FUTURE MINERALS FORUM

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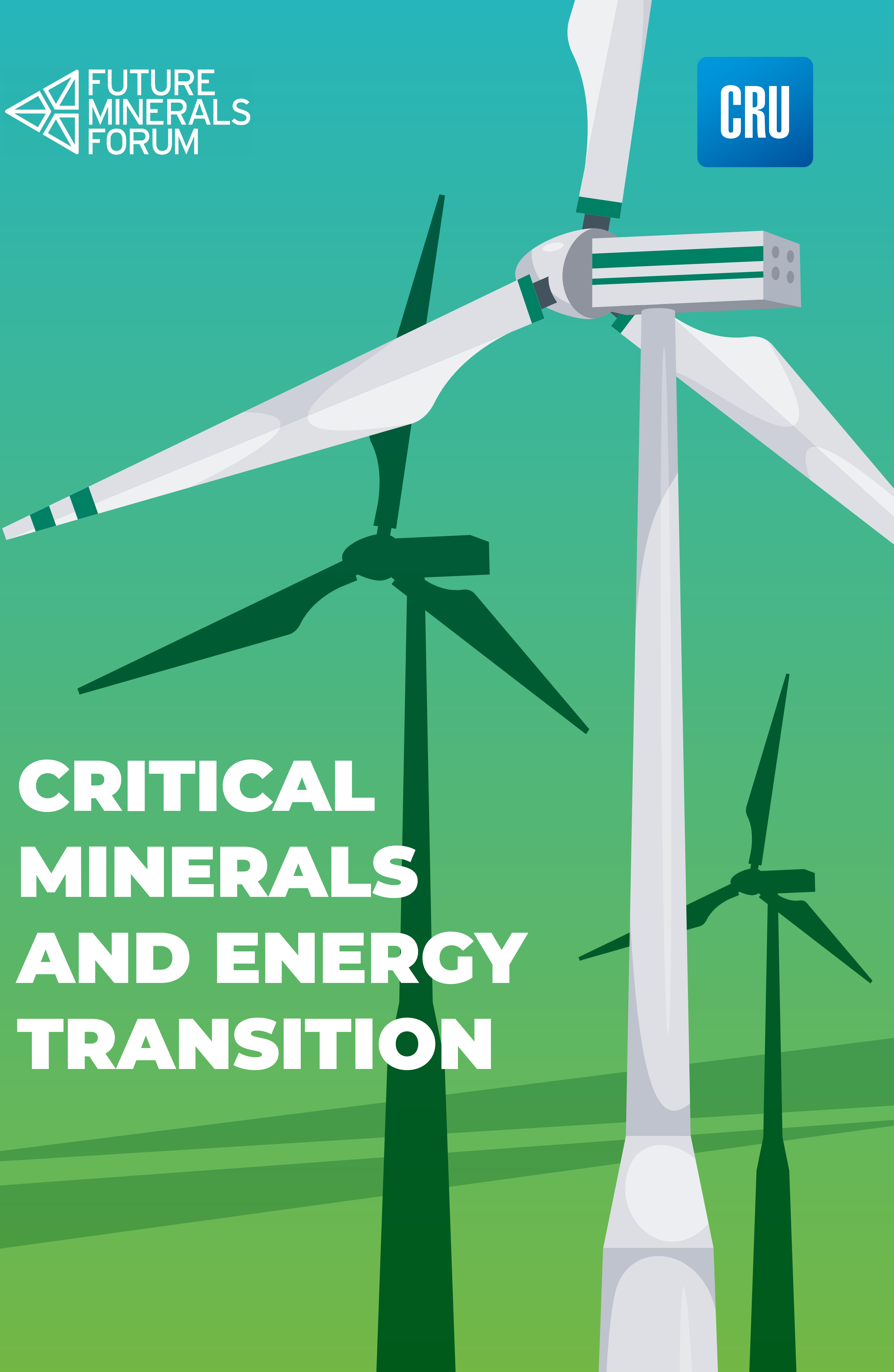

CRITICAL MINERALS AND ENERGY TRANSITION

KEY TAKEAWAY

CRITICAL MINERAL BOTTLENECKS MUST BE SOLVED TO ACHIEVE CLIMATE GOALS.

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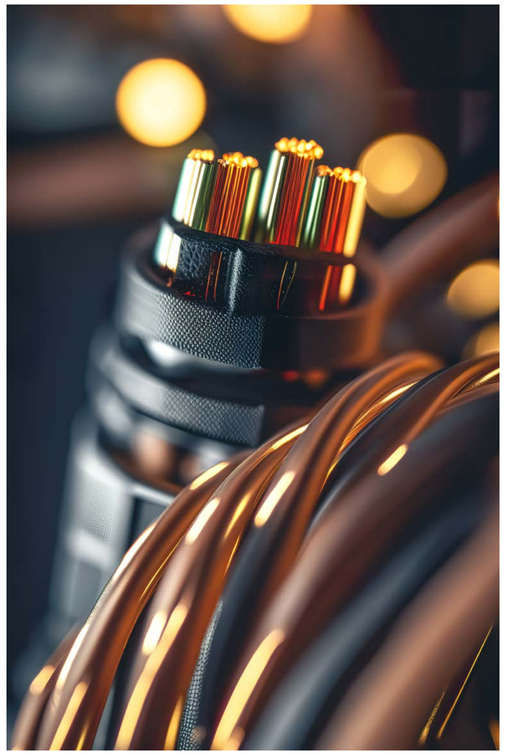
The energy transition will drastically change the landscape for commodities. Producing, transferring and storing energy without the use of fossil fuels will require vast amounts of minerals to build the necessary infrastructure. Commodities like copper, aluminium, green steel, silicon, rare earths and battery metals like lithium and nickel will face significant changes to future demand.



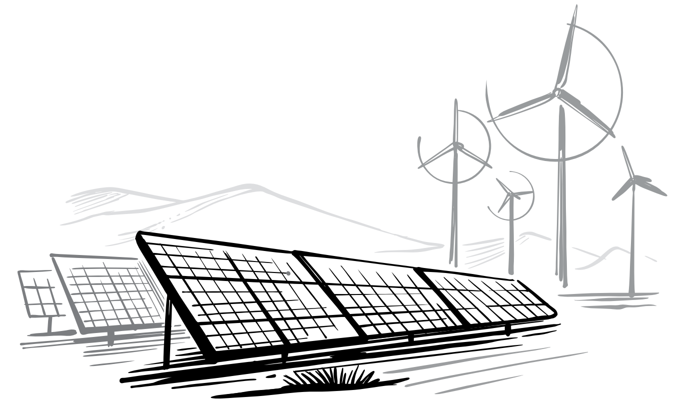
The pace of change needed is rapid. The world is only at the beginning of the journey and the current trajectory is not compatible with a 1.5°C world – indeed, mass energy transition is yet to occur. CRU estimate that none of the major commodity markets are on track with limiting emissions to be compatible with 1.5°C global warming by 2050.

For some commodities, the rapid rise in demand has earned them the “critical” tagline. Reasons for criticality can be different and can originate in either the demand or supply side, or both. Market predictability, supply pipelines, substitution potential, and sovereign risk are key examples that can define criticality. Whatever the reason, the critical designation implies there is a bottleneck making it challenging to match supply with demand.

Breaking these bottlenecks will be crucial in achieving climate goals. To break the bottlenecks, the world must:

- Comprehensively map value chains and further standardise the definition of criticality.
- Discuss solutions across all financial, regulatory, development and civil stakeholders – everyone needs a seat at the table.
- Show increased flexibility and innovation on all sides to overcome the challenges, particularly in project finance.
- Align global targets with local decision-making.
- Promote and maximise the contribution from regions that have potential to break bottlenecks.

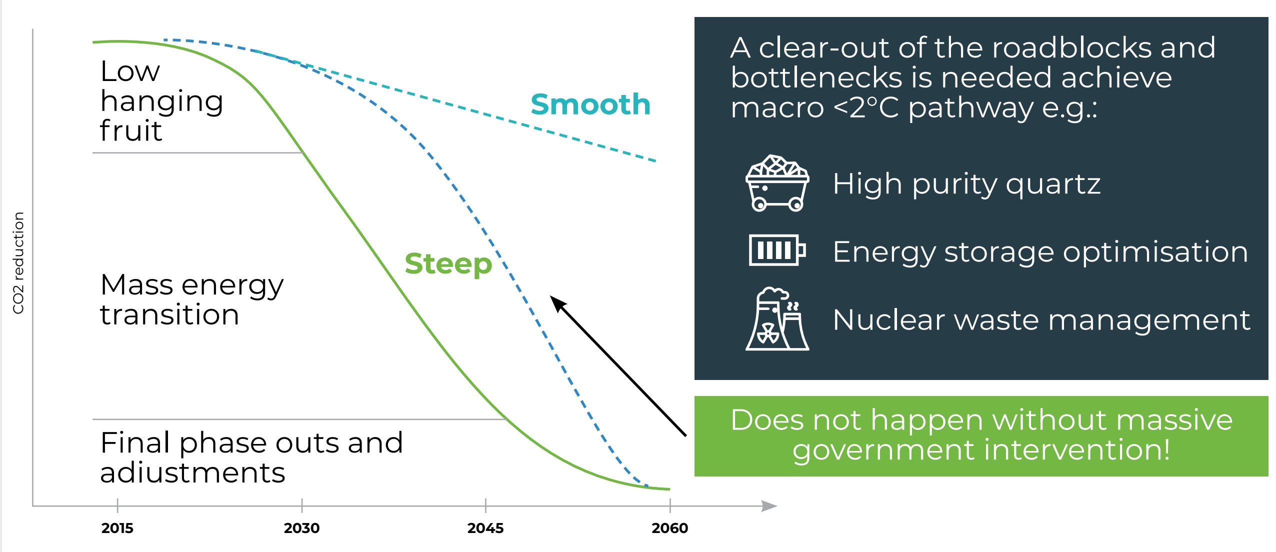
The Middle East, Africa and Central Asia have the potential to play a key role with some of the best untapped mineral deposits the world can hope to develop, and favourable dynamics for processing and value add. As such, governments, financial institutions, industry participants and the civil society in these regions should be at the forefront of the global conversation about the energy transition.



THERE ARE THREE STEPS TO THE ENERGY TRANSITION

The world has made timid but important steps towards energy transition, and installed renewable capacity has more than doubled over the last 10 years. This year, solar capacity globally will exceed 1.5TW, up from ~0.5TW in 2018 – but still, this represents only 6% of total generation in 2023. Wind and solar farms have been installed in promising locations, such as in the United Arab Emirates where solar has risen from 0% to 10% of the energy mix since 2018. The combination of large-scale precedents and intensive R&D work has reduced the cost of installing and running this capacity to levels that are competitive with fossil fuel installed capacity. Of course, mass transition to renewable energy requires the ability to store energy to account for the variable and interruptible nature of energy generated through solar or wind; it also requires the building of transmission lines, often on an unprecedented scale, to take energy from where it’s best generated to where it’s most needed.

To go from “smooth” to “steep”, targeted intervention is key



DATA: CRU

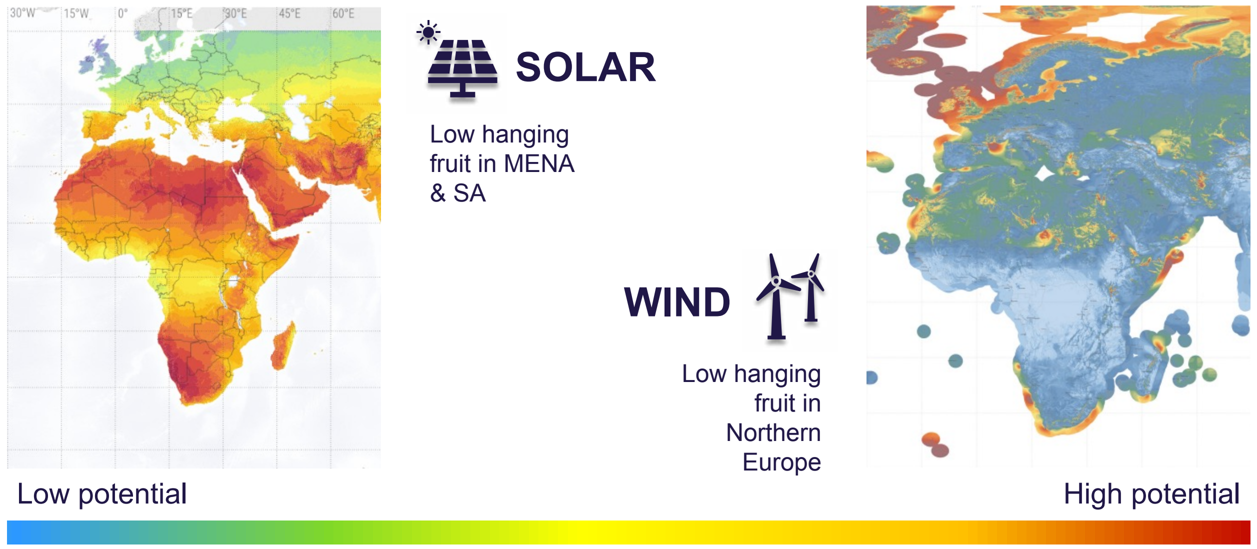
The energy transition has, in theory, three key steps.

The first involves the setting of successful precedents in “low hanging fruit” areas in order to create momentum and establish confidence in economic viability. Some of these early precedents have, indeed, been set, particularly in areas that combine maximum renewable energy potential with easily reachable power consumption markets and, crucially, with transition-friendly jurisdictions able to provide quick regulatory and financial incentives. China, the USA, and EMEA have to some degree embraced the precedents. For example, solar capacity in the USA has more than tripled since 2018 and will continue to grow rapidly due to federal measures like the Inflation Reduction Act (IRA). Many countries in the Middle East have embraced solar power and provided a clear mandate for large-scale development of solar farms, with Saudi Arabia committing to an ambitious target mix of 50% renewable energy by 2030. The UAE and Jordan have already installed large-scale solar farms, with more projects expected before the end of the decade.

Once momentum has been established, **the second step** would involve mass transition to renewable energy, where a combination of solar, wind and energy would be installed globally in large volumes, with inevitable trade-offs likely to be needed on installation costs, running costs, efficiency, or proximity to consumption. Energy storage would have to be deployed on a mass scale to counter the variable and interruptible nature of most renewable energy, with fossil fuel capacity used to balance the grid while storage is fully installed.

The third and final stage would, in theory, cover the final decade, and involve final adjustments to an overwhelmingly renewable grid and final phase-outs of fossil fuel capacity.

Solar and wind potential is limited by geography, low hanging fruit will only go so far

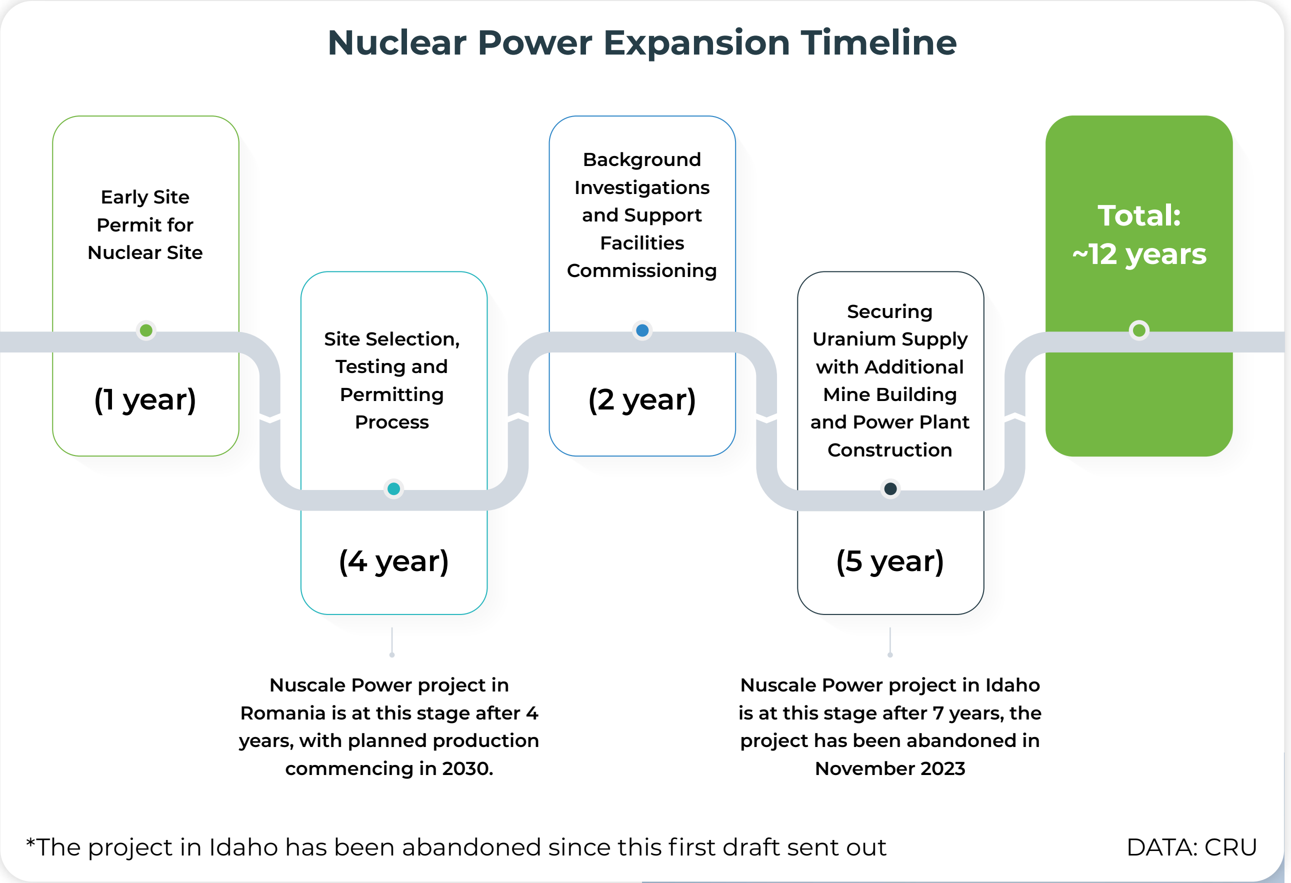


DATA: “Solar Resource Map” and “Wind Resource Map” | World Bank, ESMAP, DTU Wind Energy, Vortex, SOLARGIS

There is a finite number of ways to reach a “green” electric grid:

through a combination of solar and wind power (backed up by the necessary storage capacity) plus nuclear power. Technology improvements have already reduced the cost of solar energy to ever-more competitive levels. Storage technology is currently undergoing a similar evolution, which will benefit the all-in cost of solar and wind alike. Nuclear technology is, slowly, catching up, with small modular reactors looking to overcome capital intensity and waste optimisation challenges – both big challenges with clear, but expensive solutions. Lead time is a problem with limited obvious solutions – even optimistic scenarios have minimal nuclear capacity delivered before the mid-2030s. However, from the point of view of mapping critical minerals, barring technology choices in each type of power, the requirements of critical minerals should be clear.

Major timeline related constraints for nuclear power



The consensus view is that progress made until now has been insufficient to reach most Net Zero targets globally, and that substantial acceleration will be needed to complete even the first step early enough to still envision anything resembling a 2C scenario. CRU's current base case points towards a continuous smooth, gradual transition, based on carefully scrutinised projects undergoing traditional economic and financial due diligence before seeing the light of day. Such a gradual shift would point to a 3C world where Net Zero targets are missed, but substantial progress is made, and renewable energy represents a majority of power generation by the 2040s.

CRU analysis of the likely path of industrial emissions incurred in the production process of some key commodities reflects this reality – some emission reductions have occurred, but progress so far is not consistent with a plausible route to a 2°C world.

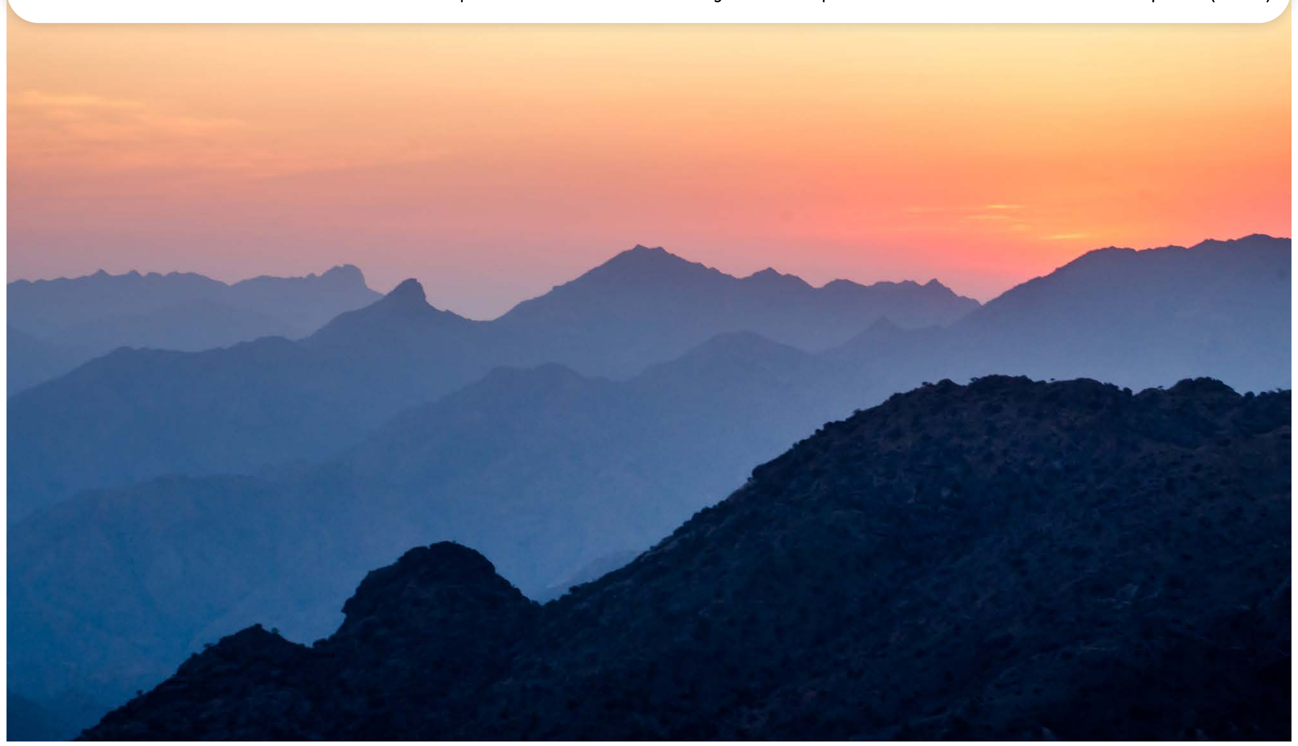
Temperature pathways for commodity markets improve over time, but most are >3.0°C

Emission pathway up to given year based on carbon budget used

Sector	2027	2031	2040	2050
Steel	>3.0°c	>3.0°c	>3.0°c	2.0-3.0°c
Nickel (mining)	>3.0°c	>3.0°c	>3.0°c	-
Power	>3.0°c	>3.0°c	2.0-3.0°c	2.0-3.0°c
Alumina	>3.0°c	>3.0°c	-	-
Thermal coal	>3.0°c	2.0-3.0°c	2.0-3.0°c	-
Ammonia	>3.0°c	-	-	-
Met. coal	2.0-2.5°c	2.0-2.5°c	2.0-2.5°c	-
Total aggregated emissions	>3.0°c	>3.0°c	2.0-3.0°c	2.0-3.0°c

>3.0°c 2.0-3.0°c 2.0-2.5°c 1.5-2.0°c

Data: CRU | CRU Emissions Analysis Tool | IPCC Sixth Assessment Report (AR6)

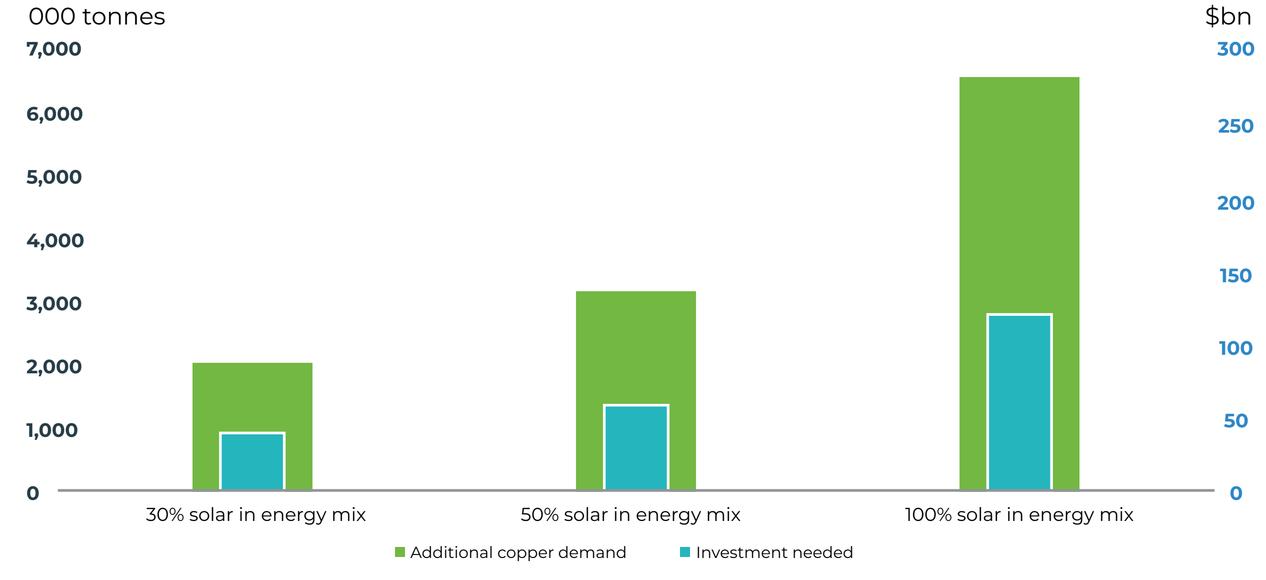


UNDERSTANDING AND BREAKING THE BOTTLENECKS WILL BE ESSENTIAL TO REACHING CLIMATE GOALS

Across solar and wind power generation and energy storage, demand for a wide range of commodities is set to grow rapidly. To put commodity demand into context – energy generation will need to at least double by 2050 to meet demand from ~30TWh currently to at least 60TWh in 2050. On top of this, the proportion of total energy generation that is low carbon will need to increase at the same time to meet climate goals. That means more demand for power, and ever-increasing demand for the power to be low-emissions.

CRU can estimate how much copper, aluminium and steel will be need to go from 30TWh to 60TWh. But predicting how rapidly the 30TWh, mostly high carbon generation, will transition to low carbon is challenging, and depends on climate scenarios. In a 3.0°C world, not much of it will be replaced. In a 1.5°C, the picture is very different. Using solar as a case study; for solar to generate a third of the world's electricity by 2050, at least 2 million tonnes of copper will be needed per annum for on-site infrastructure only. In a hypothetical world of 100% solar generation, over 6 million tonnes will be needed, equivalent to 3x the predicted annual output from the Democratic Republic of Congo, and 1.5x the annual output from Chile. Such additional demand would equate to ~$80bn in copper mining investment to meet demand. **For every additional gigawatt of solar capacity added, ~$50-100m will need to be invested into copper production.**

Copper demand and investment needed by solar scenario, 2050. Left hand side: copper demand for solar capacity, thousand tonnes | Right hand side: CAPEX investment to meet demand, $bn



DATA: CRU

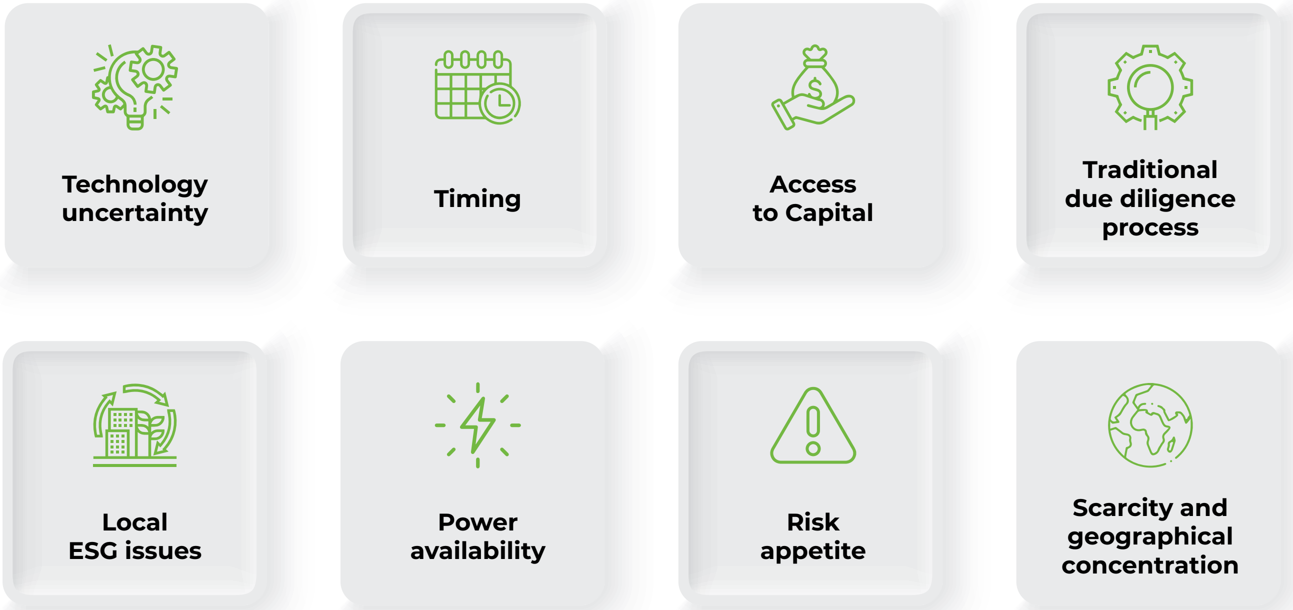
Copper is one of many commodities that will see vastly different demand in climate scenarios. Some of these commodities have never been in the spotlight before and the industry is ill-prepared to deliver the required growth in supply. **There is poor understanding of individual sector specifics and associated risks,** little experience in processing and distributing the product in large quantities. For example, CRU has seen record demand for studies explaining the basics of niche commodities such as gallium and germanium; meanwhile, the stakeholder teams in lending and institutional investment firms have not seen a matching increase in personnel and in-house expertise.

The pace of absorbing information, due to complexity and scarcity, is therefore also a problem and creates inevitable delays. With so much pressure on start-up and junior companies to set successful precedents, matching digestibility with enough detail to provide confidence has been a tricky balancing act.

Research by CRU suggests that each of the value chains involved in energy transition comes with some very specific challenges. Some of these may be labelled as "roadblocks": a problem we do not yet know how to solve. For example, many of the obstacles in the path of nuclear energy development fall under this category – how do we optimise radioactive waste on a much larger scale than is currently required? how do we get to the economies of scale required to make capital intensity competitive?

Others are **"bottlenecks", or mass balance issues: ensuring there is enough material to satisfy the volume requirements of a part of the value chain.** Key bottlenecks can include but are not limited to:

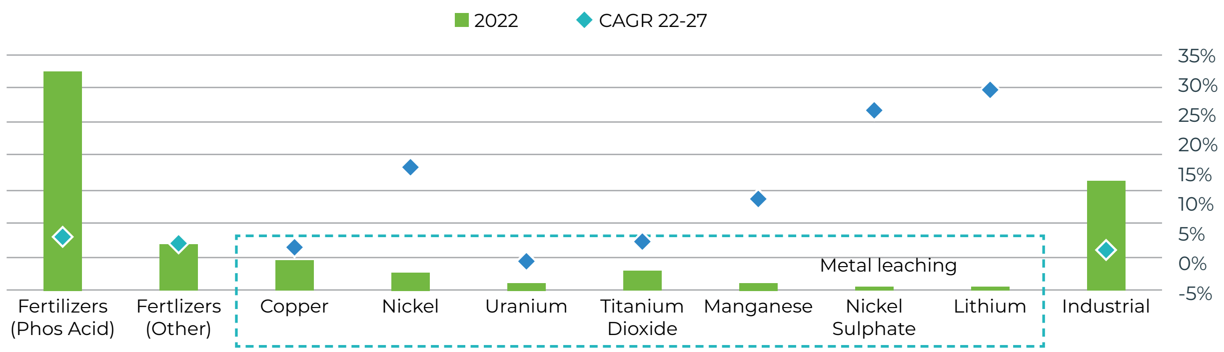
Example of reasons for value chain bottlenecks



DATA: CRU

As discussed, many of the bottlenecks are in niche materials for which future demand will be a multiple of current consumption; these materials are not well known or understood, such as graphite, gallium, selenium, or germanium. Others have historically established markets but will likely see changes in their fundamentals. Ammonia may move from fertilizer to becoming primarily a fuel. Nickel, cobalt, and lithium have metal markets that are about to be dwarfed by demand for their chemical compounds, and they will all need sulphuric acid to be processed. Indeed, sulphuric acid presents an excellent example of a potential material bottleneck which sits outside the mainstream of energy transition and can occur even though the resource itself is not scarce.

Global Sulphuric acid end use growth rate (LHS: Mt, RHS: %)

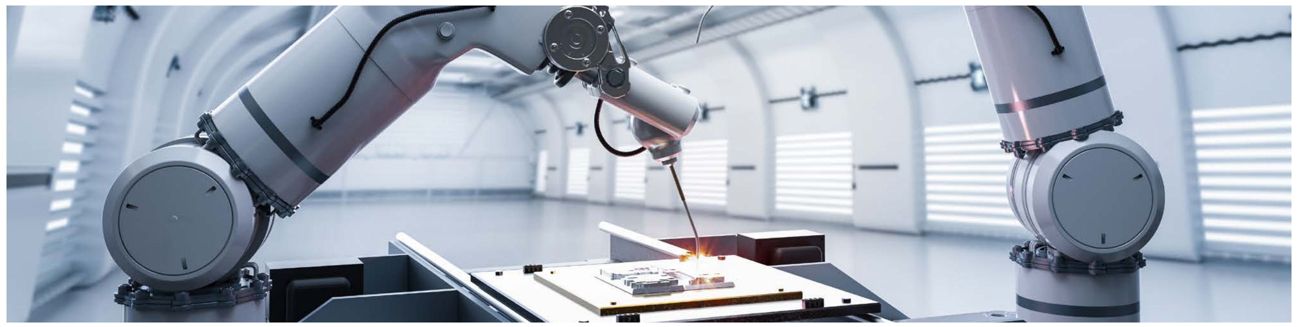


With increasing material production, some processes may require a sulphur burner to be integrated on-site due to sulphuric acid intensity (e.g., 25 t sulphuric acid per 1 t Ni).

DATA: CRU

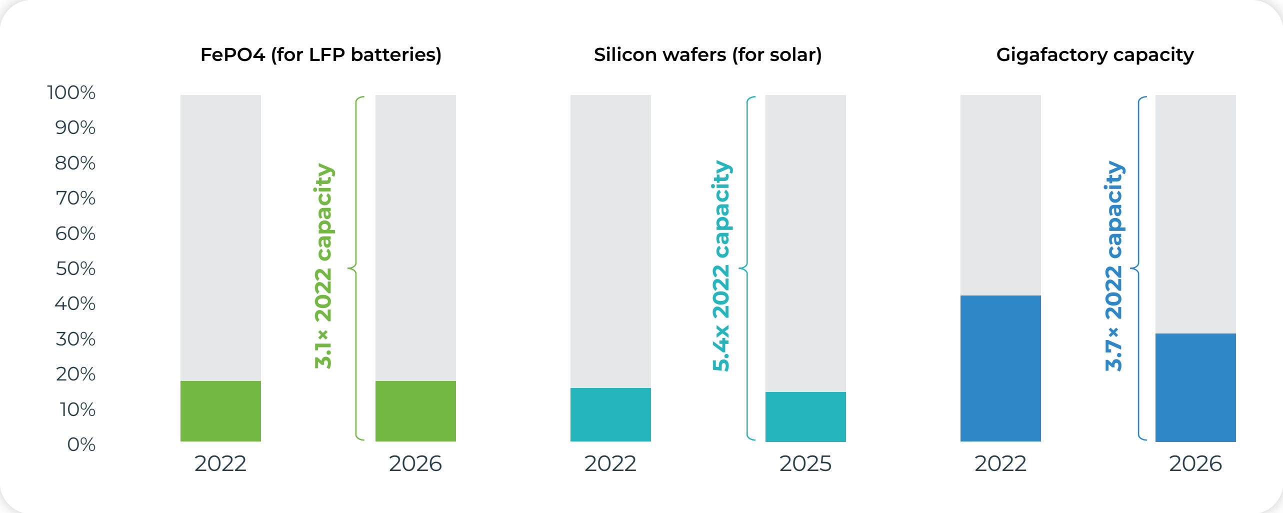
MIDDLE EAST AND AFRICA COULD HOLD TO KEY TO BREAKING BOTTLENECKS

While these challenges have held up project development pace in most of the world, Chinese industrial production has included a pro-active approach to developing processing capacity for many of the critical minerals essential to energy transition. In many cases, including silicon smelting, needle coke processing and rare earths separation, **China has grown into a dominant position as the world's largest supplier,** as well as one of the biggest investors in innovation. Much of this capacity is energy-intensive and coal-fired, adding substantial emissions while satisfying demand. Not only that, but Chinese companies have integrated upstream and built capacity well ahead of future demand from the energy generation and storage part of the value chain. In a number of critical commodities, including iron-phosphate, graphite and silicon carbides, China has built capacity that is in large surplus to domestic requirements. Not all that capacity is likely to be capable of operating at a high utilisation rate, nor is it necessarily designed to – a lot of it is built to satisfy integrated demand. Understanding the situation in China, including the build-up of capacity, the timing of new entrants and the degree of integration in the value chain, is therefore essential to get a global view. This makes it even harder to progress projects outside China – not only is the danger of competition from Chinese exports always present, but China also dominates expertise in a number of key technologies.



Chinese Overcapacity Preventing Financing Outside of China despite Increased Future Demand

Domestic Chinese demand as a share of Chinese capacity, %

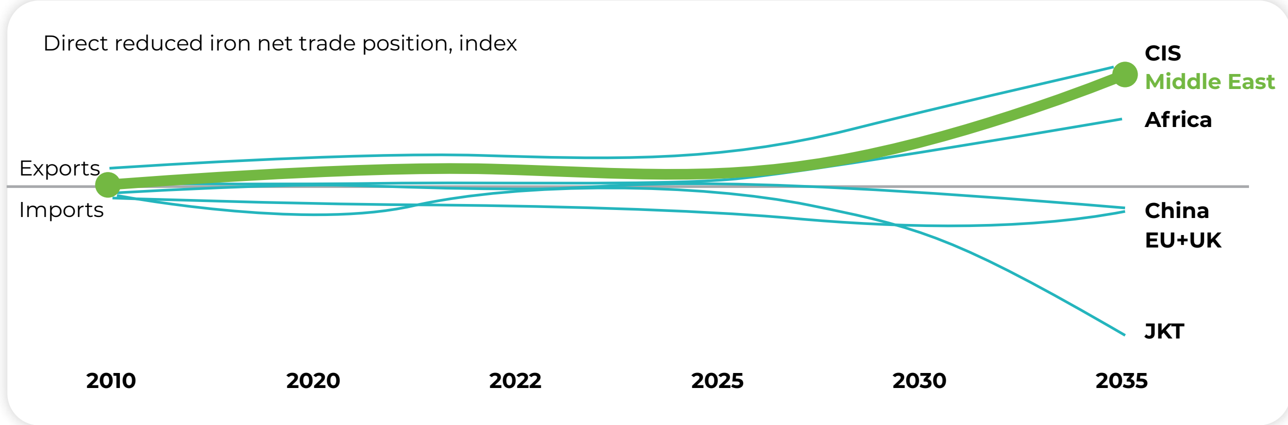


DATA: CRU

The Middle East, East Asia and the African continent are going to be particularly important in the effort to avoid delays in energy transition caused by bottlenecks. As well as being a recognised powerhouse of copper mining, the region boasts promising resources of graphite, Rare Earths, quartz, and many other critical commodities. **It is one of the few regions that combines ample resource with energy and capital availability,** and as such it is uniquely insulated from many of the teething problems, like access to capital, that energy transition has encountered elsewhere outside of China; indeed, it is slowly becoming a hotbed of greenfield project development both in mining and mineral processing.

Within the Middle East countries, mineral industry represents one of the pillars of diversification away from petrochemicals, as well as a promising outlet for investments facilitated by sovereign wealth funds, institutional and private investors. Take steel as an example: production in the region is expected to double between now and 2040, with key metallics inputs like direct reduced iron (DRI) essential for greener steel making also expected to follow the same path. Regulatory support helps, as was evident during the regional aluminium boom of the early 2000s. The current round of development needs continued focus, so that projects can be delivered consecutively and successfully but the region's commitment is clear.

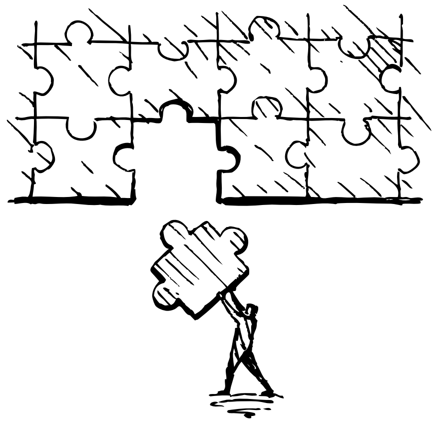
Middle East and Africa set to become key strategic suppliers of steelmaking raw materials on the global market



DATA: CRU

Meanwhile, the African continent has seen a new influx of investment into greenfield mining. In the case of copper, DRC and Zambia have become critical players with their combined production representing 14% of global production in 2023, growing from just 8% in 2012. Going forward, a further $13bn has been committed in CAPEX in the DRC and Zambia in 2023 and 2024. Recent investment in Zimbabwean lithium projects has positioned the country to become a key player in the global lithium-ion battery supply chain. Chinese mining companies are the main drivers of development in the region, with lithium capacity rising from 13 kt/y in 2022, to expected capacity of 192 kt/y in 2027 as a direct result with 5 mines.

The pace of development is hampered by regional challenges such as unpredictable geopolitics and the difficulty of securing logistics to transport material to ports and destinations. There is also a legacy of lender wariness: outside of copper and gold, it remains difficult to finance greenfield mining in Africa, although the growing role of governmental and pan-governmental entities such as South Africa's Industrial Development Corporation (IDC) or the African Development Bank have helped support project credibility.

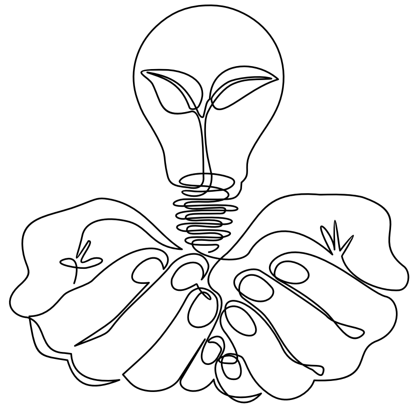


FLEXIBILITY AND INITIATIVE WILL BE NEEDED TO OVERCOME THE CHALLENGES

For the world to accelerate energy transition onto the steep path that leads to a 2C world, more flexibility in project development is needed. Time, in particular, is not on anyone's side here. Development timelines expand with every step upstream in the value chain, and there are very few ways to compress the required schedule for project development – the few that exist require consensus, cooperation, and coordination between the financial, regulatory, development and civil stakeholders. All the stakeholders need to have a basic level of understanding of the logic for development – independent advice and training with no interest in the outcome by experts like CRU is essential. They also need access to a consistent set of data that can clearly point to future demand in a structured way that provides confidence. Some of the data covers technological parameters and performance indicators; it has to be combined with a detailed translation into volume requirements and mass balances.

Partnerships between stakeholders have been one of the solutions for accelerating development, and they have resulted in successful delivery of renewable energy and "green" industrial projects. Such examples can be seen in lithium, for example, where automakers like BYD in China and VW in Germany have partnered with key lithium producers to ensure reliable offtake and accelerate development. While partnerships help share the burden and risk, they do not resolve the issue of standing out from the crowd. How does any company contribute meaningfully and demonstrate the value of its contribution?

CRU believes that these bottlenecks represent excellent opportunities for individual stakeholders to both meaningfully contribute and stand out. These are industries whose annual value is measured in the billions of dollars, where each additional billion makes a substantial difference, not just to the segment, but to the industry overall.



WITHOUT FINDING SOLUTION ACROSS STAKEHOLDERS, THE ENERGY TRANSITION CANNOT HAPPEN

However, investing at the bottlenecks is not easy. The value chain has to be comprehensively mapped, and the requirements for each material have to be clearly understood. Lenders and investors alike may be reluctant to make technological choices that can render a bottleneck material obsolete, so the risks of substitution have to also be understood and clearly communicated. The "critical" label helps attract state investments and incentives, but they come with strict requirements around delivery timelines and quality standards. Achieving some consistency in what is defined as "globally critical" would be a first step towards identifying projects that can resolve the most pressing bottlenecks. That could, in turn, encourage governmental and multi-governmental financing organisations take the additional step of not only joining partnerships, but actively guaranteeing loans and incentivising financing, thereby breaking a major deadlock in the path of greenfield capacity delivery. This would help solve a current fundamental challenge: while the scale of new capacity needed is starting to be understood, there are few locations where that capacity is welcome at local and regional level.

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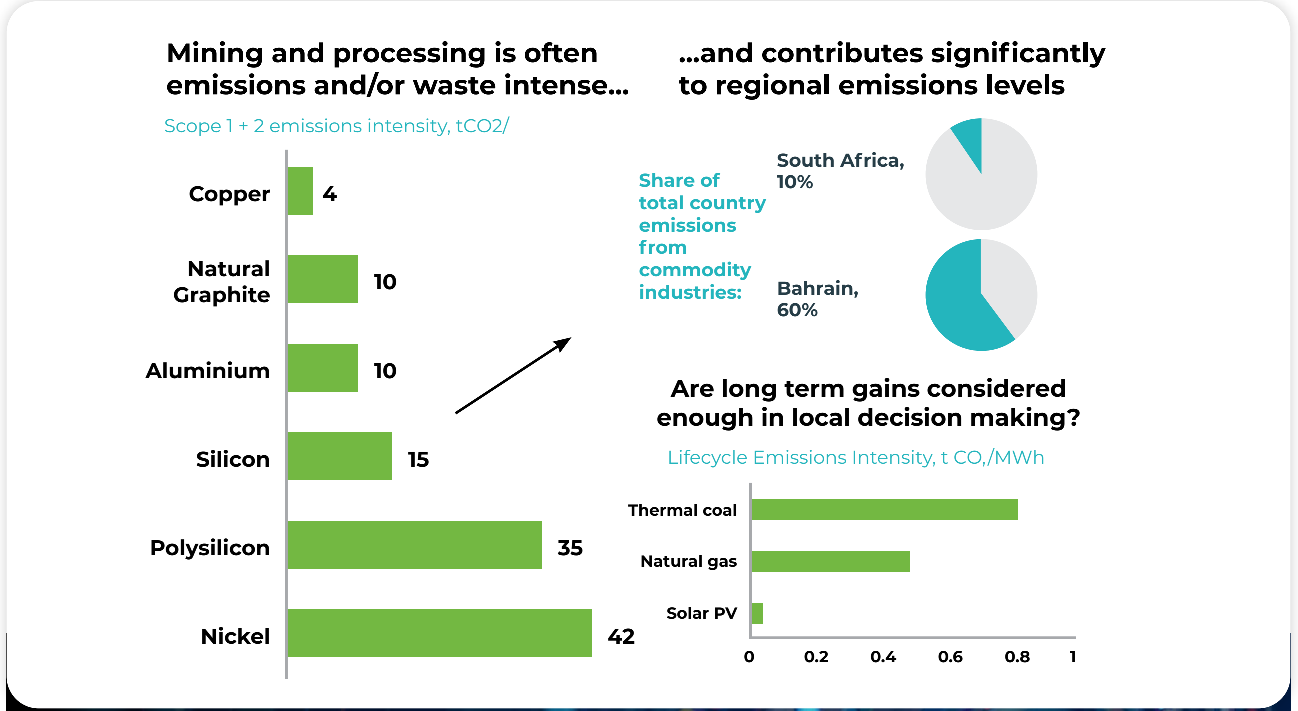
Local ESG challenges often don't align with long term climate goals



DATA: CRU

All these challenges have creative solutions, whether involving partnership opportunities, financing options, regulatory compliance, or production routes. CRU is well placed to provide advice on the best avenues, as well as the reliability of the likely "prizes" on offer, whether they be green premia for low-carbon materials or fiscal exemptions for critical mineral production. **Above all, Governments and civil society need to accept and embrace the challenge that without these materials, energy transition cannot happen.**