AN ELEMENTAL PROBLEM

3	27	28	29	60	66
Li	Co	Ni	Cu	Nd	Dy
LITHIUM 7.0	COBALT 58.933	NICKEL 58.693	COPPER 63.55	NEODYMIUM 144.24	DYSPROSIUM 162.50

Critical minerals will underpin the global clean energy transition, but the threat of constraints on supply is forcing investment and research into new and alternative forms of extraction

WORDS **STEPHEN COUSINS**

With the US floating a multi-billion dollar deal to gain access to Ukraine's precious mined resources – an agreement that may help advance the end of Russia's war – the strategic global importance of critical minerals has arguably never been more clearly demonstrated.

Critical minerals – a set of metals and other raw materials needed for the production of various high-tech products (see *What are critical minerals?*) – are particularly important for the green energy transition as nations retool to tackle climate breakdown and move away from fossil fuels.

Elements including copper, cobalt, lithium and nickel are needed in the electrification of power networks, industry and transport, and required for the manufacture of wind turbines, solar panels and batteries for grid storage and electric vehicles (EVs).

Geopolitical competition for access to critical minerals has soared in recent years, increasing their value. According to the latest figures from the International Energy Agency (IEA), the market for energy transition minerals reached £320bn in 2022, double its value five years earlier. Demand is expected to triple by 2040 if climate pledges are met in full.

Critical minerals are abundant in the Earth's crust. However, the dominance of certain countries in their mining and processing – most notably China – and reliance on illegal, unsafe or unenvironmental practices has left Western democracies scrambling to find new ways to bolster their supplies and keep clean energy commitments within reach.

The paradigm shift is fuelling efforts to open up new mines, identify alternative, less damaging forms of extraction, and invest in innovations designed to either substitute critical minerals or boost their reuse and recycling.

Professor David Knowles, chief executive of the Henry Royce Institute, tells *E+T*: "Governments and decision-makers are starting to take this issue seriously – they recognise that a move away from critical materials is a way of de-risking the process … The biggest challenge is transforming materials innovations into investable technologies so it becomes clear to the investment community that they represent a commercial opportunity."

Changing priorities

Many countries have adopted strategies to decarbonise energy by shifting electricity generation towards zero-emission sources and electrifying various sectors. But the move to clean energy involves another environmentally tricky proposition: the switch from a fuel-intensive to a material-intensive system.

Solar photovoltaic (PV) arrays and wind farms do not require fuel to operate, but they generally require more materials – including harder-to-find critical minerals and rare earths – to construct than polluting power stations. According to the IEA, an onshore wind plant requires nine times more mineral resources than a gas-fired plant of the same capacity, while a typical electric car requires six times the mineral inputs of a conventional car.

With deployments of low-carbon tech on the increase, decision-makers are increasingly concerned that certain critical minerals may become harder to source, putting climate targets in jeopardy.

Minerals including lithium, cobalt and nickel and rare earth metals such as neodymium, dysprosium and copper are vital for the production of energy storage systems, efficient electric motors and renewable energy infrastructure. Yet according to projections by the IEA, confirmed supplies of copper are only sufficient to meet 70% of global demand by 2035, while lithium supplies can only meet 50% of demand in that timeframe.

A 2023 study of material scarcity related to wind energy found that demand for glass fibre, nickel and rare earth elements could be so high that, without increased production, competition for access to them will escalate.

A major challenge in satisfying the world's hunger for critical materials is the geographical concentration of mining and processing operations. This narrowing of supply exposes global markets and supply chains when there are disruptions such as trade conflicts, wars or political instability, increasing geopolitical risks.

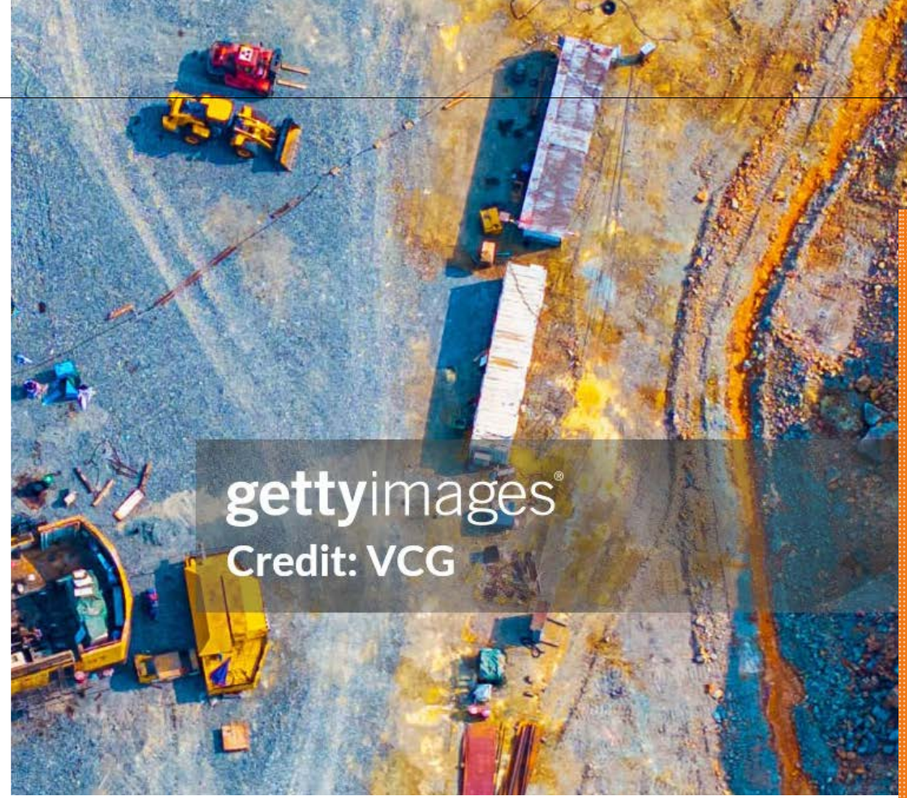
"China rears its ugly head across the periodic table because they've been very strategic and built up global positions in a whole range of different metals and minerals, not just in mining, but in refining through to the manufacturing," explains Gavin Mudd, director of the Critical Mineral Intelligence Centre.

A major concern is the level of control China exerts beyond its borders, he says. "Australia is responsible for over 50% of world lithium production and Indonesia around 50% of world nickel production, but the vast majority of that is Chinese money … China also takes cobalt concentrates out of places like the Congo then refines it to bring into its manufacturing ecosystem."

Rogue traders

Geopolitical factors aside, reports of unsustainable and inhumane material extraction practices at large-scale mining operations further undermine

Photography: Shutterstock



China is a dominant power in mining and processing

confidence in the sector and demand a rethink of supply. The EU is also under mounting pressure to suspend a controversial minerals deal with Rwanda blamed for fuelling the conflict in the east of the Democratic Republic of the Congo.

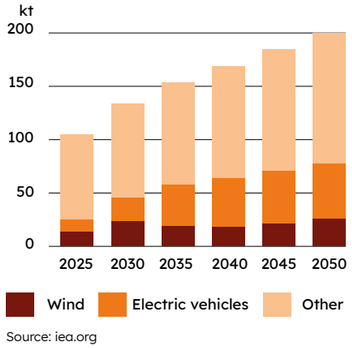
A 2019 Business and Human Rights Resource Centre report found that 20 out of 23 of the largest companies mining key minerals essential to renewable energy had faced allegations of human rights abuses including violence and death.

According to Tom Streather, technical director for social performance at Mott MacDonald, human rights considerations are increasingly taking centre stage in decision-making at energy network operators, utilities and financiers involved in energy transition projects. This is supported by evolving regulation and ESG guidance, such as EU Regulation 2017/821, which sets out supply chain due diligence obligations for EU importers of tin, tantalum, tungsten and gold originating from conflict-affected and high-risk areas.

"Dependency on equipment and materials for the transition to renewable generation and electrified networks often ties us to regions with poor human rights records, which includes the significant amounts of copper needed for distribution networks and other critical minerals for wind turbines and solar PV panels, which have been known to be mined using forced and child labour," says Streather. "In response, companies are taking action to increase transparency."

This transparency should raise standards, but could exacerbate interim shortages as organisations realign. Dr Arjan Dijkstra, assistant professor in earth materials at the University of Twente in the Netherlands, tells *E+T*: "If we don't want to buy from those countries anymore, we don't have a lot of alternatives at the moment and that leads to scarcity."

Total demand for magnet rare earth elements (announced pledges scenario)



Source: iea.org

Alternative sources

Western democracies may have been complacent, becoming dependent on dubious critical mineral imports, but work is underway to rectify that situation and diversify import sources.

Geological investigations have revealed significant untapped resources covering most metals and minerals needed for the energy transition in Finland, Norway, Sweden and Greenland. Finland is the most promising in the short term due to its streamlined permitting process and a national strategy to expand extraction of lithium, nickel, cobalt and graphite.

Last summer, the EU trumpeted plans to reopen one of Europe's largest lithium mines – a crucial material for EV batteries – in Serbia's Jadar Valley. However, activists claim the move will cause irreversible environmental destruction.

Mining has a poor reputation in Europe, and its lack of popularity with the public and planners is making the establishment of new mining operations difficult. The EU's Critical Raw Materials Act aims to address this issue and bolster supplies by requiring the fast-tracking of mining permits for new projects, with less room for public objection.

Sensitivity around new mining operations has led to a focus on exploring alternative projects that recover critical materials as a byproduct of existing mining or industrial processes. Salty water brines associated with geothermal power plants can contain high concentrations of lithium and several projects in Europe are looking at how to optimise extraction.

In the UK, Cornish Lithium's Trelavour Hard Rock project is aiming to produce 10,000 tonnes of sustainable domestic lithium a year by 2027 using acid to extract the element from granite, as opposed to the fossil fuel roasting method commonly used by China.

Replace and recycle

Reliance on critical minerals can be reduced through the development of innovative substitute materials for products and systems. The National Materials Innovation Strategy, published by the Henry Royce Institute to guide future UK government decision-making, highlights opportunities to develop a range of new materials in the switch to decarbonised energy.

Next generation battery chemistries needed to run EVs and store energy to increase grid capacity include post-lithium-ion cells based on sodium ion, solid state and lithium-sulfur. "At the moment, it's about moving to solutions like sulfur ions and sodium ions – a gradual reduction in cobalt is key," says Knowles.

Solar PV is set to become the dominant global power source by 2050 and materials innovation could boost energy harvesting efficiency while reducing reliance on China's silicon-based systems. These include perovskites, a hybrid organic-inorganic lead or tin halide-based material used as the light-harvesting active layer in panels.

Alongside investment in extraction and alternatives to critical minerals, reuse and recycling can create a valuable secondary supply source to enhance the security of supply. According to figures from the IEA, successfully scaling-up recycling could lower the need for new mining activity by 25-40% by 2050 in a scenario where national climate pledges are met.

Although EV batteries are not yet available for recycling at scale, because most cells have not expired, global recycling capacity is increasing rapidly. In Europe, recycled batteries are projected to meet about 30% of the region's lithium and nickel demand by 2050, based on announced pledges, which is notably higher than the global average of around 20%.

However, recycling still presents challenges. Lithium iron phosphate cathodes have gained a significant market share from nickel-based chemistries in recent years. According to the IEA, the associated lower material value impacts recycling economics. This underscores the need for new business models and regulations to prevent batteries from ending up in landfill.

As global efforts to cut carbon emissions intensify, and demand for critical minerals rises significantly, recycling represents a key challenge for authorities to grapple with as they strive for more responsible and sustainable approaches. Society needs clean energy solutions well in advance of 2050 to keep climate targets within reach, so decisions made today will be fundamental to all our futures. ET

GREEN EXTRACTION

New research centre targets greener methods of copper mining

Copper is vital for electricity generation, storage and transmission, and more will be mined over the next decade than was extracted in the whole of the last century. Scientists say this will have enormous environmental consequences, principally because mining uses acids that poison rivers, contaminate soil and pollute the air.

The newly established Rio Tinto Centre for Future Materials, based at Imperial College London, has $150m of funding for its first 10 years of operation with an initial challenge being to find sustainable new ways to extract and recycle copper. The centre plans to turn its attention to other energy transition materials in future.

According to the university, research efforts will explore how to extract copper from fluids in the Earth's crust, utilise micro-organisms to harvest metals from rocks with minimal copper content and optimise waste recovery from old mining sites. Mining copper typically involves extracting it from minerals that have crystallised out of very saline, copper-rich brines, a process that requires huge amounts of energy.

To get around this issue, the centre and its partners have been looking at underground geothermal sites where copper-rich brines are created by volcanic systems.

Speaking to *The Guardian*, Professor Matthew Jackson, chair in geological fluid dynamics at Imperial College, said: "That means we can extract the copper by pumping the brines to the surface via boreholes – which is relatively easy – and also use local energy to power the mine itself and possibly provide excess energy for nearby communities."

ELEMENTS

What are critical minerals?

Lithium, neodymium and dysprosium

Critical minerals are metals and other raw materials needed for the production of high-tech products, particularly those associated with the green energy transition.

Lists of critical minerals vary from country to country, based on local domestic and geopolitical objectives. For example, a 2023 list of critical materials drawn up by the US Department of Energy includes 18 materials considered critical for energy technology, among them aluminium, cobalt, copper, dysprosium, iridium, lithium and neodymium.

Rare earth elements are a subset of 17 chemical elements, several of which are vital for the energy transition. Neodymium, praseodymium, dysprosium and terbium are key to the production of permanent magnets used in electric vehicles and wind turbines. Yttrium and scandium are used for certain types of hydrogen electrolysers, while europium is used in nuclear power station control rods.

Most of the rare earth elements are not in fact rare, but their extraction and refining is notoriously difficult and environmentally highly destructive so production is concentrated in very few places, mainly China.

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