by an internationally accepted, independent organization.[109] The Platts ZCAP for primary aluminum leverages Platts existing CORSIA-eligible carbon-credit price assessments (Platts CEC) to calculate the voluntary cost of offsetting the carbon emissions of the LCAP assessment to zero. In summer 2023, the level of these premiums ranged between 11% and 13% of the LME price. However, ultralow and zero-carbon aluminum requires technology changes and thus could be undersupplied by 2030, reaching significantly higher premiums.

Investors have a first mover advantage, as well as reputations as sustainable and responsible investors with a high ESG rating.

Governments that have created incentives for technology development receive additional jobs and economic diversification as a return in addition to environmental benefits in the form of reduced emissions.

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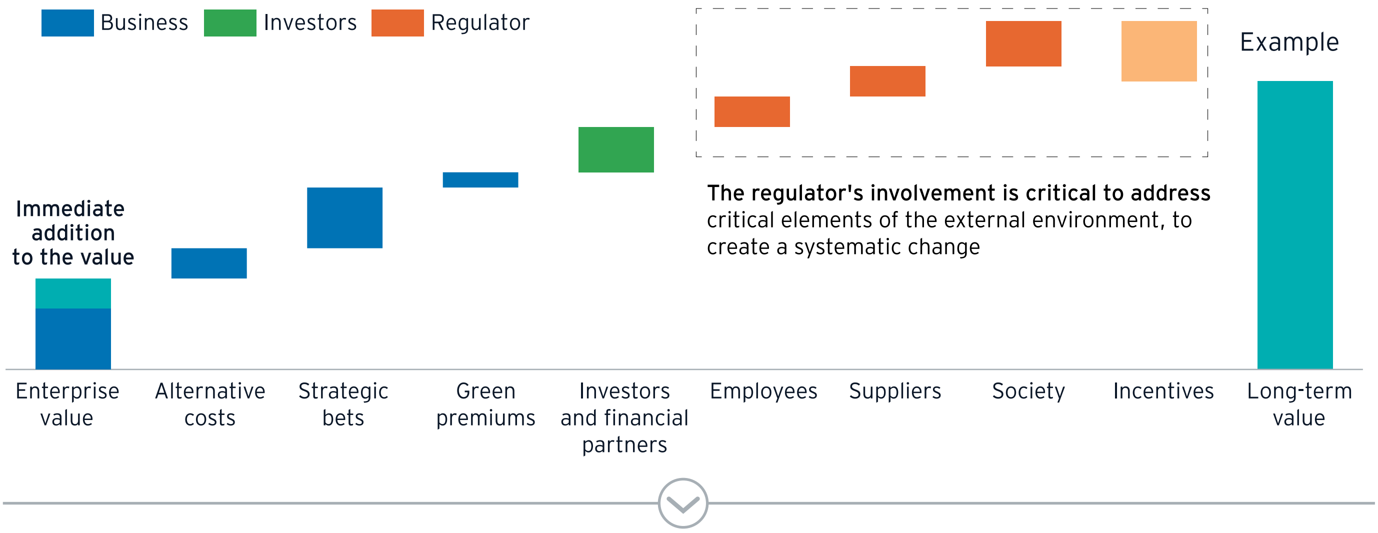
[108] https://re-source.tech/.

[109] https://www.spglobal.com/commodityinsights/en/our-methodology/price-assessments/metals/low-carbon-and-zero-carbon-aluminum.

Enterprise value and LTV relationship (illustrative)



The regulator's involvement is critical to address critical elements of the external environment, to create a systematic change

- Avoidance of CO_2 penalties
- Cost reduction in RES, CCUS and electrolyzers, H_2
- Additional revenue
- First mover advantage
- Reputational benefit, ESG improvement
- New and better educated jobs
- Technology development
- Value chain impact
- CO_2 emission reduction
- Waste reduction
- Higher living standards
- Nonfinancial incentives
- Investments in R&D and infrastructure
- Demand incentives: transport, metallurgy, etc.

Faster maturity and structural cost reduction due to economies of scale, experience curve and ESG perception

Source: EY.

Moreover, the competition for critical minerals is creating new avenues for **global cooperation**. As the US and the UK do not have a free trade agreement,[110] UK companies are currently ineligible for Inflation Reduction Act credits.[111] However, the US-UK Atlantic Declaration launched negotiations on a critical mineral agreement, which would allow UK-sourced components to become eligible for credits.[112] Similar negotiations have been conducted between the US and the EU.[113] Japan signed a critical minerals agreement with the US in March 2023.[114] Together, these nations are exploring the opportunity of creating a "buyers' club" to reduce their reliance on abroad supplies.[115] In addition, the Mineral Security Partnership (Australia, Canada, Finland, France, Germany, Japan, the Republic of Korea, Sweden, the UK, the US, the EU, Italy and India)[116] has planned 15 potential projects for development across several regions.[117]

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[110] https://crsreports.congress.gov/product/pdf/IF/IF11123.

[111] https://www.whitehouse.gov/wp-content/uploads/2022/12/Inflation-Reduction-Act-Guidebook.pdf.

[112] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1161879/THE_ATLANTIC_DECLARATION.pdf.

[113] https://ec.europa.eu/commission/presscorner/detail/en/IP_23_3214.

[114] https://ustr.gov/about-us/policy-offices/press-office/press-releases/2023/march/united-states-and-japan-sign-critical-minerals-agreement.

[115] https://www.wsj.com/articles/u-s-and-eu-advance-buyers-club-for-ev-battery-minerals-5288287e#:~:text=Under%20the%20plan%20to%20form,to%20people%20familiar%20with%20it.

[116] https://www.downtoearth.org.in/news/energy/minerals-security-partnership-india-joins-the-critical-minerals-club-here-s-why-this-is-important-90278.

[117] https://www.reuters.com/markets/commodities/us-uk-partners-working-15-critical-minerals-projects-2023-10-05/.


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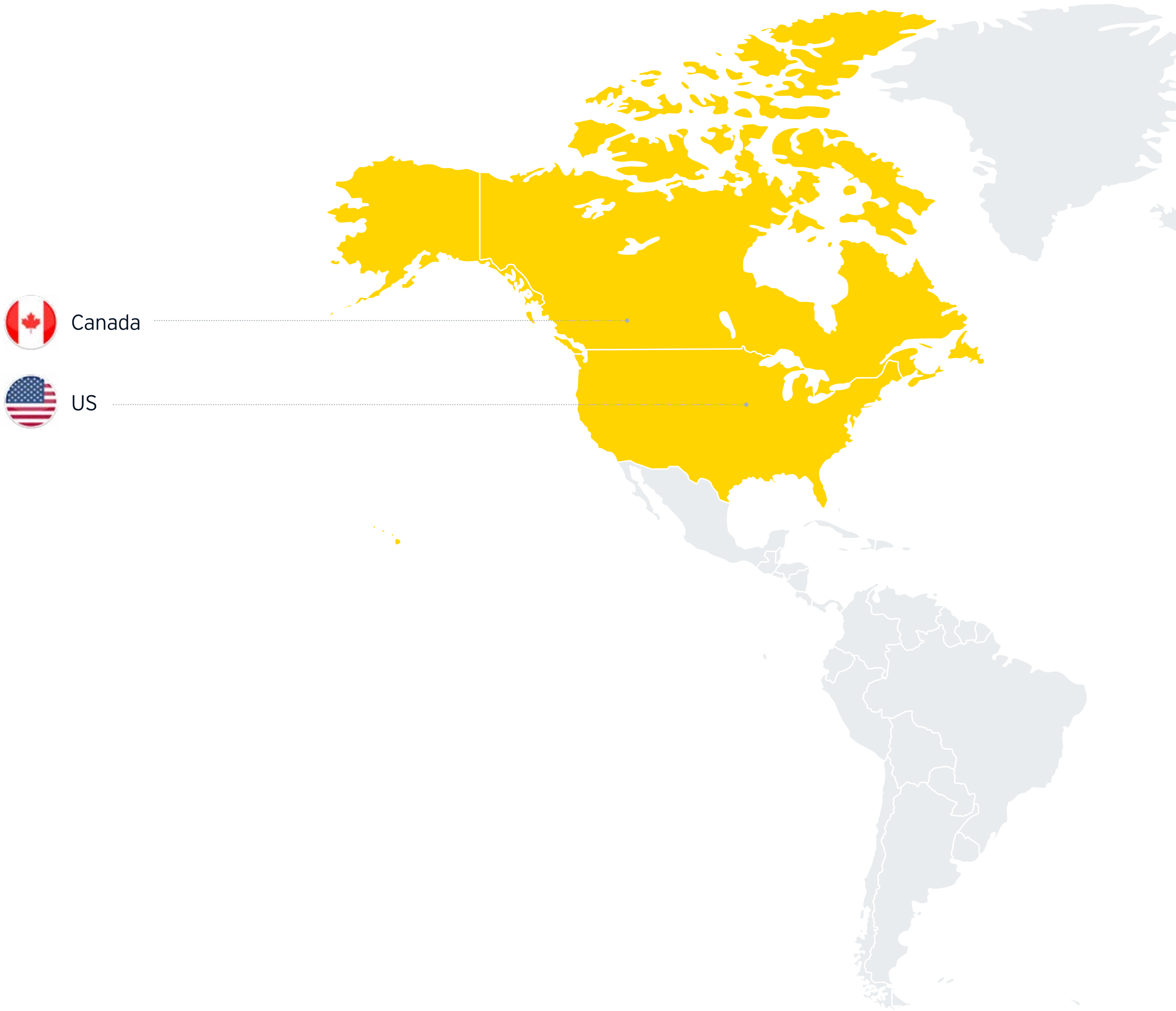
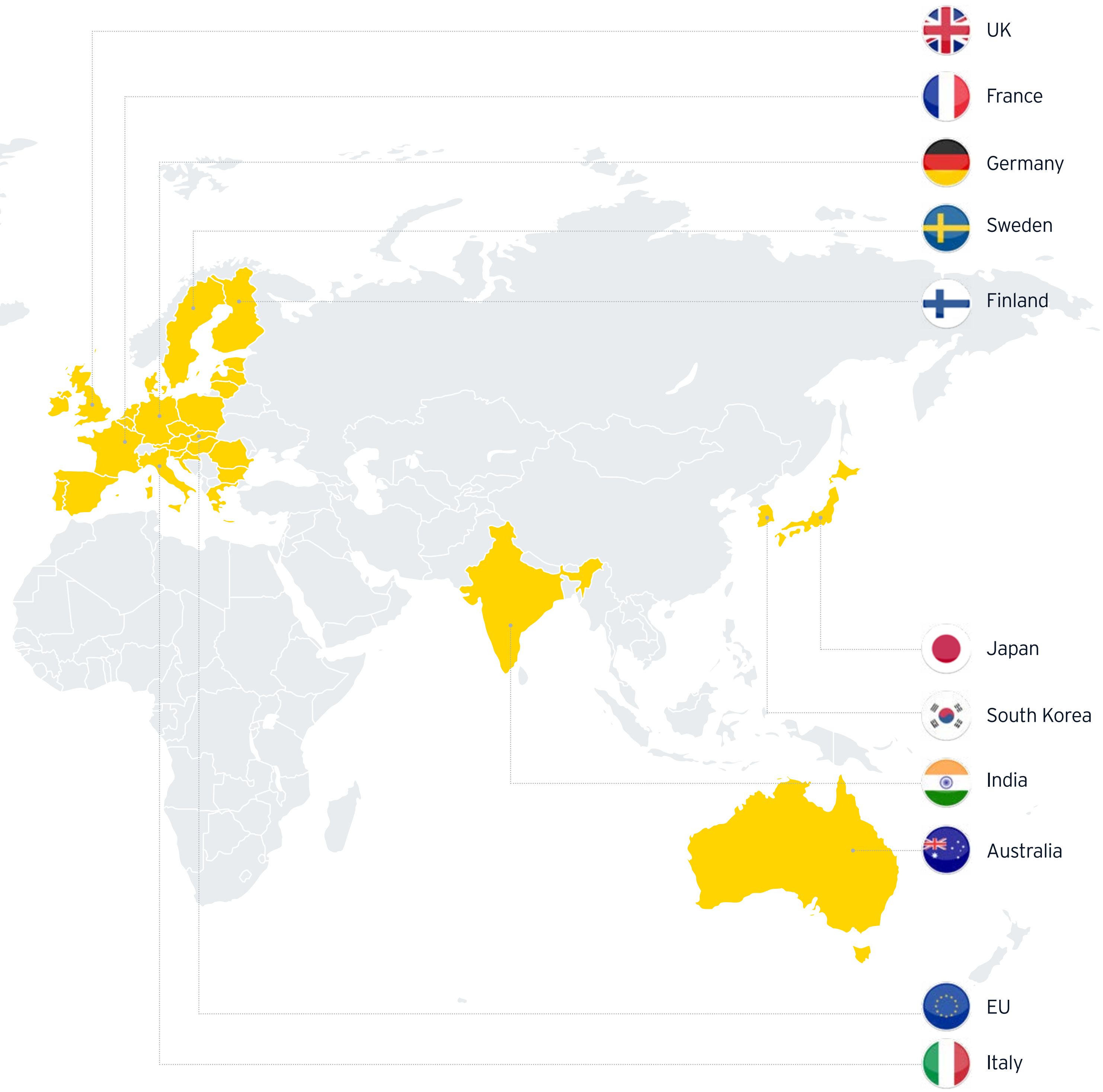
Mineral security partnership members



Source: US Department of State.


UK
France
Germany
Sweden
Finland
Japan
South Korea
India
Australia
EU
Italy

What are the implications for doing business in Central, Eastern and Southeastern Europe and Central Asia?

Central, Eastern and Southeastern Europe and Central Asia (CESA) is a diversified macroregion with businesses across the entire value chain of critical minerals.

Central Asia is home to a wide range of critical raw materials and served as the main source of metals for the Soviet Union. The region holds 39% of global manganese ore reserves, 30% of chromium, 20% of lead, 13% of zinc, 9% of titanium, as well as significant reserves of other critical materials.[118] Central Asian countries are already among the top 20 global producers of critical materials.

Kazakhstan, which alone is comparable in size to Western Europe, has one of the world's richest and most diverse mineral resource bases with almost all the periodic table's elements (99 from 118[119]). It is playing a significant role in mining industry, being the largest uranium producer, the second producer of chromium and the 10th largest copper supplier with a 4% share of global output.[120] The nation can generate about half of up to 30 critical materials that the EU identifies as critical (including nickel[121], cobalt[122], lithium[123], tungsten[124] and rare earth elements[125]).[126]

Metallurgy is one of the largest domestic industries in Uzbekistan, and the most mined minerals are copper, gold, silver and uranium. In terms of copper, the country has the world's eleventh-largest copper reserves.[127] However, only 40% of the country's territory is subject to geological study,[128] and there is wider potential. To increase the level of awareness, the government developed long-term programs and regulations to conduct geological research in recent years. In 2023, Uzbekistan announced the preparation for mining and processing launch within the large lithium mine.[129]

Azerbaijan, Kyrgyzstan, Turkmenistan and Georgia have been little investigated and could be attractive for exploration and production purposes. Reassessment of the potential in these countries seems to be reasonable.

There are also discussions on going deeper in Central Asia – from mining to value-added products.

In **Central, Eastern and Southeastern Europe** (CESEE), the concentration of CRMs is lower than that globally. However, there are countries which could be valuable for the EU in terms of security supply of specific minerals. The Czech Republic is estimated to have about 3% of the world's lithium resources, with the vast majority located close to the German border (Cinovec).[130] When developed, Cinovec is expected to produce 21,000 tonnes of lithium carbonate per annum plus 1,000 tpa of cassiterite (tin).[131] Serbia's lithium accounts for only 1.3% of the world total.[132] However, the government has revoked licenses for the lithium project, which could supply 90% of Europe's current lithium needs.[133] Roughly 45% of EU nickel production is provided by Greece and 2% by Poland.[134] In the Balkans and Turkey, cobalt grades and tonnages are known in 27 nickel laterite deposits. Currently, only nickel is recovered from these deposits, but new processing technologies such as high-pressure acid leaching could enable cobalt recovery in the future.[135] Magnesium operational mines exist in Greece, Slovakia and Turkey with 11% of global reserves.[136]

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[118] https://www.nupi.no/en/news/how-central-asia-can-help-the-global-energy-transition.

[119] https://unece.org/fileadmin/DAM/project-monitoring/unda/16_17X/Nat.Baseline.RevReport/Baseline.Review.SED.Kazakhstan.pdf.

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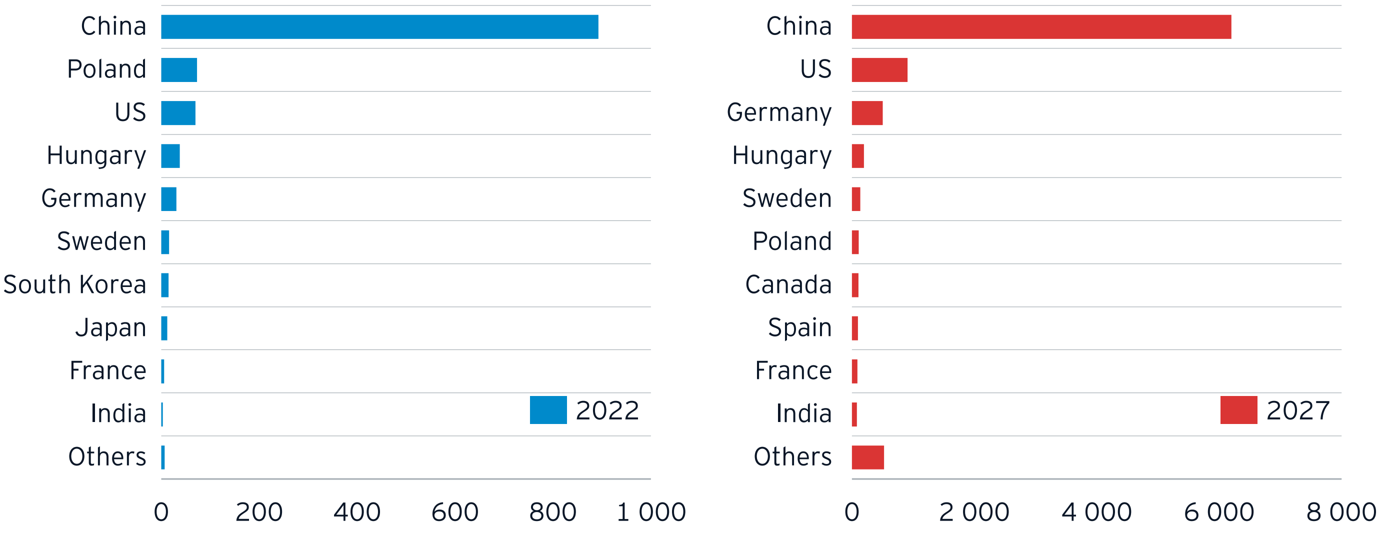
Copper is produced in Poland, Bulgaria, Serbia, Slovakia, Romania and North Macedonia.[137] In Ukraine, 21 out of 30 CRM deposits are concentrated (including lithium, cobalt, scandium, graphite, tantalum, niobium).[138]

There are also plans for midstream projects in the region. For instance, a production plant for battery-grade lithium hydroxide is planned to be built in Romania in collaboration with a Canadian company and with the help of its raw material.[139] It is anticipated that it will produce enough lithium hydroxide annually to produce batteries for 500,000 electric cars.

CESEE nations also promote development of CRMs downstream. After a series of investments in Li-ion battery manufacturing, Poland's capacity increased to 73 GWh in 2022, overtaking the US to become the second largest in the world, behind only China.[140] Poland now has 6% of the world's total production capacity, compared with 14% of all European countries combined. Hungary represents 3% with 38 GWh. New investments are in the works for existing factories in the region. It is expected that later Hungary could surpass Poland as it plans to increase annual battery output to almost 200 GWh by 2027. Poland follows in second, not only expanding its presence in the battery manufacturing sector (by more than 50% during the same period) but also attracting new EV factories.[141] Other countries in the region, such as Serbia with 16 GWh in Subotica, the Czech Republic with 15 GWh in Horni Sucha and Slovakia with 10 GWh in Bratislava, are also set to make their mark in the global battery value chain.

Top 10 countries by projected battery capacity in 2022 and 2027



Source: BloombergNEF.

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It is fair to assume that Central Europe is looking to replicate the model that made it a major force in the production of gasoline and diesel cars. The region is relied on for its cheap but skilled labor and close ties to car making hubs including Germany to build up huge car industries. Moreover, Poland hosts European OEMs' factories as well as making trucks, buses and a vast number of subassemblies and components. Slovakia is the world's largest per capita car producer, while the industry is also crucial to the economies of Hungary and the Czech Republic.

These manufacturers could face the needs of battery recycling in line with the European regulations. There are already recycling initiatives in terms of battery waste production in Poland and Hungary, which plan to expand their gigafactories, as mentioned above. In Hungary, South Korean company set up battery processing plants in Batonyterenye and Szigetszentmiklós.[142] In mid-2022, an opening ceremony of the new battery recycling plant in Legnica in Poland.[143] The nation also plans to launch the recycling facility in Zawiercie this year with the support of EBRD.[144,145] There are expectations of another facility in Bukowice.[146]

The previous stages of the supply chain (upstream, midstream and downstream) will need to be compliant with sustainability regulations as well. Notably, Central Asian companies will also need to be in line with the European regulation if they plan to enter its critical raw minerals market as suppliers.

Moreover, we are already observing growing cooperation between Kazakhstan and the EU. In May, they announced a set of concrete actions to implement a Memorandum of Understanding between the bloc and the nation on a strategic partnership in the field of raw materials. They agreed and endorsed an Operational Partnership Roadmap for the upcoming period 2023-24. It reflects current needs such as the modernization and decarbonization of the Kazakh mining industry and includes technology transfers and supports the development of renewable energy.[147] German companies expressed interest in further collaboration with Kazakhstan on renewable energy projects and announced their readiness to implement projects in the exploration, extraction and processing of critical minerals.[148] Kazakhstan is also expanding cooperation with the UK. The UK-based companies are operating today in the mining and metallurgy sector of Kazakhstan (including vanadium, rare earth elements, rhenium and others).[149]

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142 https://www.hepaoffice.gr/en/sungeel-hitech-is-opening-a-new-global-green-battery-recycling-plant-in-batonyterenye/.

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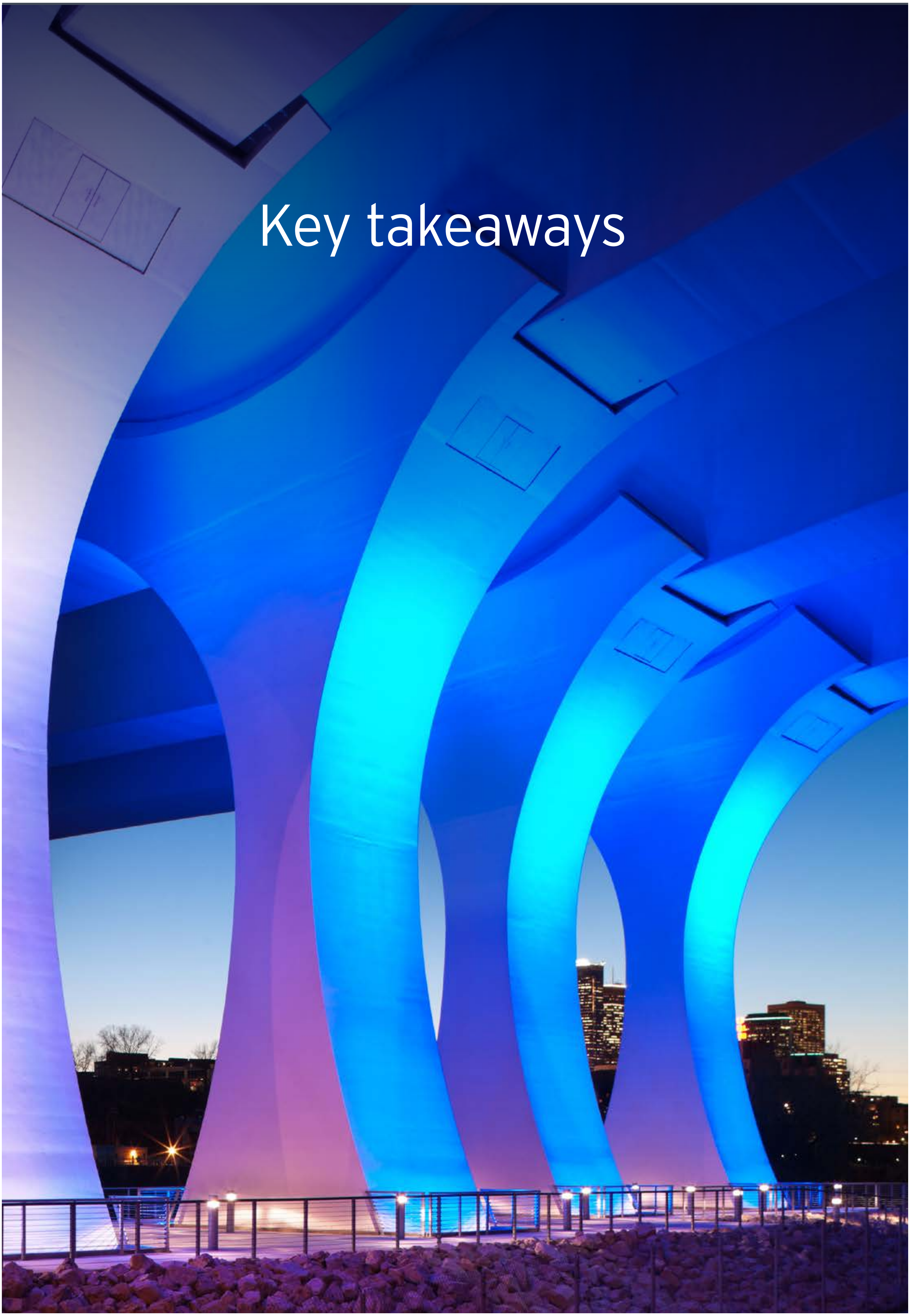
Key takeaways



In summary, despite existing capabilities from mining to recycling, the CRM supply chain remains fragile.

Primary production is geographically concentrated and to become players in global and regional markets, countries with mining potential will need to re-evaluate their CRM resources and intensify exploration. However, the process both time and financially intensive.

The license to operate (LTO) application process can be lengthy and complicated in most nations. The lead time from discovery to production could be over a decade. Moreover, the quality of ore is reducing, while costs are growing.

As most nations set their carbon emission reduction targets, government and investors have become more diligent in observing ESG. Thus, CRM producers should be more transparent and careful with their sustainability reporting. Moreover, they will need to make significant investments in low-carbon and efficiency processes and equipment to implement fundamental changes to their business processes over the coming decades. Renewable energy in power demand, electric and hydrogen vehicles in transport will support carbon footprint reduction. However, these solutions cannot decarbonize the process completely. Decomposing metal ore using a source of carbon such as coke or coal as a reductant, generates CO_2 as a by-product, and carbon capture technologies could offer a solution here. In lithium production, a disrupting Direct Lithium Extraction (DLE) process could reduce emissions by 50% and cut processing time compared with traditional lithium refining.

Secondary supply (recycling) is not a silver bullet, but it can support the supply-demand balance for specific CRMs. More companies launch or expand electric battery recycling facilities to avoid the mineral deficit and to improve their ESG metrics. More governments, regulators and industry players are collaborating to develop principles, acts and grants to support the growth of metal and electric battery recycling.

Each stage of EV and renewable markets – from upstream to downstream – has its own risks. Miners feel the capital risk associated with funding multiyear exploration and drilling a new mine. Midstream processers face the risk of accessing sufficient material volumes as well as the challenge associated with managing high operational expenses. Cathode active material (CAM) manufacturers must deal with technological obsolescence if product roadmaps deviate with new discoveries and end users are widely dependent on all previous stages.

Moreover, each stage is capital intensive. The IEA estimates lithium, cobalt and nickel production requirements at US$200 billion by 2030 to meet demand.

The development of an alliances will help to share risks, costs and will encourage investment and collaboration. Mining companies can intensify collaboration with their peers and even original equipment manufacturers (OEMs) and end-users to increase production scale. OEMs, car and renewables equipment manufacturers are moving upstream in the supply chain to secure critical battery minerals to accelerate the transition to vehicle electrification and industrial decarbonization. Even oil and gas majors are stepping up efforts to diversify into CRMs, especially lithium.

While vertical integration provides significant synergistic value, a multiplayer alliance model can emulate this benefit and generate additional value for nations and industry actors in its coverage.

To be successful, alliances and individual businesses must solve the following challenges:

1. **Convening public and private sector capital** to encourage investment and overcome structural operating cost disadvantages, in addition to raising private sector capital through external investment
2. **Ensuring an ESG focus** to prove that batteries and renewable facilities are sustainable from mine to wheel
3. **Aligning a technology roadmap** (including digital solutions) as development in technology has material implications throughout the value chain
4. **Increasing R&D** to provide new substitutes, new production techniques, new sources and new extraction methods
5. **Exploring regional mining potential** and alternative conversion technologies to unlock local reserves and ease the strategic deficit
6. **Creating a recycling hub**, driving circularity to enhance sustainability and develop a competitive advantage against higher emissive regions
7. **Forming a talent development strategy** to grow a new generation of professionals
8. **Engendering a strong enabling environment** through policies and incentives to support infrastructure development, covering equipment and raw materials, tax breaks and affordable finance

How can EY teams help you?

EY teams offer solutions to help you navigate geopolitical turmoil and the transition to a decarbonized world. We focus on building and executing successful business strategies, leveraging digital technology to help enable the ESG agenda, combined with integrating and analyzing data to optimize performance.

Our decarbonization services bring together a suite of cross-service line options to assist clients with their low-carbon transformation journey. Areas of focus include strategy, reporting, innovation, markets and workforce. Specific activities include greenhouse gas (GHG) footprint assessment, strategy development and execution, outcome assessment and benefits realization. The complementary EY services in renewables help clients accelerate their transition to renewable energy. Differentiated in the market by our deep industry and technical experience, we combine capabilities that clients need into a highly integrated team, from a defining long-term strategy, providing and operating power generation assets, to helping optimize tax incentives and financing structures.

Together with increasing digitalization, cyber threats are evolving and escalating for mining and metals. EY services help enable the design, implementation, and operation of an agile, resilient cyber operating model. EY teams help to identify high-value areas, providing a proven approach to advance strategic thinking and help optimize functions and processes. EY teams bring together a solution designed to address trust journeys of Energy and Resources (E&R) clients using our Trust by Design framework. This offers a focused approach to redesigning, implementing, and operating a robust cybersecurity operating model. The E&R solution provides the agility and resiliency required by clients and efficiently mitigates ever-increasing cyber risk and compliance.

Recent years have put additional strains on global supply chain structures. EY teams can help you address the traditional coordination challenges of efficiency, cost, accuracy and speed. The broad supply chain risk assessment includes demand and supply risks, operational performance, global trade implications and impacts on customers and the workforce. Digital tools improve miners' ability to address various issues, allowing a move from scheduled to predictive maintenance as well as supporting loss elimination. Digitalization enhances productivity through optimized shipping and scheduling to reduce demurrage. Furthermore, it will help enable this through real time tracking of vessels to determine optimal loading dates and ports, using customer buying behavior analysis to forecast trends in demand and subsequent prices.

The enterprise resource planning (ERP) solutions could improve efficiencies in financial processes and better support your expansion goals. The EY teams have proven experience leading large transformation projects and have already helped create ready-to-market EY Energy Industry Cloud for SAP solutions. The detailed pre-built E&R specific SAP solution, augmented by differentiators, unlocks greater value, reduces disruption and gives metals and mining companies the power to transform for the future. The value-led and people-centered approach is specifically designed for the E&R sector and tailored to the clients' business needs, with a focus on defining a clear roadmap, offering ready-to-go SAP-integrated intelligent solutions, utilizing automation to de-risk and accelerate the move to SAP S/4HANA. The solution draws on our award-winning collaboration with SAP and helps maximize implementation value, reducing the overall cost and risk of the transformation, and limiting business disruption.

EY CESA Energy contacts

Jarosław Wajer

Partner, Energy & Resources
CESA Leader, Poland
jaroslaw.wajer@pl.ey.com

Marek Mikitiuk

Partner, Poland
marek.mikitiuk@pl.ey.com

Blahoslav Nemecek

Partner, Czech Republic and Slovakia
blahoslav.nemecek@cz.ey.com

Alexander Milcev

Partner, Romania
alexander.milcev@ro.ey.com

Cristian Veteanu

Director, Romania
cristian.veteanu@ro.ey.com

Mihai Draghici

Director, Romania
mihai.draghici@ro.ey.com

Victor Kovalenko

Partner, Kazakhstan
victor.kovalenko@kz.ey.com

Kairat Medetbayev

Partner, Kazakhstan
kairat.medetbayev@kz.ey.com

Mykhailo Prykhodko

Partner, Ukraine
mykhailo.prykhodko@ua.ey.com

Attila Sagodi

Partner, Hungary
attila.sagodi@parthenon.ey.com

Olga Beloglazova

CESA Energy Center Leader,
Azerbaijan
olga.v.beloglazova@az.ey.com

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