INTERGOVERNMENTAL FORUM
on Mining, Minerals, Metals and
Sustainable Development

CRITICAL MINERALS: A PRIMER

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Mineral resources are essential components of the things we use in our daily lives. They are key inputs in agricultural and industrial production and are core to the functioning of modern technologies.

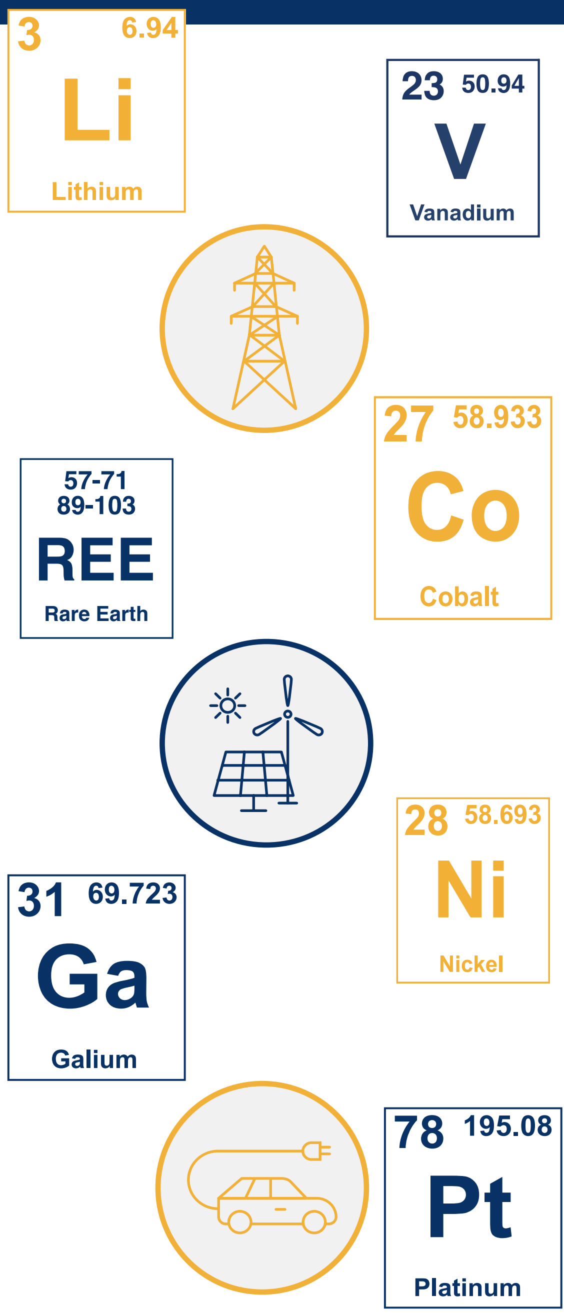
What are "critical" minerals, and why do they matter?

The raw materials—minerals and metals—that are necessary for renewable energy, clean technology, and our transition to a more sustainable, low-carbon future are often referred to as **critical minerals**.

The term "critical minerals" is the most common terminology, and it is often used interchangeably with the terms "strategic minerals,"[1] "strategic and critical minerals,"[2] and "energy transition minerals."[3]

There is no universally agreed upon definition of what "criticality" means, and **criticality changes over time**, depending on the needs of society and the availability of supply.

Criticality is also very country- and context-specific, particularly with respect to mineral endowment, the relative importance of the minerals to industrial and economic development, and a strategic assessment of supply risks and volatility. These considerations would then determine the mineral strategy of each country and/or region.



1 Anderson, E. W., & Anderson, L. D. (1998). *Strategic minerals: Resource geopolitics and global geo-economics*. Wiley.

2 Society for Mining Metallurgy and Exploration. (n.d.). *Critical and strategic minerals: Importance to the U.S. economy*. https://www.smenet.org/What-We-Do/Technical-Briefings/Critical-and-Strategic-Minerals-Importance-to-the

3 International Energy Agency. (2022). *The role of critical minerals in clean energy transitions*. https://iea.blob.core.windows.net/assets/ffd2a83b-8c30-4e9d-980a-52b6d9a86fdc/TheRoleofCriticalMineralsinCleanEnergyTransitions.pdf

To help determine criticality, two perspectives can be considered:

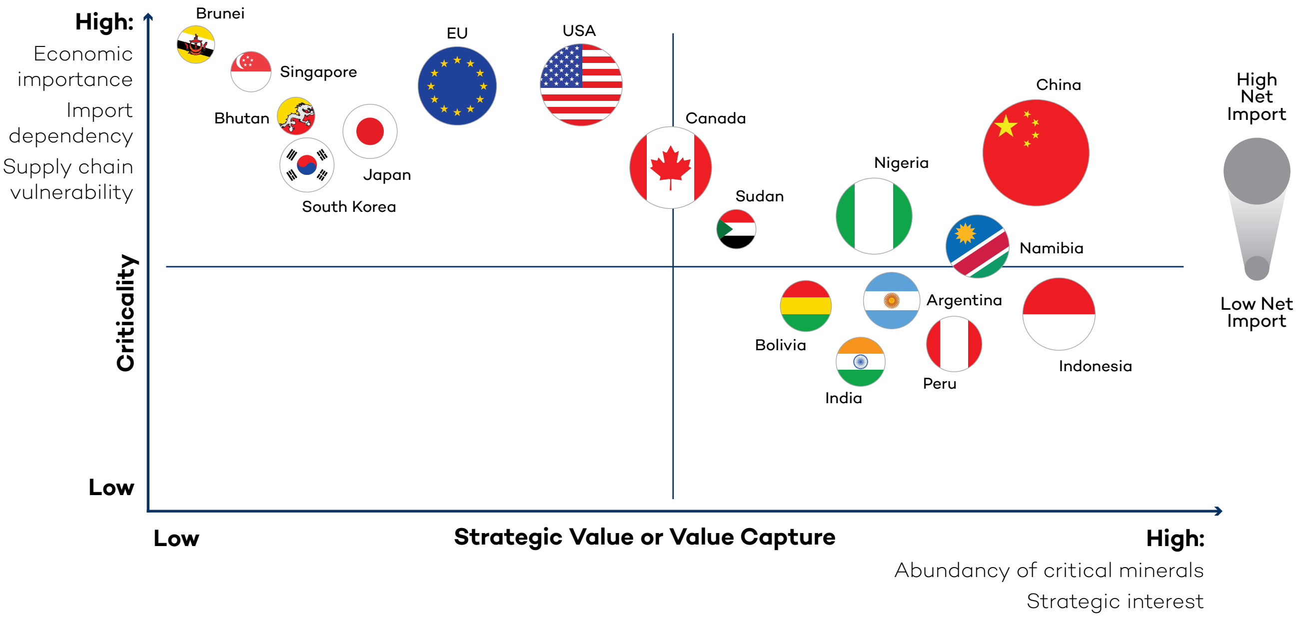
1 Security and Control of Supply

Minerals are considered critical when they are of high economic importance but are scarce and therefore subject to high import dependency. A key element in this definition is the vulnerability of the supply chain due to risks associated with potential supply disruptions, governance issues, political risks, or the overconcentration of production in a few countries. This definition is largely adopted by European countries, the United States, and Japan, for instance.

2 Value Capture

Minerals are also considered critical when they are present in abundance, and the country has a strategic interest in using its dominant position to gain competitive advantage in the global supply chain. Countries using this lens to define criticality are Canada, Australia, and China. This lens is also relevant for countries with substantial reserves of minerals and metals needed for the low-carbon transition, such as Indonesia (nickel, bauxite), Gabon (copper, manganese), Mozambique (graphite, bauxite), Namibia (rare earth elements, tantalum), Nigeria (manganese, lithium), Bolivia (lithium, gallium), and Kazakhstan (copper-lead-zinc).

CRITICALITY PERSPECTIVES AMONGST NATIONS*



* *Indicative assessment based on a compilation of country statements (e.g., Executive Order, Mineral Strategy), recent data on production, reserves and discoveries (e.g., copper in Peru, chromium in Sudan), and international reports and publications (e.g., IEA Country Reports).*

There are also factors that can influence or inform what criticality means to individual countries and/or regions, and these factors can be determined by considering criticality from the following five dimensions:

Dimension	Factors to Consider
1. ECONOMIC	• Economic security • Strategic or competitive advantage • Industrial development objectives • Social development goals • Infrastructure development needs
2. SUPPLY CHAIN	• Supply risks and vulnerability • Import dependency • Geographic concentration of production and processing (refinery) • Viability of substitutes and availability of secondary sources • Value chain opportunities
3. TECHNOLOGY	• Essential input to clean technologies • Required for low-carbon transition • Technological innovations and emerging mineral substitutes
4. GEOPOLITICAL	• National security considerations • Risks of resource nationalism and stockpiling • External shocks and geopolitical realignments
5. GEOLOGICAL	• Natural resources endowment • Availability of reserves and production capacity • Location and quality of ores, metal or mineral content, and depletion rates

What about rare earth elements?

What are rare earth elements (REEs)?

REEs are a set of 17 metallic elements that are considered critical because of their properties. Depending on their atomic numbers, there are two groups of REE: Heavy REE (9 elements) and Light REE (8 elements).

What makes REEs *rare*?

Unlike the name suggests, REEs are actually not rare. In fact, they are relatively abundant and quite commonly available in the Earth's crust.[4] What makes these materials rare is how difficult they are to extract and how complex it is to process them.[5]

The single largest and most important end-use for REEs is permanent magnets, making up an estimated 29% of demand in 2020.[6] Permanent magnets, and thus REEs, are essential for clean technologies and consumer electronics, such as electric vehicles, wind turbines, televisions, mobile phones, and other digital devices.

[4] U.S. Geological Survey. (n.d.). *Rare earths statistics and information*. https://www.usgs.gov/centers/national-minerals-information-center/rare-earths-statistics-and-information; Mineralinfo France. (n.d.). *Substances critiques et stratégiques*. https://www.mineralinfo.fr/fr/securite-des-approvisionnements-pour-leconomie/substances-critiques-strategiques; Somarin, A. (2013). *What's so rare about rare earth elements?* ThermoFischer Scientific. https://www.thermofisher.com/blog/mining/whats-so-rare-about-rare-earth-elements/

[5] Ibid.; ICMM. (2022). *Why mining is crucial for sustainability*. https://www.icmm.com/en-gb/stories/2022/why-mining-is-crucial-for-sustainability

[6] Natural Resources Canada. (2022). *Rare earth elements*. https://www.nrcan.gc.ca/our-natural-resources/minerals-mining/minerals-metals-facts/rare-earth-elements-facts/20522

RARE EARTH ELEMENTS (REE)

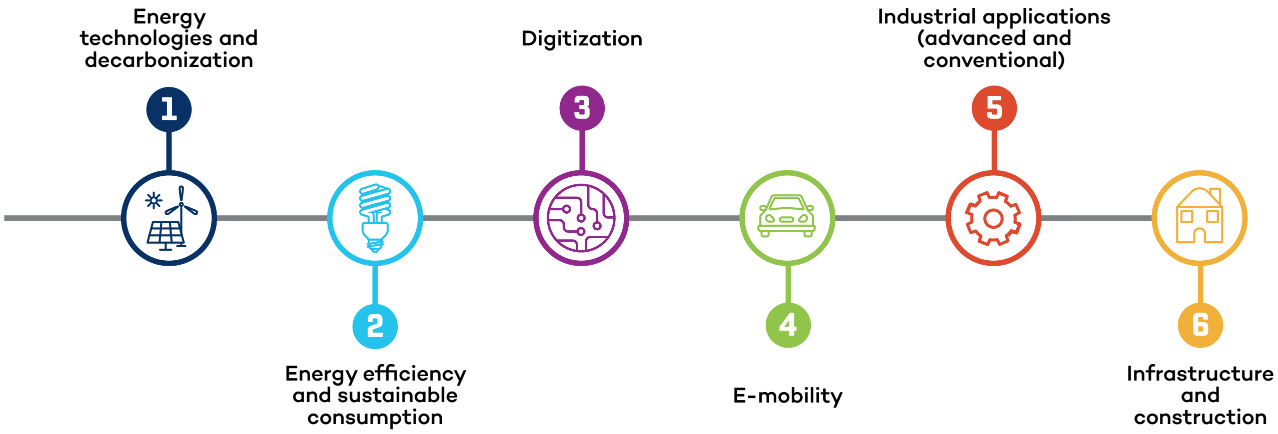
Number	Atomic weight	Symbol	Name	Type
21	44.956	Sc	Scandium	Light Rare Earth
39	88.906	Y	Yttrium	Heavy Rare Earth
57	138.91	La	Lanthanum	Light Rare Earth
58	140.12	Ce	Cerium	Light Rare Earth
59	140.91	Pr	Praseodymium	Light Rare Earth
60	144.24	Nd	Neodymium	Light Rare Earth
62	150.36	Sm	Samarium	Light Rare Earth
63	151.96	Eu	Europium	Light Rare Earth
64	157.25	Gd	Gadolinium	Light Rare Earth
65	158.93	Tb	Terbium	Heavy Rare Earth
66	162.50	Dy	Dysprosium	Heavy Rare Earth
67	164.93	Ho	Holmium	Heavy Rare Earth
68	167.26	Er	Erbium	Heavy Rare Earth
69	168.93	Tm	Thulium	Heavy Rare Earth
70	173.04	Yb	Ytterbium	Heavy Rare Earth
71	174.97	Lu	Lutetium	Heavy Rare Earth
61	144.91	Pm	Promethium*	Light Rare Earth

■ Heavy Rare Earth ■ Light Rare Earth

** Actually rare, usually not included because it is rare and unstable*

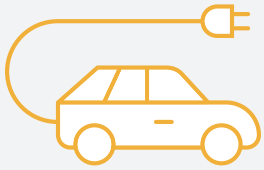
What are the key demand drivers?

The surging demand for "critical" minerals has been driven for the most part by their role in the transition to clean energy and a low-carbon economy. The specific demand drivers can be classified into six pathways:



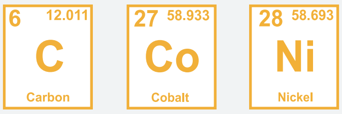
Rising demand for critical minerals will also place even more significant pressure on extraction, production, and refining processes, presenting both challenges and opportunities for governments to consider.

CRITICAL MINERALS SNAPSHOT[7]

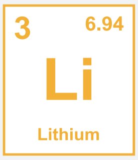


6x more materials needed to produce an electric vehicle compared to a conventional car (IEA, 2020)

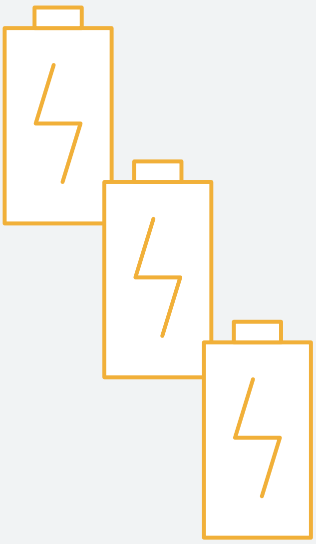
3 BILLION TONNES ‘critical’ minerals required to decarbonize the global energy system by 2050 (Word Bank, 2020)



20x projected increase in demand for graphite (carbon), cobalt and nickel (IEA, 2021)



13x estimated increase in demand for lithium between 2020 and 2040 (IEA, 2021)



USD 105.63 BILLION estimated market value for battery

9.6% expected CAGR

USD 239.4 BILLION revenue forecast of by 2030

39.2% global battery market revenue 2021 for Asia-Pacific

[7] Sources: International Energy Agency 2022, supra n. 3; World Bank. (2020). *Climate-smart mining: Minerals for climate action*. https://www.worldbank.org/en/topic/extractiveindustries/brief/climate-smart-mining-minerals-for-climate-action

What are the main sources of supply?

Minerals and metals are extracted and produced by large-scale mining and artisanal and small-scale mining (ASM) operations. Since it typically takes between 5 and 10 years for large-scale mining to become operational, ASM is playing an increasingly significant role in the production of critical minerals.

In the case of cobalt in the Democratic Republic of the Congo, ASM accounts for around 15%–35% of cobalt production.[8] For tantalum, about 26% of global production comes from ASM.[9] Around 70%–80% of ASM operates within the informal sector, either illegally or in legal grey areas, and the inclusion of ASM in the formal sector presents one among many policy considerations.

In addition to primary sources, critical minerals can also be produced through secondary sources, such as through wastewater for REEs and mine tailings for tungsten, tantalum, and molybdenum. Increasingly, recycling, particularly in the context of the circular economy, is becoming an important and viable source of supply.

New or alternative sources are also emerging, including deep-seabed mining, which is considered controversial but a feasible frontier for manganese, cobalt, nickel, and REEs[10]; marine-derived mining for lithium[11]; and phytomining[12] of native plants to extract or collect minerals from the sap, leaves, and/or fruits. The increased attention and research and development allocated to secondary and emerging sources could have certain implications for supply and demand dynamics, pricing, environmental sustainability, and geopolitics.

What are some of the end uses and applications of critical minerals?

Critical minerals are components of every aspect of modern life, from television to mobile phones, from renewable energy to medical technologies.

Wind and solar energy require more than 10 different critical minerals, while an electric vehicle needs at least eight. Around 42 critical minerals, including REEs, are required for emerging digital devices, such as those related to information technologies and mobility. These minerals are also essential for the healthcare and medical sector as key ingredients for cancer and radiation therapies, x-rays, MRI and CT scans, and medical research.

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8 Cobalt Institute. (2021). ***Cobalt mining in the Democratic Republic of Congo***. https://www.cobaltinstitute.org/cobalt-mining-in-the-democratic-republic-of-congo/

9 Fritz, M., McQuilken, J., Collins, N., & Weldegiorgis, F. (2018). ***Global trends in artisanal and small-scale mining (ASM): A review of key numbers and issues***. https://www.iisd.org/publications/report/global-trends-artisanal-and-small-scale-mining-asm-review-key-numbers-and

10 U.S. Government Accountability Office. (2021). ***Deep-sea mining could help meet demand for critical minerals, but also comes with serious obstacles***. https://www.gao.gov/blog/deep-sea-mining-could-help-meet-demand-critical-minerals%2C-also-comes-serious-obstacles

11 Patel, P. (2022). ***New biodegradable, recyclable battery is made of crab shells***. Anthropecene. https://www.anthropocenemagazine.org/2022/09/battery-made-with-crab-shells-is-biodegradable-and-recyclable/

12 Also known as agromining, which is being explored by various institutions, including University of Queensland, and in select countries, such as Indonesia, Malaysia, South Africa, and Zambia. See Sustainable Minerals Institute. (n.d.). *Leaders of the energy transition are calling for a sustainable source of critical minerals —is phytomining the answer?* University of Queensland. https://smi.uq.edu.au/leaders-energy-transition-sustainable-source-critical-metals-phytomining

WHAT GOES INTO WHAT? WHAT ARE SOME OF THE CRITICAL MINERALS AND METALS NEEDED?

Minerals and metals for electric vehicles by weight (in kg) and major producing countries

27 58.933 Co Cobalt

Cobalt 13.3 kg
Australia, **Canada**, DR Congo, **Madagascar**, **Philippines**, Russia

3 6.94 Li Lithium

Lithium 8.9 kg
Argentina, Australia, Chile, China, Zimbabwe

28 58.693 Ni Nickel

Nickel 39.9 kg
Australia, **Brazil**, **Canada**, Indonesia, New Caledonia, **Philippines**, **Russia**

25 54.938 Mn Manganese

Manganese 24.5 kg
Australia, **Brazil**, Cote d'Ivoire, **India**, **Gabon**, **Ghana**, **Georgia**, **South Africa**

6 12.011 C Carbon

Graphite 66.3 kg
Brazil, **Canada**, China, **India**, **Madagascar**, **Mozambique**

26 4.000 Fe Iron

Iron and Steel
China, **Brazil**, **India**, **Germany**, Japan, South Korea, **United States**

57-71 89-103 REE Rare Earth

Rare Earth 0.5 kg
China, **Myanmar**, **Madagascar**, **United States**

29 63.55 Cu Copper

Copper 53.2 kg
Australia, **Canada**, Chile, DRC, **Kazakhstan**, **Mexico**, **Peru**, **US**, **Zambia**

Blue *indicates IGF membership.*

Minerals and metals in the medical supply chain

78 195.08 Pt Platinum

Platinum Metals
(Ruthenium, Rhodium, Palladium, Osmium, Iridium and Platinum)
Corrosion Resistant, Cancer Fighters, Chemotherapy Drugs, Radiation Therapy, Implants, Cardiac Technology

4 9.01 Be Beryllium

Beryllium
Optical Surgery, Heat Resistant Properties
Reduce Radiation Levels, Improves Efficiency in X-rays/CT Scanning, Mammography

29 63.55 Cu Copper

Copper
EPA Antimicrobial Touch Surface, MRI Scanners, Malleable Recyclable, High-tech Computers

Minerals and metals in digital, IT and Mobile devices

- 3 6.94 Li Lithium — **Lithium**
- 27 58.933 Co Cobalt — **Cobalt**
- 28 58.693 Ni Nickel — **Nickel**
- 29 63.55 Cu Copper — **Copper**
- 31 69.723 Ga Gallium — **Gallium**
- 52 127.60 Te Tellurium — **Tellurium**
- 57-71 89-103 REE Rare Earth — **Rare Earth Elements**
- 73 180.95 Ta Tantalum — **Tantalum**

Minerals and metals for renewable energy

- 24 51.996 Cr Chromium — **Chromium**
- 25 54.938 Mn Manganese — **Manganese**
- 27 58.933 Co Cobalt — **Cobalt**
- 42 95.95 Mo Molybdenum — **Molybdenum**
- 29 63.55 Cu Copper — **Copper**
- 30 65.38 Zn Zinc — **Zinc**
- 31 69.723 Ga Galium — **Gallium**
- 32 65.38 Ge Germanium — **Germanium**
- 50 118.71 Sn Tin — **Tin**
- 52 127.60 Te Tellurium — **Tellurium**
- 28 58.693 Ni Nickel — **Nickel**
- 57-71 89-103 REE Rare Earth — **Rare Earth Elements**

Sources: IEA, Energy Monitor, National Mining Association, NRCan.

What benefits and challenges should governments consider?

As we transition to a low-carbon future and away from a fossil fuel economy, the need for and dependence on critical materials will only increase, creating new supply and demand forces in the global economy. Resource-rich producing countries will play a key role in developing reliable and resilient supply chains, while non-producing countries can benefit from economic opportunities and spillovers in the value chain through, for example, investment in manufacturing capabilities, innovation, and technology. Value-chain creation will bring employment opportunities, with significant potential to address gender imbalances in occupations and pay gaps. Improved governance, as well as policy and regulatory frameworks, will offer new and/or additional sources of revenue, trade partnerships, and private sector investment.

Alongside the benefits, certain risks and challenges need to be considered, and how governments address these challenges will have an impact on their transition to a low-carbon economy.

Key risks to consider

- **Supply risks** arising from a concentration of mineral production and processing in just a few countries and companies, scarcity of supplies from geological depletions over time, and technological innovation that will give rise to substitutions and new sources of materials.
- **Off-take agreements** could present challenges around a mismatch between the production volume and the required volume, pricing issues due to price volatility that could be exacerbated by external shocks (e.g., COVID-19), and geopolitical instabilities (e.g., the Russia–Ukraine war).
- **Macroeconomic risks** resulting from revenue volatility due to cyclical volatility in the global economy, currency crises, and global fluctuations in commodity prices, as well as issues related to what is known as Dutch disease.[13]

[13] Dutch disease refers to an economic paradox named after the experience of the Netherlands in the 1960s after the discovery of large natural resource deposits that actually led to currency appreciation, reduced competitiveness, and harmed the rest of the economy. https://www.imf.org/external/pubs/ft/fandd/basics/dutch.htm

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