Unearthing Tomorrow:

Trends shaping the future of mining

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About State of Play™

State of Play™ was initiated in 2012 to create a platform to support industry discussion of innovation and performance at a strategic level and provide macro-level insights into the industry ecosystem.

The State of Play™ surveys enable us to uncover the impediments and success factors driving innovation across the industry supply chain and provide business executives with a health-check of how their companies benchmark against their peers. More broadly, the results have the potential to position the industry for a strategic shift.

This is our sixth biennial report on strategy and innovation in the global resources industry. The report represents a broad cross-section of the industry; it surveyed every continent, across mining and services companies and features a large number of respondents from executive or senior management levels.

The report, data pack and various supporting reports on key regions and issues of critical importance to the industry are available at: **www.stateofplay.org**

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We acknowledge the traditional owners of all lands on which the mining industry operates globally. We pay our respect to their Elders past, present, and emerging.

About our major sponsors

METS Ignited

www.metsignited.org

METS Ignited is the Industry Growth Centre for the Mining Equipment, Technology and Services (METS) sector, funded by the federal government Department of Industry, Science and Resources. The goal of the Industry Growth Centre is to accelerate commercialisation of innovation, enhancing industry capabilities and grow exports in sectors where Australia has a natural competitive advantage. METS Ignited supports Australian technology companies in translating local innovation into products and services, to serve global markets from within the national economy.

CSIRO

www.csiro.au

As Australia's national science agency and innovation catalyst, CSIRO solves the greatest challenges through innovative science and technology. They work with organisations large and small, delivering world-leading research and development solutions to help their business innovate, improve and grow. CSIRO is involved in developing technologies that enable the transition to renewable energy, including critical minerals discovery, environmentally sensitive extraction, and value-adding through processing and manufacturing in Australia.

Slate Advisory

www.slateadvisory.com

Slate provides strategic advice to the natural resources, energy and infrastructure industries to help solve the challenge of adapting to external forces. Slate advises established businesses on navigating these forces, through the design of business and functional strategy and tailored reviews. Slate also builds new businesses based on deep industry insight, through the design of business models and the bringing together partners, capital and capability.

The State of Play team would like to thank individuals from the following organisations for their participation in this research through interviews and interpretation of survey results:

Anglo American	METS Ignited
Aquila Consulting	MineHub Technologies
BHP	Mining3
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Chalice Mining	Resource Capital Funds
Cornwall Lithium	RCF Jolimont
CSIRO	Strayos
Hiseis	Turini Consulting
Imdex	United States Geological Survey
Lumenary Investment Management	Usiminas Mining

The method:

In 2023, State of Play partnered with CSIRO, METS Ignited and Slate Advisory to undertake the biennial Mining Industry Survey.

The research consisted of:

- 720 individual surveys from miners, suppliers, government, investment and researchers involved in the mining industry. Respondents were collected from 50 countries.
- 18 interviews with industry leaders.
- Desktop research and analysis.

The recommendations in this report do not necessarily reflect the views of all our sponsors and contributors, and are conclusions drawn by State of Play after analysis of the survey data, desktop research and interviews.

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Foreword

A decade after our first survey, we are proud to deliver State of Play's sixth biennial Mining Industry Survey report.

The report comes amidst a growing movement demanding change. Society is looking for more from our industry – more consideration for the environment, more responsible practises, and more meaningful engagement with community.

At the same time, the energy transition is altering the way supply chains operate, the demand for commodities, and the price attached to them. How do we ensure that critical minerals are mined in environmentally responsible ways? How will companies be rewarded for being more ESG conscious? What role does technology play? How do we navigate the geopolitical tensions that will re-form supply chains? And how do we find enough skilled workers to enable the success of the energy transition?

There also remains a gap between society's perception of the industry and what the industry is actually doing to address the energy transition. How does the mining industry create greater visibility and recognition for the hard work already underway?

As the industry evolves, so does the research State of Play conducts. We stand by our vision to positively influence the resources industry and communities through the strategic insights we create. To do that will require working even closer with the industry and the broader community to make sure our data can have the most impact possible in decision-making and strategy.

One thing that won't change is our fierce independence and curiosity. We will keep asking the big questions and uncovering the important insights needed to assist senior executives in their decision-making process.

Finally, we say thank you to all those who have generously given their time to respond to surveys, join our interviews, and participate in wide-ranging conversations. Your insights and support are the reason we can continue to do what we love.

Graeme Stanway
Chair of State of Play

Introduction

"Let's not forget we're going into an era which is going to be defined by metals. We're coming out of an era that has been defined by burning stuff."

CEO, Mining Company

We are entering an era of mining which has a firm focus on the energy transition. Mining companies are scrambling to figure out how to incorporate renewable energy sources and electrified equipment into their greenfield and brownfield sites. Mining service companies are trying to understand what miners need and how they can best support the transition. Underpinning all of this are questions around how companies will actually operate going forward, what each stakeholder role is in the development of the new energy economy, and the opportunities new energy scenarios enable within mining operations.

The energy transition will have flow on impacts to every aspect of the mining value chain. In section two of this report, we ask the question – is mining about to enter the golden age of exploration? As part of the transition the world needs more minerals than ever and with the rapid development of new technologies, there is no reason why we shouldn't see significant advancements in exploration innovation. Or is there?

While COVID-19 is no longer causing widespread delays throughout the supply chain, there are still numerous disruptions, this time resulting from the energy transition. As the political scramble to come out on top of the critical minerals boom continues, so do the unintended consequences for downstream processing and manufacturing.

Perceptions are fine until they become a reality and start having tangible impacts on mining operations. Industry is under no illusion how they are viewed by society, in particular around the topic of climate change, and we are starting to see more widespread repercussions of these views. How will the energy transition impact society's perceptions of the mining industry?

Throughout this report we aim to dig deep into some of these trends and how they may impact industry going forward. Our goal, as always, is to facilitate conversations on topics of importance to industry and we hope this report acts as a launchpad for those discussions, whether it be in the board room or at coffee with colleagues.

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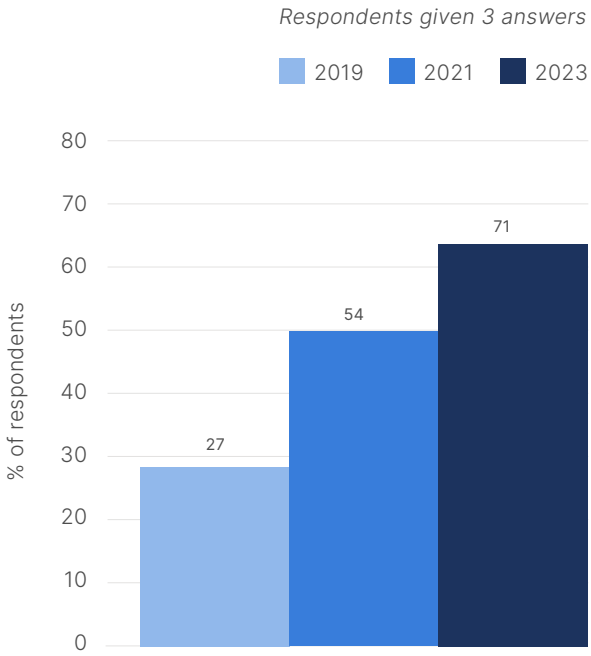
Energy

Written by Xavier Evans

It would be remiss of any report to discuss major strategic drivers in an industry and not focus on the energy transition. As humanity grapples with the challenge of mitigating climate change, the requirements of the energy transition have profound implications on all sectors of the economy. It is therefore unsurprising to see that 71% of executives believe that the energy transition is a primary driver of their corporate strategy.

More remarkable is the pace of change in this view. Our survey in 2019 revealed that only 27% of executives prioritised energy as a strategic driver, and in just four years that proportion has almost tripled. Decarbonised energy has moved from a business unit focus to a fundamental existential concern. Mirroring both safety and digital before it, energy is now constantly front of mind of CEOs on the short and long-term investment horizon.

Proportion of respondents who believe the energy transition is a top 3 strategic driver in mining over the next 15 years

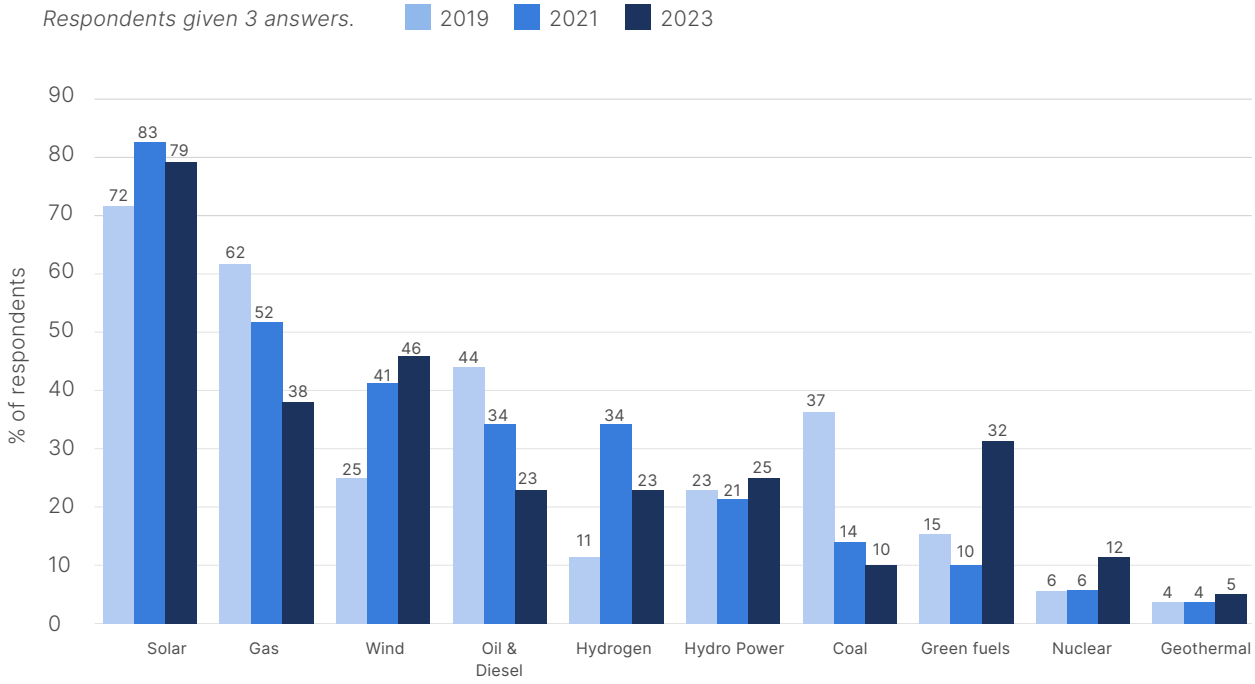


What separates mining from other industries in this respect is twofold: its fundamental role in the development of the new energy economy, and the opportunities new energy scenarios enable within mining businesses given its relative energy intensity. As the supplier of the critical minerals required to manufacture everything from solar panels and wind turbines to transmission lines and batteries, the energy transition journey is really a mining-led story. Any veteran of the iron ore industry will tell you to take demand projections with a grain of salt, but to take one set of projections from the International Energy Agency, we will require approximately 1000Mt more refined copper ore by 2050, having produced just 825Mt in all of human history to date.[1] The growth potential for critical minerals for the energy transition is well understood, even if the development of supply faces significant challenges.[2]

1. IEA
2. See our 2022 and 2023 reports on Critical Minerals for an in-depth perspective.

Internally, the role of energy in mining itself has evolved. The industry is very energy intensive – the metals and mining were responsible for approximately 3.5% of total global final energy consumption.[3] Since 2019, environmental concerns have been the major driver of industry change according to our survey data. Renewable energy was simply a component of environmental stewardship, alongside low-footprint mining and water management. In 2023, the focus has shifted – energy transition now leads as a driver of internal industry change (60%), eclipsing environmental concerns (50%). There has been a clear decoupling of renewably powered mining from strictly environmental concerns. The primary driver of the shift has been cost – renewable energy is now consistently cheaper on a per unit basis than fossil fuels in many mining geographies.[4] Some sites have had a head-start, combining wind and solar power with baseload hydropower to manage intermittency. Antofagasta's Zaldivar and Los Pelambres copper mines in Chile are exclusively powered by renewable energy – a mix of wind, solar and hydropower.

QUESTION **What energy sources will become the most widely used in your country's mining companies over the next 15 years?**



For sites without on-demand hydropower, intermittency and unreliability remained a core concern for continuous operations, but recent evidence from regions such as Australia suggests that renewables can power up a vast majority of off-grid energy consumption for mining assets. Bellevue Gold's Eastern Goldfields project is forecasted to generate 80% electricity from renewables, with sizeable wind, solar and battery storage components.[5] Goldfields have recently announced they are investing in a wind and solar power complex at their St Ives mine, which will meet 73% of the mine's electricity needs when its operational in 2025.[6]

3 Engineering and Mining Journal
4 Our World in Data
5 Renew Economy
6 Renewables Now

While feasible in renewables-rich Australia, many other regions do not yet present the same economic case for renewables compared to fossil fuelled operations. Ultimately, the degree of renewables penetration is contingent on the cost and availability of renewable energy, installed distribution infrastructure, the cost of energy storage, and technical capability. As the industry matures, we are likely to observe viability increasing across geographies, where a reduction in costs and increase in technological capability reaches a tipping point in favour of renewables more broadly.

The shift to renewables may also be reinforced by increasing pressure on fossil fuels – carbon taxes, supply volatility and external decarbonisation pressure will continue to increase the cost and risk profile of traditional fuels.

According to the IMF, 2022 saw the largest global subsidies for fossil fuels in recorded history at over 7% of GDP – a growth rate which is unsustainable with both public budgets and environmental priorities.[7]

Meanwhile, 26% of global emissions are now covered by a carbon tax or emissions trading scheme, up from just 15% in 2020.[8] In addition to greater direct costs of extraction, greater scrutiny over end-of-life rehabilitation is increasing the whole-of-life costs of fossil fuel projects and mining projects alike. Where miners look at lower footprint extraction methods, fossil fuels have less certain cashflow to fund expensive clean-up efforts. Rystad Energy, a consultancy, estimates that the global pool of decommissioning projects in oil and gas will reach $42bn in 2024. In rich countries, much of the burden is falling on governments – clean up and rehabilitation has required policy investment in the United States (US) and Spain.[9] [10] In developing countries, rehabilitation work is often abandoned, such as in South Africa's old gold and coal mines or Brazil's abandoned urban mines.[11] [12] [13] Finally, non-economic factors may increase investment in renewably powered operations, from security of energy supply to reduction in diesel particulate matters, particularly in underground mining.

7. IMF calculations include a combination of explicit subsidies (undercharging supply costs) and implicit subsidies (not factoring externality costs into pricing – e.g. the cost of flood damage due to climate change)
8. Dolphin and Xiahou (2022) – with minor processing by Our World in Data
9. E.g., The U.S. Infrastructure Investment and Jobs Act of 2021
10. The International Labour Organisation
11. Human Rights Watch
12. The Associated Press
13. Mhlongo et al.

Decarbonise to derisk?

Throughout our conversations with mining leaders, the risk in current and future energy systems was a key concern. Fossil-fuel systems suffer from a supply risk but benefit from legacy infrastructure and local maintenance capability. A new renewable economy solves the supply risk as renewables can be generated anywhere, but storage and infrastructure development become major concerns that also increase risk.

Start with the supply of joules of energy. Here, a shift to renewables is a shift to the local. Generation projects are generally located close to operations to reduce transmission costs, and the general prevalence of at least one source of renewable energy in most geographies enable some type of renewables to pair any operational site. Compared to geographically constrained deposits of fossil fuels, renewables are decentralised, local and enable greater autonomy for operators. As the industry renewably electrifies, there is less exposure to volatile hydrocarbon markets that are intrinsically linked to geopolitics. From the OPEC-instituted oil shock of the 1970s to the European gas price shock in 2022, hydrocarbon supply has always been risky, particularly in non-producing countries. Renewables meanwhile derisk energy supply by democratising generation capacity and allowing operators to generate their own power.

However, a renewably powered system increases other risks. Today's strong investment in energy transition technology has demonstrated the risk of concentration in energy technology components. Chinese manufacturers dominate much of these new industries, from solar panel production, to refined critical minerals, to electric vehicles.[14][15][16] China has already used its dominant position to limit trade including export restrictions on magnesium in 2021, gallium, germanium, and graphene in 2023 – all in response to geopolitical tensions with the West. Have energy consumers simply exchanged one set of politically sensitive supply chain bottlenecks for another? Executives have differing opinions depending on geography – in particular American (43%), European (38%), and African (30%) respondents were the most concerned about geopolitical tensions impacting their industry.

> **"The rest of world has given China a twenty-year head start on critical minerals processing capability."**
> **Mining Board Member**

Recognising the supply security threat as well as the growth opportunity, governments worldwide are investing in domestic energy technology industries. The two largest policy packages addressing the energy transition (and critical minerals supply) are the Inflation Reduction Act (IRA) in the US and the European Green Deal in the European Union (EU). For the mining industry, the policy trend has two major upsides. First, governments are increasingly investing in enabling critical mineral supply by streamlining approaches to project development through permitting and capital raising reform.[17] Second, governments are investing in the development of renewable generation projects, including those developed by operators to power mine sites. In effect, these policies are working to mitigate the significant decarbonisation and geopolitical risk factors faced by their countries.

14. IEA
15. European Commission
16. MIT
17. See our 2022 Critical Minerals: An Industry Perspective report.

Government action on supply resilience

Ownership of energy generation

The **European Union** has developed its *REPowerEU* plan to diversify energy supply away from Russian gas

The **Chinese** government invested US$40bn in renewable generation in 2022 alone

Chile has attracted over US$1bn from global capital markets for the development of a green hydrogen

Ownership of green manufacturing & processing

The **United States** Inflation Reduction Act commits US$27bn to the development of green manufacturing

The **Indonesian** government has restricted nickel exports and received US$16bn in FDI for onshore processing

Australia committed a further US$1.3bn to the development of downstream refining of critical minerals

What does this mean for the industry? Mining has always had a political component to it, from managing expectations of local communities, striking agreements with governments for large capital projects, to managing taxation and regulation regimes. The nature of this relationship has been tricky, as governments balance economic returns with (often negative) perceptions of mining activity. As minerals are designated as "critical" for the transition, and amount to a core strategic priority at a national level, miners are likely to feel the benefits. The EU is currently considering policy options to streamline approvals for new mines, including making it easier to override opposition at a local level in its Critical Raw Materials Act.

Ultimately the energy transition is driven by forces larger than the minerals market. Government is intrinsically involved in the process, and miners have an opportunity to ride the wave. Depoliticising energy supply through renewable electrification reduces risk on one hand but exposes companies to greater risk on energy component bottlenecks. Governments are also on hand to support the development of energy projects – if anything energy just became more political.

"Government must play a central role because climate change is inherently a government issue. Without government intervention, we would fail to move."

CEO, Mining Company

Having the energy to innovate

The clearest impact of the energy transition on the mining industry is the enablement of electrified operating models. Plenty of innovation is occurring in this space, with the Electric Mine Consortium (EMC), Global Mining Group, and the International Council on Mining and Metals among other bodies looking not only at retrofitting or replacement of existing equipment, but also the opportunity to mine in different ways to extract resources more efficiently.[18] In 2023, Newmont made a significant transition to a full battery-electric fleet. Replacing old diesel equipment avoided a projected 65,000 tonnes of CO2 through to 2030, the new equipment delivered higher productivity, lowered unit costs, and enhanced efficiency. Some original equipment manufacturers (OEMs) are electrifying new sets of equipment including Epiroc's first-ever battery electric surface dill rig.[19]

While electrified fleets and long duration energy storage technologies are currently headlining innovation efforts, an increasing area of focus for executives is processing.

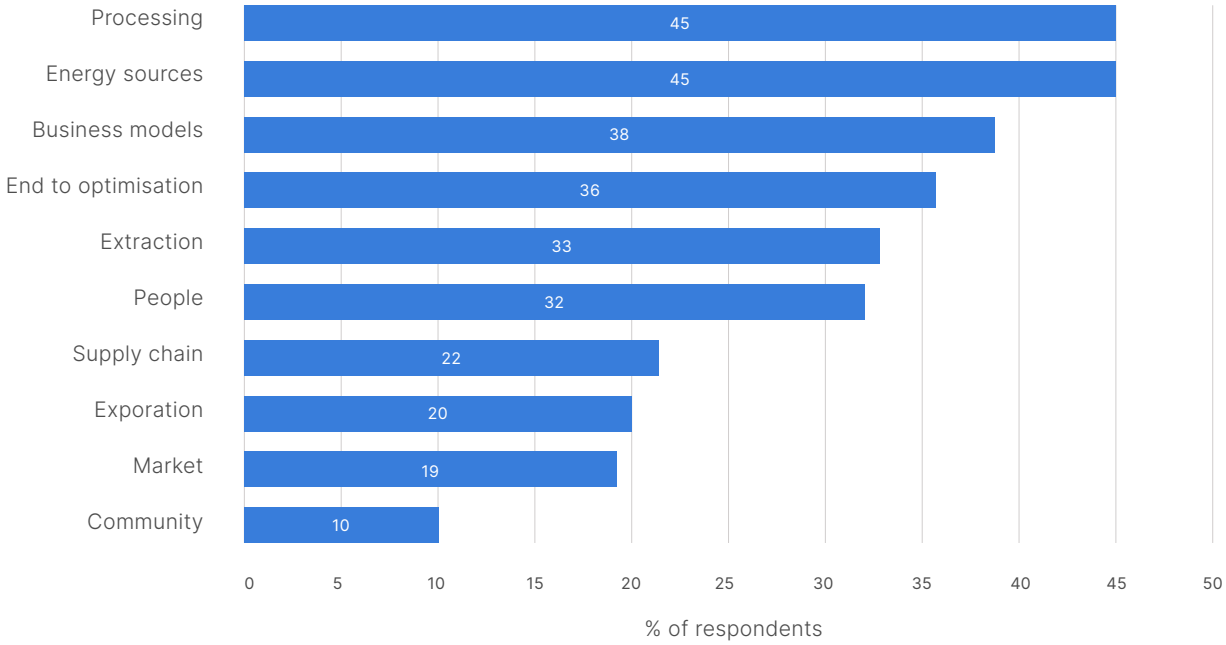
18. See our The Electric Mine Consortium: A Case Study on Transformative Collaboration report.
19. Epiroc

Processing has traditionally been slower to innovate compared to other parts of the value chain. This is primarily because foundational innovations in physical processes like extraction and refining (unlike digital technologies) are complex, large scale and capital-intensive endeavours which typically take decades to develop. They are therefore associated with very high investment return risk. We are seeing the emergence of potentially disruptive leaching extraction technologies such as those from Jetti Resources, however the time frame from the original scientific work to significant market adoption is still measured in decades. Processes such as the Bayer process to extract alumina from bauxite can be up to 150 years old. To date, technology has vastly improved their scale and safety, but the underlying method has remained largely consistent.

Processing and energy are the two clear leaders in innovation efforts in today's mining industry – 45% of executives see each as primary focus areas respectively.

QUESTION **Where in the value chain are your innovation efforts primarily focused today?**

Respondents given 3 answers.



Changing energy input characteristics could represent a fundamental shift in processing innovation. Outside of safety considerations, all processes are optimised specifically to reduce energy costs per unit of processed mineral output. An abundance of cheap renewable energy could have significant impacts on processing in a number of ways.

The first is location. Currently processing often occurs close to energy abundance, be it hydropower or cheap (mainly coal-fired) electricity grids. Solar and wind power in particular change the decision-making calculus. Much in the same way that renewables enable greater energy autonomy for extraction, energy-intensive processing may not need large, centralised infrastructure to operate efficiently. For every new opportunity renewables enable in sun-drenched or wind-swept geographies, other countries may lose sources of competitive advantage. Countries such as Malaysia have developed a competitive advantage using hydropower to power energy-intensive smelting operations, which may be increasingly under threat from new entrants based on new energy capabilities.

The second is flexibility. Currently most processing operations are run continuously, both to avoid start-up and shutdown costs, and crucially to maximise production in the shortest timeframe possible given current installed capital with access to a continuous supply of energy. It makes more sense to produce now with ongoing gas supply, than it does to store that gas for later. Continuous production reduces storage costs and maximises the time value of energy. But in a world where energy is not continuously available, electricity production can exceed total demand at any point and storage remains expensive, how do project developers manage renewably powered operations? One option is to innovate around the concept of continuous operations, and potentially develop new operating models that are cheap to start-up and shutdown that can become a better option to virtually store the energy – produce excess mineral product that can be stored more cheaply than the energy itself.

As smart grid and demand response technology becomes more viable, the infrastructure and market mechanisms that enable it will mature. Firms like VIOTAS are already integrating with electrified systems to time production for low-energy demand and selling excess energy for a profit. On large grids this approach may be led by more flexible manufacturers, however in smaller or more decentralised networks, miners might be a core component of grid stabilisation.[20]

The third is changing the process itself. Changing renewable energy inputs have already opened a market for products such as green hydrogen and steel, where production methods have evolved to accommodate the use of 100% renewable electricity. As this trend continues, it will continue to catalyse the development of new processing techniques and enable more efficient operation of existing techniques. Cornish Lithium are one such company rethinking processing with a geothermal based Direct Lithium Extraction (DLE) process yielding lithium from, and powered by, zero carbon energy from hot springs, consequently refining lithium at a lower cost per unit and environmental impact than traditional methods.[21] Increasing renewable energy availability could also play a role in adapting existing mining processes

"We are seeing a structural change within the mining sector, as processing becomes a more dynamic step in the value chain – a decoupling of the processing plant from mining operations"

– CEO

for greater cost-effectiveness. Leaching as an example, is a low-capital and flexible method to process low-grade stockpiles of copper, gold and uranium, utilised by companies such as Rio Tinto who have recently developed a sophisticated and sustainable bio-leaching technology, Nuton, to yield high-quality results.[22] [23] However, this relatively energy-intensive process presents a high cost when operating with typical power means. By adapting this processing system, matching its high flexibility with cheap renewable energy power access in high supply periods, suddenly the process could become far more efficient. The likelihood is that processing solutions, whether existing or new, will adapt to capture the opportunity presented by changing renewable energy inputs.

20. VIOTAS
21. Cornish Lithium
22. Rio Tinto
23. Jetti Resources

Mining's Changing Energy Equation

Local processing	Changing energy competitive advantage enables processing to occur in new geographies, potentially closer to extractors or customers
Flexible processing	Instead of storing electrons, flexible processing enables ramping up and down of production based on energy availability, storing value for later
Extraction methods	New extraction methods that required significant energy input could bypass existing processing methods altogether

Not all transitions are created equal

Climate change is a global crisis, but uniformity ends there. Renewable energy endowments vary widely across and within countries, legacy infrastructure and demand requires very different approaches to the transition, and the nexus between energy and mining ultimately presents a highly diverse transition pathway.

Mining is no stranger to heterogeneity – an open-pit iron ore mine in Australia may as well be a different industry to an underground coal mine in South Africa or a lithium brine extraction facility in Chile. The energy transition only adds to this complexity and heterogeneity.

Take Europe for example. The long history of industrialisation combined with a relatively small geographical footprint compared to other continents has led to a dwindling mining industry. There is a fundamental mismatch between exploration and demand – the EU represented just 3% of global exploration spend while representing more than 15% of global minerals demand.[25] Efforts to reverse this decline in discoveries and production are further impacted by a precarious energy environment. The supply of natural gas was abruptly interrupted by Russia's invasion of Ukraine, and the resulting shock caused significant industrial disruption for energy intensive industries. Industry and government

"We all know how to dig stuff out of the ground…So what is the innovation required? The way you process minerals without using fossil fuels in an irresponsible way, and that is chemical engineering, not mining engineering".

CEO, Mining Company

alike are developing renewable generation options on the continent, from Hydro Rein's (Norsk Hydro) Joint Venture with Macquarie Asset Management to develop a 6.9GW portfolio of renewable energy projects in the Nordics and Brazil, to Boliden's 15-year, 1,000GWh per year contract to power operations in Sweden and Finland.[26] [27] However, land availability concerns and high project development costs could ultimately drive European miners up the cost curve and vulnerable to further supply shocks if the limited renewable generation capacity is directed towards other industries and sectors.

Conversely, roughly the majority of Brazilian energy mix is derived from hydropower, with a further 10% from other renewables and biofuels. Already a significant producer

24. BP
25. European Commission
26. Norsk Hydro
27. S&P Global 2020

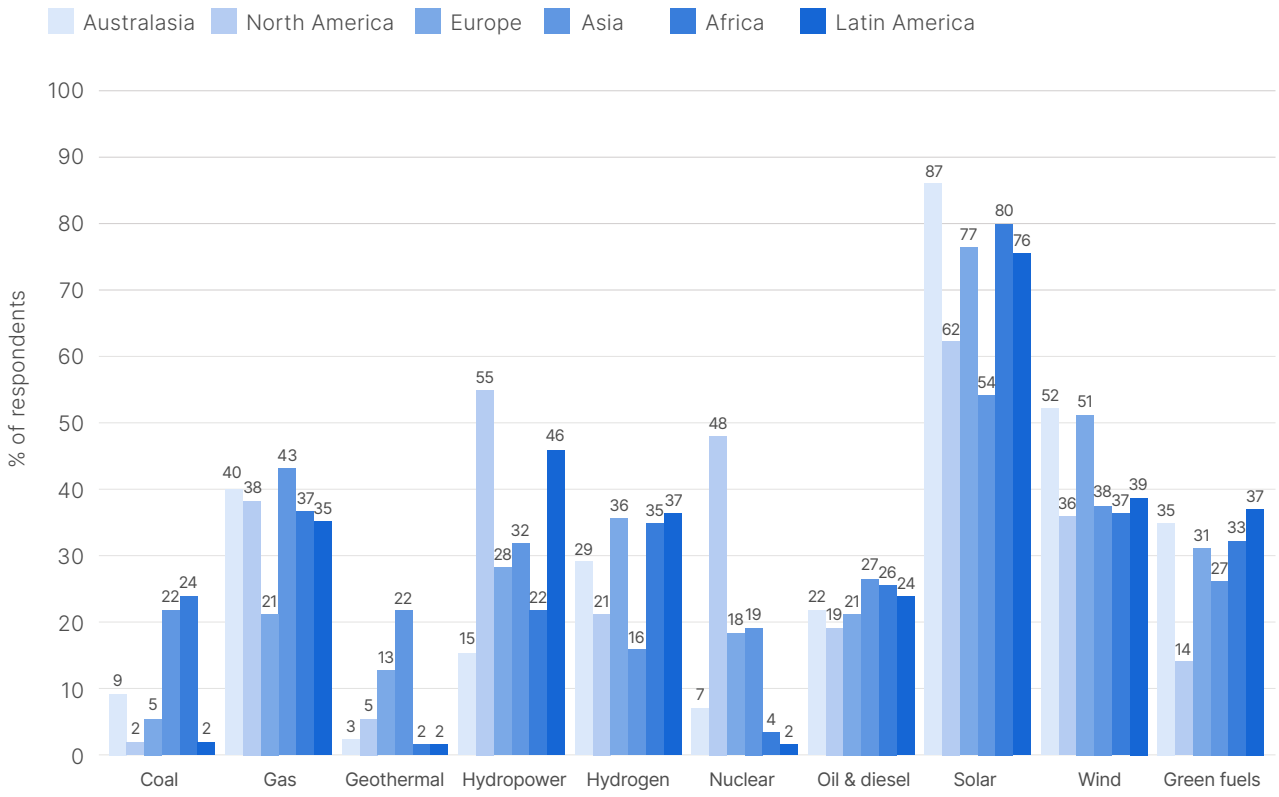
As an illustrative example, coal use for electricity generation is not equal across the world – it is 15% in Europe, 63% in China and 84% in South Africa.[24]

of ore, existing renewables penetration and capture in Brazilian energy systems could open the opportunity for the development of a more mature downstream capability. Whilst it only holds a 3% share in global population, Brazil is responsible for almost 7% of the planet's renewable energy production, this surplus signalling that meeting future energy needs with Brazilian clean energy would be more viable and cheaper than expanding fossil fuel capacity.[28] The World Bank sees this as an opportunity for Brazil, who are 'ahead of the race', to use this abundance as an advantage to develop its onshore processing and storage capacity to become a world leader in clean energy.[29] Initiatives such as the Lithium Valley project, the nation's unprecedented collaborative effort between mining companies and state and local governments in the in the region of Minas Gerais, indicate the desire of the nation to capitalise on its aforementioned endowments. The project has goals of attracting capital and private investments to Brazil's lithium battery supply chain, a concentrated effort to develop a holistic mining and processing hub, driven by ever-increasing demand for batteries, as well as the opportunity to produce sustainable "green lithium".

28. IEA
29. World Bank

QUESTION **Question: What energy sources will become the most widely used in your country's mining companies over the next 15 years?**

Respondents given 3 answers.



One concern with this approach in a hydropower-dependent energy system is the impact of climate change on water availability. Changing rainfall patterns and increasing drought could continue to threaten the viability of hydropower assets and leave them stranded.

"If Australia wants to win in processing in this new energy environment, it must think and act like German manufacturing – high-tech, high value-add, high levels of productivity."

Executive, Mining Company

Australia on the other hand has both significant renewable generation capacity and minerals production. The concern is scale and non-energy costs, which has undermined previous downstream processing ambitions for decades. Could solar and wind abundance be enough to tip the scales? One option is high-end specialisation, focusing on specific markets where green premiums may exist, and scale is secondary to quality. Here, higher costs are compensated with better margins and backed by energy availability that delivers the required resilience for long-term contracts for specialised products. Consumers can trust that production continues, knowing that energy supply disruptions in similarly technologically capable Europe may present an intolerable risk.

The energy transition is the fundamental trend of our time. An entire species increasingly dedicated to avoiding a calamitous future by fundamentally re-engineering the global society we live in. Mining is once again offered a ride on the wave of long-term change, and in doing so will have the need and opportunity to remodel itself, establishing the scene for a truly innovative future for the extraction of raw materials to meet humanity's needs.

Exploration

Written by Madi Ratcliffe

The role of exploration in the mining industry is underpinned by the fact that without an ore body, there is no value. As known economic surface resources deplete, the world will need to uncover deeper, more complex, and costlier deposits to meet the growing projected global mineral demand.

It is therefore fair to assume we are entering an era where innovation in exploration will be at the top of the industry's agenda – however, it remains relegated to the periphery, where it has been since the golden days of Western Mining Corporation over half a century ago. Only 21% of resource companies currently view exploration as one of their top 3 innovation priorities, a perplexing statistic given its central role in value creation.

Indicators reaffirm that this has been the case for some time – the productivity of exploration success has not materially advanced in the last three decades, despite efficiency gains witnessed in other areas of the mining industry.

This chapter aims to delve into the underlying reasons for this situation and will present a set of key indicators to monitor. These indicators will help gauge the likelihood of a revival of exploration innovation in the near future.

"There's a stunning number of mining companies that do not have a geoscientist on their board... mining is a geoscience-led profession that's run by engineering-led boards and executives."

CEO, Services Company

Why has innovation in exploration lagged?

There are several technical factors that can be seen as reasons for the low rates of innovation in exploration. The earth's subsurface is made up of geological formations and structures that occur in diverse and intricate patterns. Predicting the presence of minerals is an extremely complex task that requires the integration of specialised knowledge from multiple scientific disciplines. Furthermore, the application of exploration is highly capital intensive, the outcomes are highly uncertain, and the payback periods are long. As a result, exploration has been perceived as too risky and technically complex to attract external investment. The ability to overcome such complexities is exacerbated by the structure of the industry – mining exploration and mining operations are segmented into two completely different domains.

The upstream portion of the mining industry is characterised by companies with a clear division of focus. Typically, it is the junior companies that specialise in exploration, and the larger companies that specialise in development and operations. Both play complementary but distinct roles in the value chain, reflecting differences in risk appetites, capital resources, objectives, operations, and characteristics.

The junior explorers' core mission is to identify valuable greenfield resources that have the potential for future extraction. They tend to be relatively small-scale entities who embrace a higher degree of risk for the inherent financial and geological uncertainties of exploration. The juniors do not generate revenue, and often rely on investor capital to fund their activities with the expectation that they will be acquired upon making a discovery.

In contrast, the larger operators take on the responsibility of extracting, processing, and marketing the materials. Despite having significant financial resources, they are structured to operate with a much lower risk-threshold, and as a result are more inclined to invest in operational efficiencies than the high-risk activity of greenfield exploration. When looking to grow their portfolios, these entities tend to rely on either brownfield exploration or the acquisition of later stage explorers to gain access to new resources.

For the juniors, the industry structure encourages a focus on near-term feasibility to make a project enticing for acquisition. This approach, while achieving quick financial viability, results in significant knowledge gaps, undermining the development of comprehensive ore body knowledge and underplaying life-of-mine implications. A history of doing the bare minimum has resulted in the stagnation of the industry's learning ability and has impeded progress in exploration. Neglecting to push the boundaries of knowledge kills innovation, and unless a longer-term perspective is incentivised there will be little change.

The financial constraints of junior explorers further compound the challenge. Limited budgets result in a preference for traditional, proven exploration methods – typically this means looking for near surface deposits using existing drilling technologies. This approach inhibits the sector from embracing innovative technologies or methodologies, which then in turn disincentivises technology manufacturers and service providers from engaging in innovation efforts, particularly related to greenfield exploration.

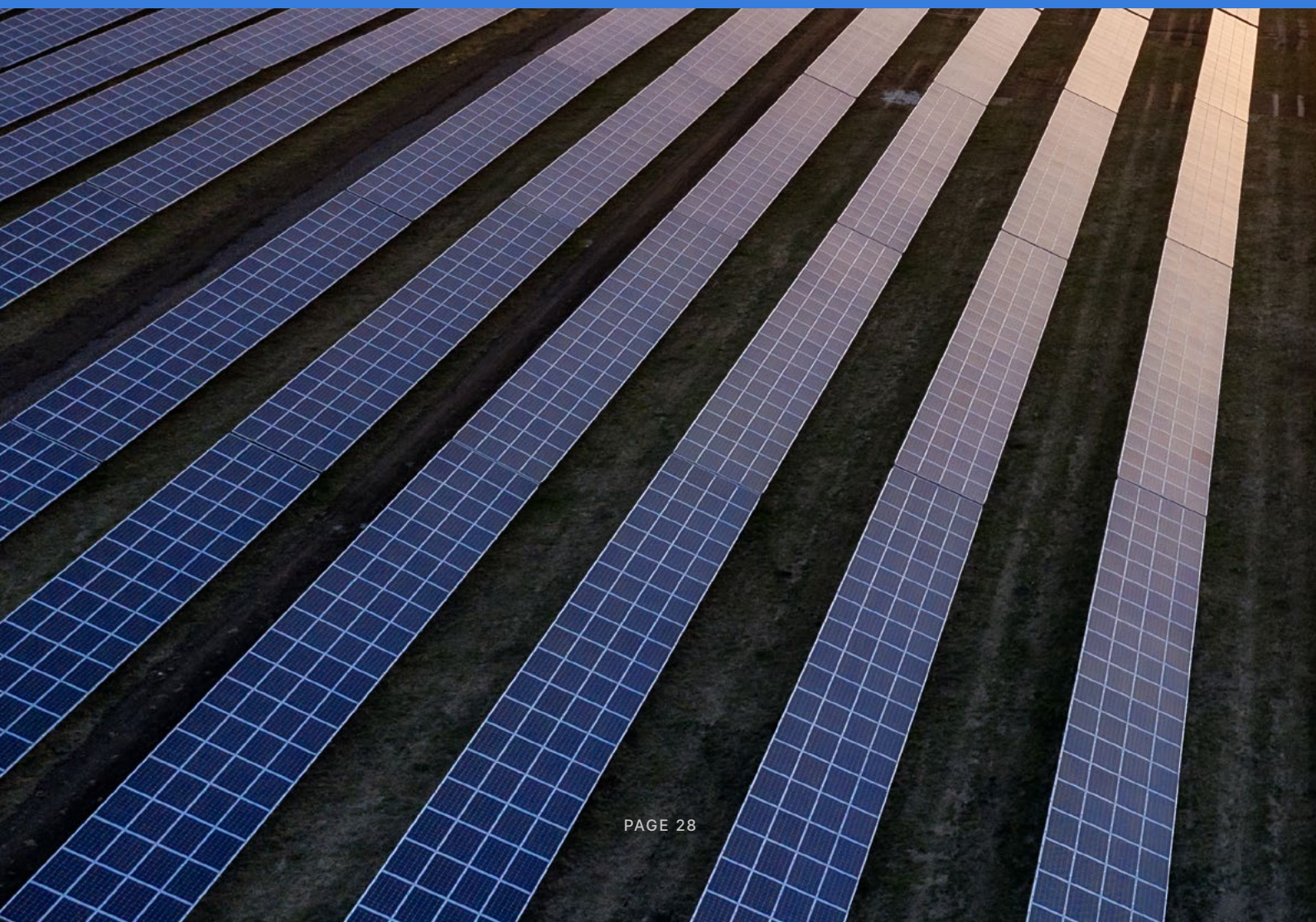
The current industry structure of segmentation is impeding innovation in exploration.

"We are not doing anything differently in how we find rocks, than we have in the last 50-60 years - not remotely embraced any innovation."

Mining Company Executive

Whilst some of the larger operators do participate in greenfield exploration (with the backing of substantial budgets), the way in which they engage also fails to drive innovation outcomes. Either engaging for the purpose of securing new assets through discovery, or to ensure they retain the internal capability to be an "educated buyer" of early-stage assets (akin to venture capital), the large operators do not place greenfield exploration within their core business. Inevitably, this culminates in a reluctance to invest in long-term technology-based innovation programs.

The current segmentation in the greenfield exploration industry, particularly the reliance on junior explorers pursuing acquisition-driven strategies, has inadvertently hindered innovation. The emphasis on short-term feasibility, coupled with financial constraints, stagnates learning and discourages the adoption of advanced exploration technologies and methods. If we are to believe that the industry is headed towards a golden age for exploration, the current structure will need to morph into one that is more integrated, incentivises long-term knowledge and technology development and offers greater financial support for the adoption of new technologies and methodologies.



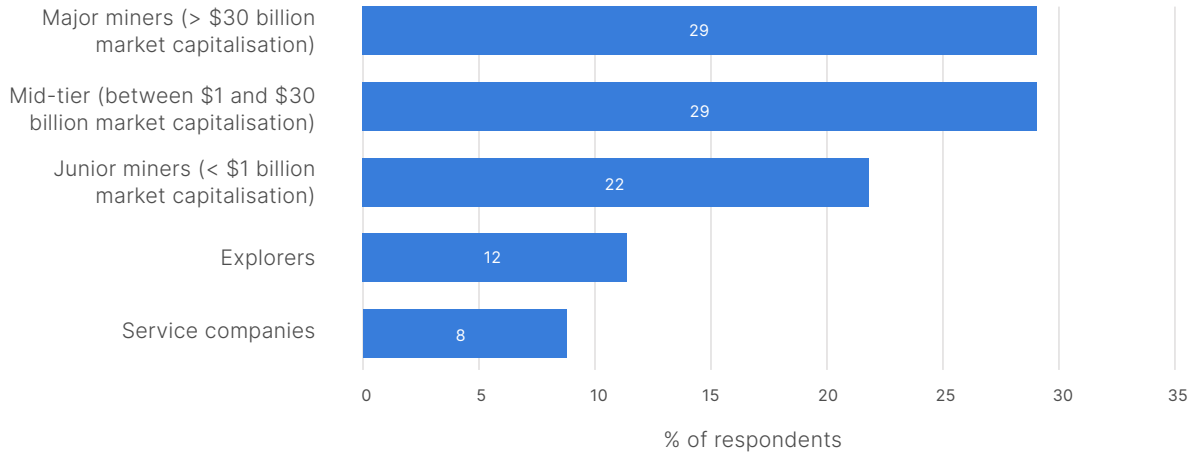
Who is industry looking at to take a lead?

Given the growing need to explore deeper, more complex geologies, the requirement for transformative changes in exploration methods is likely reaching a tipping point. Only 12% of industry believe explorers will drive this transformation. If industry is correct in assuming that innovation currently sits outside the budget and skillset of the explorers, then who is going to fill the void?

When asked who they expect to lead the way in delivering exploration innovation, approximately 60% of industry believe it to be the major and mid-tier miners. If this is the case, these companies will need to significantly intensify their current efforts.

QUESTION **Which companies are leading exploration innovation?**

Respondents given 1 answer.



Despite lacking in technological innovation, over the last two-decades junior companies have outperformed the majors and mid-tiers in delivering exploration results.

In the Western world, the juniors have been responsible for unearthing approximately 70% of the total number of mineral deposits, accounting for roughly half of the industry's overall value. In contrast, major and mid-tier miners have discovered only 18% of the total number of deposits, contributing 35% of the industry's value.[30]

Whilst these figures may indicate success, they do not demonstrate efficiency.

As surface or near-to-surface deposits continue to deplete, it is likely these already low efficiency rates will decrease even further. For reference, it costs nearly 8x more to discover an ounce of gold resource today than it did in the 1960's.[32] To ensure the unit discovery costs stay within the bounds of economic feasibility, especially as capital markets become more challenging to obtain financing, there will need to be some form of innovative intervention.

For every dollar raised by juniors, the average return on investment has been less than 75 cents.[31]

30. MinEx Consulting
31. Anecdotal data from one of our interviews with a CEO of a mining services company
32. Gold Fields Exploration Strategy Analyst Day

There are two simple indicators that we can monitor to further assess whether the major and mid-tier miners are adopting a leadership role in delivering this much needed exploration innovation.

The first indicator is the share in total exploration spend. Of the 769 metals and mining companies listed on the ASX in March 2024, only 55 of these have a market capitalisation of over A$500 million – the other 714 are considered junior companies.[33] In 2022, junior exploration companies accounted for a notable 43% of the global exploration budget, reaching an 11-year peak. This figure was only 11% less than the combined budget of major and mid-tier miners.[34] Considering the substantial financial resources at the disposal of major and mid-tier mining companies in comparison to juniors, we should expect their share of the global exploration expenditure to be considerably higher if they aim to take a leadership role in this domain.

The second indicator, whilst typically more difficult to monitor, lies in how the individual companies allocate their exploration budgets. According to one of our interviewees, over half of every dollar spent by a mining company investing in exploration, goes into drilling. As companies begin to transition to newer exploration technologies and methodologies, we expect this proportion to decrease, as a greater emphasis is placed on innovative ground selection and targeting techniques, ahead of drilling.

The last year has delivered intriguing signs for these two indicators evolving in the required direction. Against the backdrop of unfavourable macroeconomic conditions, S&P Global analysis shows global greenfield exploration budgets have reduced 9.8% from 2022. September drilling activity was the slowest in three years, and funds raised by juniors and mid-tiers was 14% lower than this time last year.[35]

Whilst overall there has been a contraction, it has come from the junior and mid-tier end of the industry. The major companies, who are less impacted by depressed financing conditions, delivered a 1.2% increase in their exploration budgets. Whether this is a strong enough divergence to suggest the majors have taken on the leadership mantle of driving exploration innovation remains questionable.

"Better targeting technologies will drive better exploration outcomes. But that will be the purview of the majors or new generation technology companies, not traditional juniors."

CEO, Mining Service Company

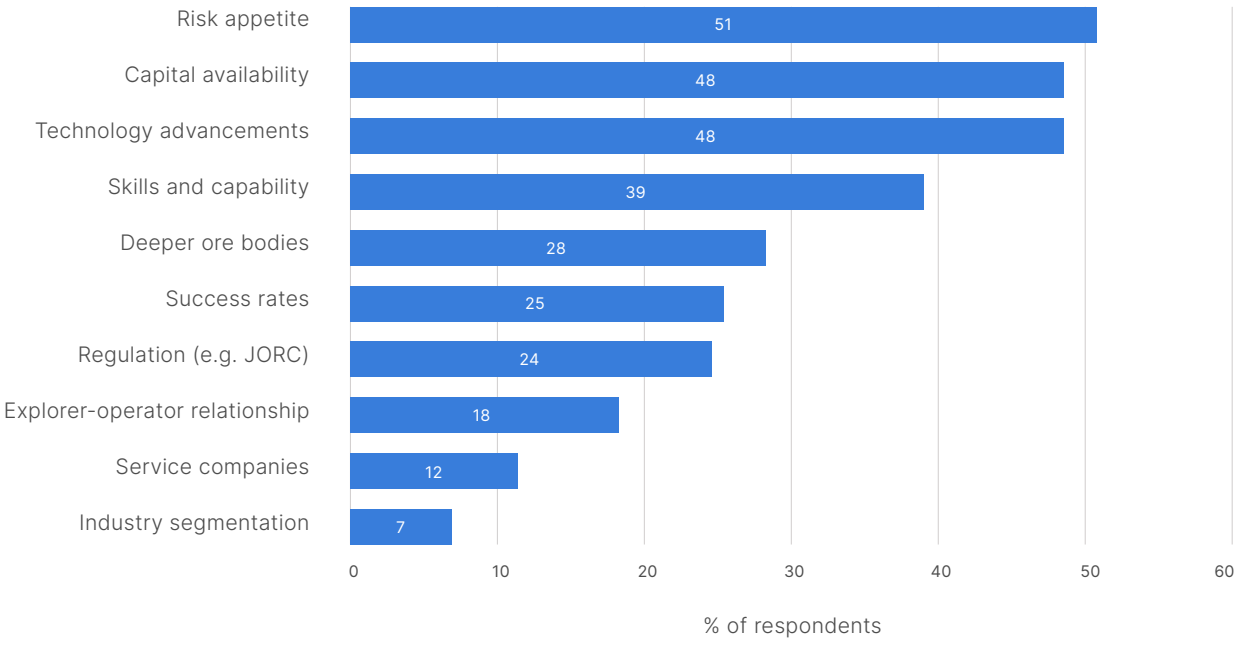
33. Listcorp
34. S&P Global 2023
35. S&P Global 2023

What will drive exploration innovation?

Whether innovation is coming from a major, mid-tier, junior or services company, our survey results suggest a readiness to embrace risk, access to capital, and the capability to assimilate technologies from other sectors is necessary to successfully innovate. However, these three drivers reside in different stakeholder groups, making it challenging to execute all three. While juniors possess the risk appetite, they often lack the necessary capital. On the other hand, majors boast substantial capital but shy away from significant risk. Services companies excel in technology, yet frequently grapple with limitations in risk appetite, capital, and incentives. The solution likely lies in an incentive model that fosters collaboration among these different players in the value chain, bridging the gaps and propelling exploration innovation forward.

QUESTION **What has the biggest impact on the rate of innovation in exploration?**

Respondents given 3 answers.



Risk appetite

Exploration is widely acknowledged as the riskiest stages in the mining value chain. It is a highly capital-intensive endeavour, and one that does not achieve payback unless successful. Success rates are extremely low, with typically only 3 successes in 1000 tries.[36] In this way it is akin to venture capital, whereby it is commonly stated that 6% of funds deployed account for over 60% of the returns.[37] Success is highly skewed and is more often than not born from one singular exploration campaign, rather than several exploration efforts. The high-risk nature of exploration is a key reason as to why the larger operating companies have limited their participation. However, our data suggests we may be witnessing a changing of the tide.

Since 2019, we have been asking mining businesses in what areas they would accept risk in order to increase financial returns. Exploration as a response has increased by almost 10%. Given that risk appetite has the biggest impact on the rate of innovation in exploration, this trend suggests efforts in exploration may be undergoing a resurgence.

Capital availability

The mining industry is unavoidably tied to the cyclicality of commodity prices, a core characteristic that influences the capital available to spend on exploration innovation. Exploration innovation is in conflict with the boom-and-bust nature of the industry. Commodity price upswings are often viewed as an opportune time to explore new projects and invest in calculated risks. However, even during these periods, the lag in time from discovery to production (often 10-15 years) places pressure on explorers to expedite their efforts and find ore bodies as fast as possible, resulting in the adoption of traditional methods to meet short-term objectives. Conversely, during commodity price downswings, industry growth is constrained, share prices take a hit, and companies prioritise the preservation of capital, tending to only spend on cost-cutting initiatives. Exploration teams are often made redundant, meaning when the market swings back they have to start fresh with completely new people.

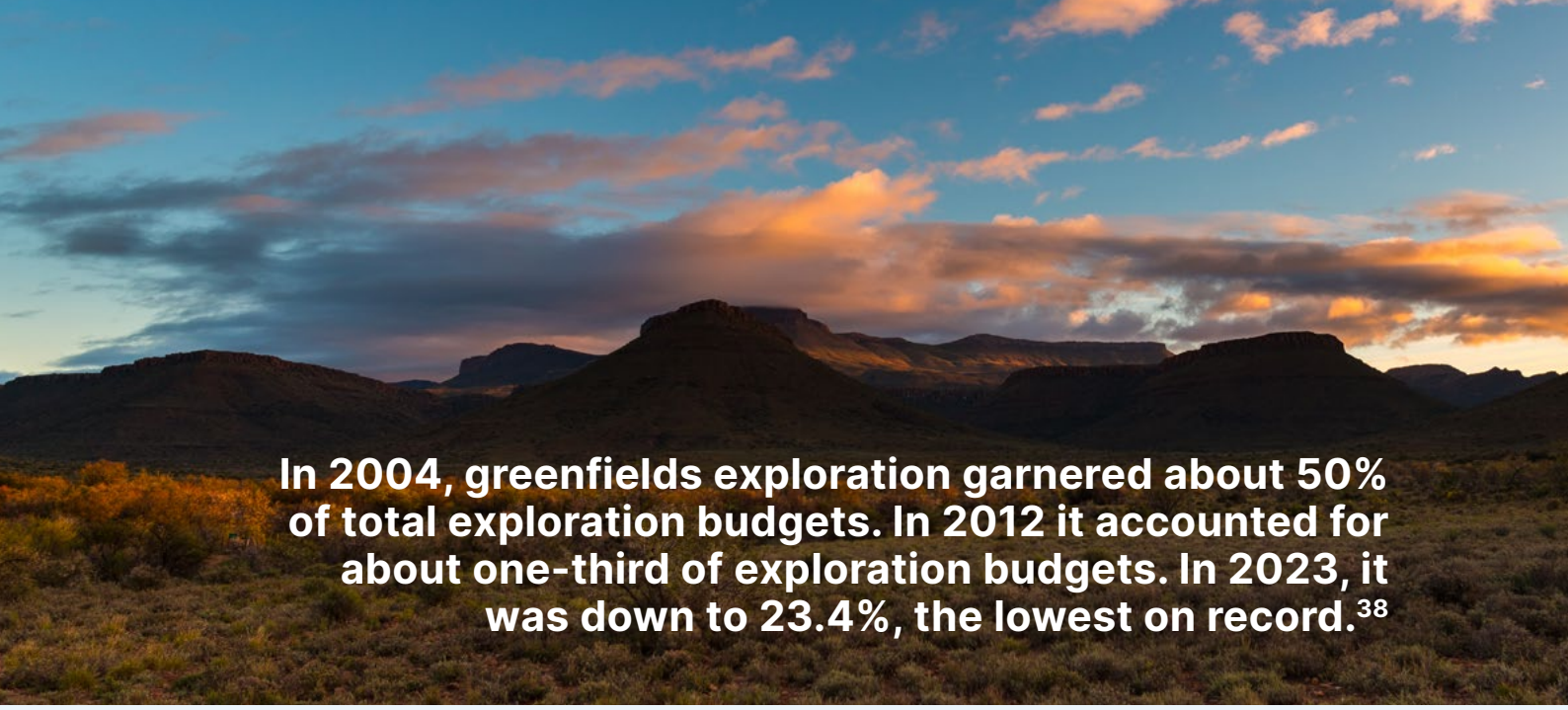
The current cycle, however, may diverge from historical trends. We find ourselves in the midst of an enormous resources boom – demand for critical minerals is growing, and is causing an upswing of exploration activity, supported by a historically diverse range of capital providers.

Downstream players, such as manufacturers and technology companies, are increasingly investing in early-stage mining projects. They are motivated by the imperative to secure a stable supply of raw materials for their production processes. Simultaneously, governments worldwide are becoming more deeply involved, recognising the strategic significance of critical minerals. Such heightened government participation is marked by a surge in incentives, financial support, and regulatory measures designed to encourage and facilitate exploration efforts.

With greater financial resources from alternate sources at their fingertips, the likelihood of explorers engaging in longer-term investments to improve exploration innovation has the potential to increase. It will, however, need to buck a 20-year trend. Irrespective of the cycle, the proportion of capital spent on greenfields exploration when compared to later-stage or brownfields exploration has decreased dramatically.

Even with greater capital availability, the question remains as to whether or not it will actually be spent on innovative greenfields exploration or be directed to the less-risky brownfields sector.

36. Kazuya Okada, 2022
37. Nicole Wealth



In 2004, greenfields exploration garnered about 50% of total exploration budgets. In 2012 it accounted for about one-third of exploration budgets. In 2023, it was down to 23.4%, the lowest on record.[38]

Technology advancements

The mining industry is a significant beneficiary of the research, development, commercialisation, and widespread adoption of technology in other industries. For instance, the defence and aerospace industry's contributions to satellite and drone technology have had a transformative impact on ground selection and definition in mineral exploration. The tech sector's progress in artificial intelligence (AI), machine learning (ML), and computing power has changed the way the mining industry processes and interprets vast geological datasets. And, the sensing technology, influenced by various industries, have substantially enhanced the precision and effectiveness of geophysical surveys. We expect that as the mining industry becomes more competent in integrating these advancements, we will see an increase in exploration effectiveness.

A barrier to successful integration remains industry segmentation. The majority of the acquisitions, strategic partnerships, and other forms of investments into adjacent industries have occurred through services and technology providers, whom only 8% of industry believe should be leading exploration innovation. Furthermore, these services companies tend to prioritise brownfields over greenfields exploration, as that is the area where clients are willing to invest, and there is a greater likelihood for sustained revenue. For technology advancements to actually increase innovation, juniors, mid-tiers, and the majors will need to work collaboratively with services companies to both encourage effort in greenfields services, as well as absorb the new methodologies into the existing way of working.

Monitoring the incidence of acquisitions and investments will form an important indication of the direction of exploration innovation, but also observing which players are carrying out these investments, and who they are partnering with to integrate them into operations will be just as key.

38. S&P Global 2023

"...You tend to find over the last 100-200 years - mining has grown through scale, rather than through innovation."

CEO, Mining Service Company

Encouraging collaborative efforts

The juniors have the risk appetite, the operators have the capital, and the service providers have the technology. The ability for the industry to evolve from a segmented, transactional ecosystem, to one that cooperates to leverage one another's strengths will be key to unlocking innovation.

There are several cooperative models to consider that could do exactly that, however the drive to integrate will ultimately require incentive models. The question then becomes, how can industry catalyse such models? An increase in the incidence of the following examples will indicate a trajectory towards greater exploration innovation.

Information sharing

Exploration involves complex technical processes and knowledge-intensive activities. For innovation to occur, collaboration and knowledge transfer is required between various stakeholders, however the competitive nature of exploration can hinder information exchange.

Typically, those that manufacture and/or develop the exploration technologies are engaged as service providers. The results of the exploration program, and the outcomes from the service providers involvement are rarely shared back, given the confidential and competitive nature of the outputs. Consequently, technology practitioners, who the industry is demanding to innovate, have limited opportunities to learn from their implementations.

By taking a new approach and fostering an exchange of information, service providers will have greater visibility over the efficiency of their technologies and methodologies and will have the tangible information to go back and invest in meaningful areas of development, leading to greater product innovation. Such information sharing will not happen without a shift in the current business model. For example, evolving from a transaction to a special purpose joint venture between the explorer and services company for a technology application can create the conditions for exchange and sharing of information.

> **"We're protected, we have the exploration license, we have the mining license. But for some reason many companies seem to think that this is very competitive IP that we shouldn't share."**
>
> **Executive, Mining Company**

Sharing capital

The exploration industry is no stranger to partnerships and collaborations – there is a history and track record of collaborative investment models such as joint ventures, farm-in agreements, and 'grubstaking' arrangements.[39] Typically, these arrangements involve a contribution to exploration expenditure in exchange for a stake in the project over an agreed period of time.

The nature of these agreements is beneficial to both parties – the explorer has access to financial resources necessary to carry out its activities, and the investor is positioned to access a potential future asset without the risk of conducting the exploration program themselves.

Whilst this helps finance the exploration program and allows the explorer to focus on their techniques rather than capital raising, there is little cooperation on the actual methods or technologies used. The agreements are more often than not structured to incentivise a quick discovery, which lends itself to the application of tried and tested exploration methods, leaving little room to pilot new approaches.

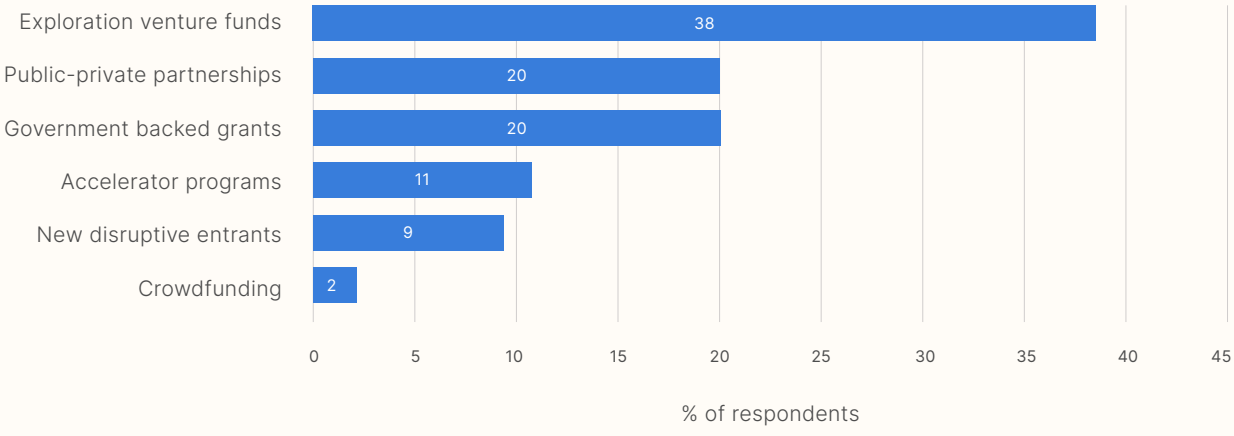
Conversely, the BHP Xplore program is an industry leading example of how a strategic partnership can foster exploration innovation. So far, the program has provided seven companies each with $500k (without taking a stake), access to BHP's network of support services, including technical experts in geology and operations, as well as corporate services such as legal and human resources.

The selected companies have been encouraged to think outside the box and present a novel geological concept. Approaches like this, have the capacity to disrupt the way the mining industry engages with the junior sector, and will catalyse innovation in new exploration methods, concepts, and opportunities.

39. Refers to the provision of funds or equipment in exchange for a share in future discoveries

QUESTION **Question: What are the best options for improving access to exploration finance?**

Respondents given 3 answers.



A job for government

Throughout this chapter, we have not yet explored the role that government can play in encouraging and facilitating exploration innovation. Investment in shared processing facilities by government would also free up a large amount of capital in the mining industry (that would otherwise not be invested due to the high risk of low to negative returns), which could be redirected into exploration activities. Our data suggests they have an obvious function in providing an enabling regulatory framework, with 24% of industry believing that has the biggest impact on the rate of exploration innovation. Government also can aid in increasing capital availability – 20% of industry believe they should do this through grants, and 11% believe it should be through accelerator programs.

In addition to these roles, government also have the opportunity to build a platform for innovation through enhancing publicly available geological data – a topic of discussion with several of our expert interviewees during this year's research efforts. While the mining sector has amassed substantial historical geological data, much of it remains untapped due to its inconsistent quality resulting from years of suboptimal collection and storage practices.

To address this, the government should invest resources in systematically cleansing and validating the existing geological information, creating a publicly available, high-quality geological data repository. This initiative would provide a data foundation for third-party innovators to apply advanced AI algorithms and conduct in-depth analysis to enhance exploration outcomes. Governments who can lead in this area will incentivise better-quality exploration, resulting in greater discoveries at a lower cost. It will create a competitive advantage for those that explore in the nation and will also support local economic development.

Several companies, including Koan Analytics and KoBold Metals, have already taken the initiative to aggregate publicly available data, proprietary information, and integrate AI technologies to identify exploration targets. Government investment in data quality would further support and encourage the expansion of these innovative efforts, ultimately benefiting the mining industry and exploration community.

The mining industry appears poised for a golden age of mineral exploration – a boom in the demand for critical minerals and the emergence of disruptive technology developments are creating the conditions for advancements in innovation. However, several factors will need to align to ensure it is possible; it is by no means inevitable. Key players, particularly the major miners will need to make decisive and strategic moves. Without their investment in greenfields exploration, innovation will continue to stagnate, and the industry will struggle to meet the growing mineral demands of the global economy.

Supply Chains and Geopolitics

Written by Xavier Evans and Wolfram Sommer

Over the last few years, we have learned the hard way about the vulnerability of supply chains and experienced firsthand the impact of their disruption. As a result, we have seen (temporary) supply shortages across the world, rising consumer prices and increasing input costs in products ranging from critical minerals and natural gas, through to computer chips and medical supplies.

"I think the one of the realizations that came with that [COVID-19] is that we need to look at localizing things and we need to find a way to move our production base... We don't need to cross the entire world to bring a truck part from wherever to Australia or something like that. Is it feasible? Yes, in some industries, it is feasible. It requires time, it requires a lot of investment of course... but I think that we are going to see more of this movement of localizing the supply chains closer to the production sites."

Founder, Mining Consultancy

In more recent years, we have witnessed events on a global scale which have not been seen in the growth decades since post-WW2 or Cold War, including armed conflicts, trade restrictions, sanctions and disturbances of some key maritime bottlenecks. Events such as the restrictions coming out of China with certain rare earth minerals, sanctions on goods coming from Russia as a result of the war with Ukraine, and disturbances of the Canal of Suez/Red Sea, the Panama Canal and the Black Sea, are becoming more of the norm. In addition to this, we the have ongoing climate change threats and the proximity of several of the world's environmental tipping points leading to problems like groundwater depletion and unbearable heat, with hard to predict and non-reversible consequences. These events have direct impacts on mining operations – assets may have to be replaced, like rail tracks which can only be used safely within a certain temperature range, or operations may have to be paused due to extreme weather events such as floods or fires.

There is no simple way around supply chain disruptions, and the mining industry is likely to witness them for many years to come. This chapter aims to unpack where supply chain disruptions are coming from and how innovation in supply chains could play out.

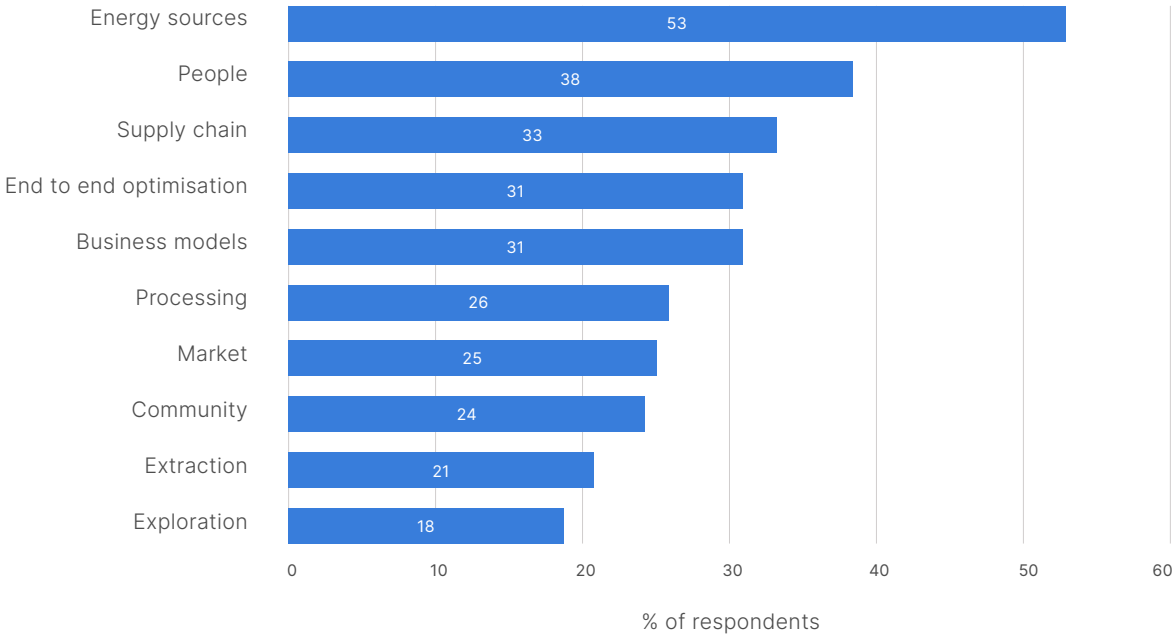
Supply chains: a complex problem

Given the rollercoaster experienced by the business community more broadly over the last few years, it is unsurprising to see supply chains rank as the third-highest source of disruption expected by mining leaders after energy and people. There are several underlying reasons why supply chains are seen as such a large cause of disruption.

First, supply chains are a major cost factor for companies. Transportation is a major determinant of the viability of projects from the supply of raw materials, semi-processed and finished goods, to the accessibility of just-in-time supply for continuous operations. For heavier commodities like iron ore, transport alone can double the marginal cost per tonne of production (CIF). And if these supply chains are interrupted, the costs just increase until companies drop out of the market altogether. The efficient operation of today's global economy is based on the assumption that materials will be available. Interruptions have large consequences from a project delivery perspective, seen in industries from computer

QUESTION **Where along the value chain is disruption in the mining industry most likely to occur?**

Respondents given 3 answers.



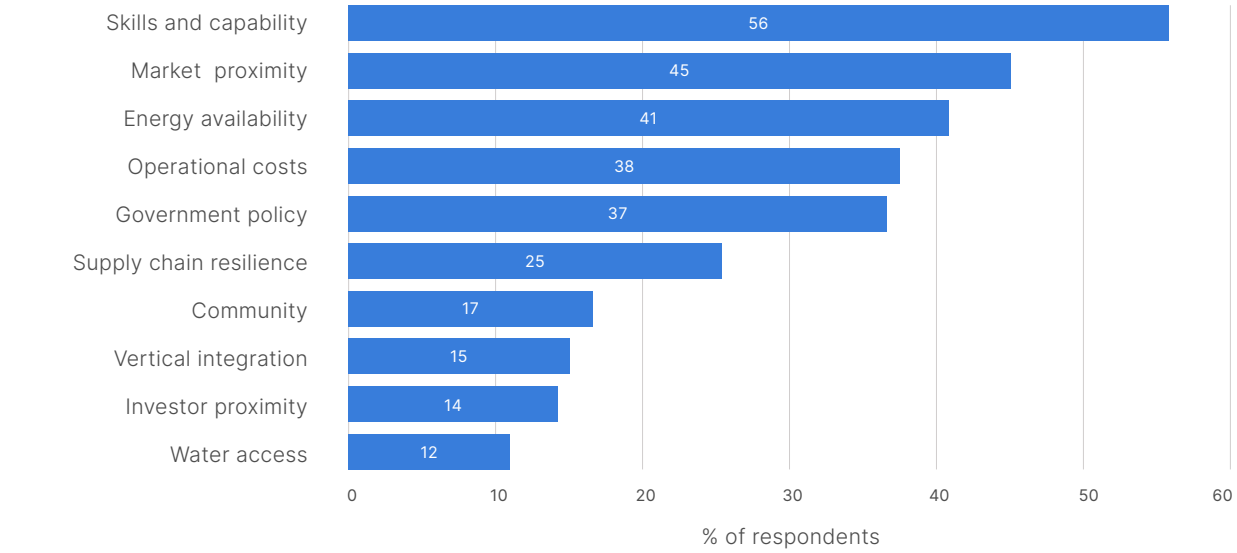
chips to electric vehicles (EVs) which all rely on mineral resources like rare earths, non-ferrous metals, or even conventional metals like steel. Companies like Tesla and Volvo have attributed supply chain issues, resulting from Red Sea shipping routes being diverted and a Chinese monopoly on many EV components, as one the reasons for a pause in production of their EVs.[40]

Supply chain design also defines a company's access to markets. Disruptions to free trade due to political or logistical concerns can be the difference between business model viability and existential crisis in an industry as globalized as mining. Supply chain risk is existential up and down the supply chain, particularly when contract terms can often stretch into the decades. This has a geopolitical impact as well – research done by the European Central Bank demonstrated that pandemic-incurred supply chain disruptions were far more impactful in advanced economies compared to emerging economies.[41]

40. The Conversation
41. European Central Bank

QUESTION **How does your business location assist your market competitiveness?**

Respondents given 3 answers.

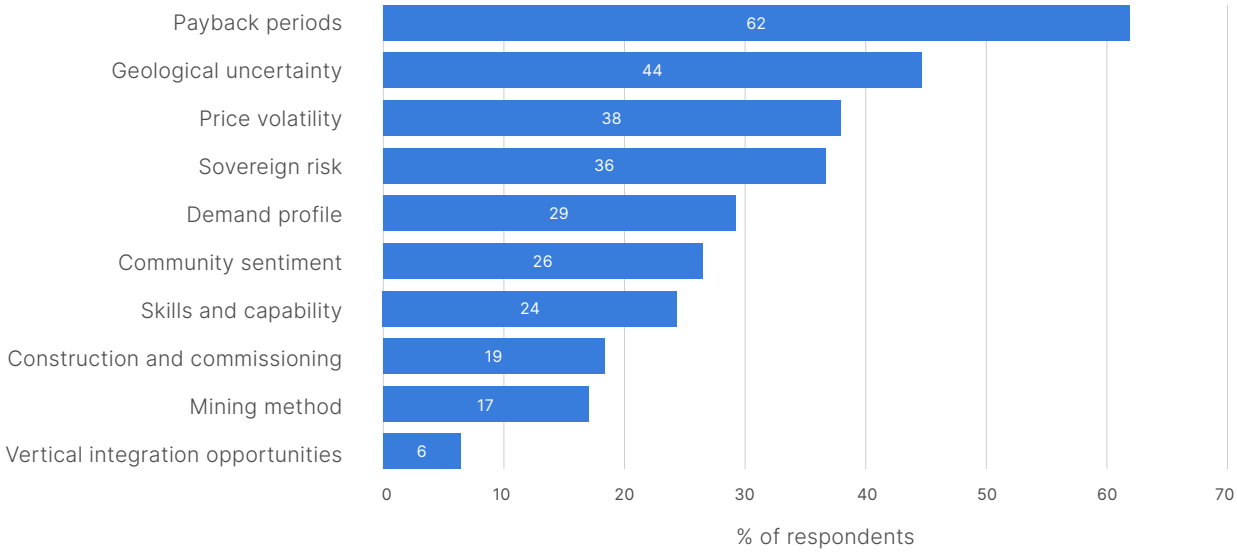


Third, supply chain disruption is tangible. Few crises are felt as immediately as a lack of goods, from supermarket shelves to industrial inventories. Supply chains are a classic case of unnoticed when operational and focused upon in the case of any interruption. The tangibility of the risk means that when things go wrong, people react – hoarding tinned food and toilet paper. They also move to substitutions which can be lasting. Another consequence is an increase in volatility in commodity prices, both on the spot market and in futures.[42] Our data shows that price volatility is a major consideration for final investment decisions. Supply chain risk matters because it is felt by businesses and customers, which has a cascading, chaotic effect on the rest of the industry.

42. Yongmin Zhang et al, 2022

QUESTION **Which of the following are the biggest considerations when investing in mining projects?**

Respondents given 3 answers.



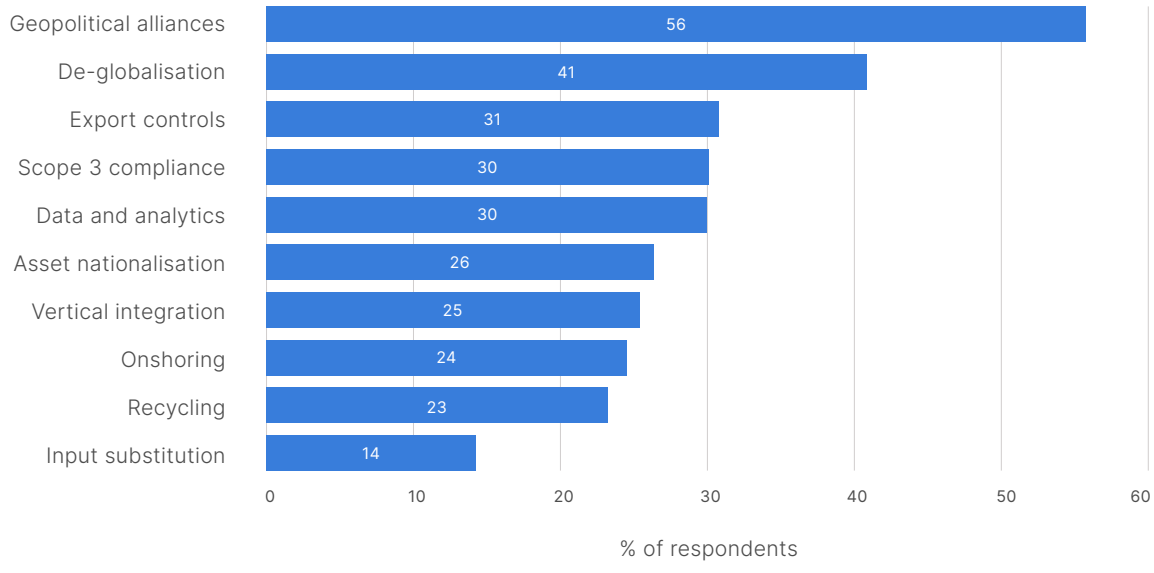
The current landscape

As the world attempts to navigate new global dynamics and the rising pressures to decarbonise, there are numerous underlying forces which are having large scale impacts on global supply chains in the mining industry.

According to our respondents, the two key factors impacting supply chains today are geopolitical alliances and de-globalisation. Once again, this isn't surprising given the current state of geopolitics and the impact both can directly have on existing value chains.

QUESTION **Which of the following will have the biggest impact on global supply chains in the mining industry?**

Respondents given 3 answers.



Geopolitical alliances

To manufacture an item, from mining exploration to downstream processing and then production, typically requires input from across the world. Take EVs as an example. China dominates the downstream EV supply chain, producing around 70% of the world's batteries and over half of its EVs.[43] If you shift upstream and start looking at the minerals required for lithium-ion batteries, it's a different story. In 2022, Chile and Australia accounted for almost 77% of global lithium production. China on the other hand, accounted for less than 15%.[44] Indonesia and the Philippines accounted for over 58% of global nickel output in 2022, followed by Russia, New Caledonia and Australia.[45] Cobalt is primarily mined in the Democratic Republic of Congo and graphite mining is primarily done in China but is increasingly diversified with projects in Canada, Madagascar, Tanzania and Mozambique.[46]

As such, the rules that govern the international trading system have a massive impact on the downstream markets for minerals. On the positive side, policy can privilege production from allies. Take the Inflation Reduction Act (IRA) for example, where electric vehicle components will need to manufacture at least 50% of the value of battery components in North America in 2023 to receive the generous green public. Additionally, 40% of the value of critical minerals used for EVs must be extracted, processed and recycled domestically in a country the US has a free trade agreement with.[47] Free trade agreements remain a core focus of international diplomacy, with opportunities to open up significant new markets, and changing the relative economics of different projects.

Sometimes adjustment is slow, as seen in long-running, well-publicised trade deals such as the EU-Canada deal. But even then, adjustment can be rapid. Just recently EU-Australian free trade negotiations abruptly broke down, and punitive approaches to geopolitics are often even more abrupt, with European gas prices spiking after Russia's invasion, a rapid whole-of-economy redirection of energy sourcing has significantly changed the energy landscape in the EU.[48] The compounding issue is that geopolitics has an unpredictable impact on supply chains – sanctions and even armed conflicts can drive up or down demand for ores in a much more unpredictable way. An example are critical minerals which are increasingly being targeted with trade restrictions or even weaponised. This is particularly relevant given our data shows that solar is predicted to be the most widely used energy source in the next 15 years, and batteries will mostly likely be used when the renewable source alone is insufficient. The production of PVs and battery technology is almost exclusively - and IP protected - in the hands of Chinese mainland companies. Recently machinery for solar panel production has been banned from exporting, meaning the expansion of solar energy is extremely dependent on a single source.[49]

43. Reuters
44. Visual Capitalist
45. Mining Technology
46. IEA
47. Bipartisan Policy
48. Financial Times
49. Asia Times

Our respondents listed input costs, market access and supplier relationships as the areas most likely to be impacted by de-globalisation of supply chains.

De-globalisation

A lot has changed over the last decade when it comes to globalisation. In 2017, 24% of respondents believed globalisation would be the global trend with the biggest impact on mining innovation in the next 15 years. Fast forward to 2023 and this has dropped to 5%. There is an ongoing trend of nationalisation – an increasing shift in focus to shoring up sovereign capabilities. This has been born from supply chain disruptions across the globe, but also from the critical minerals boom which offers countries the opportunity to make big bucks if they can develop their own capabilities.

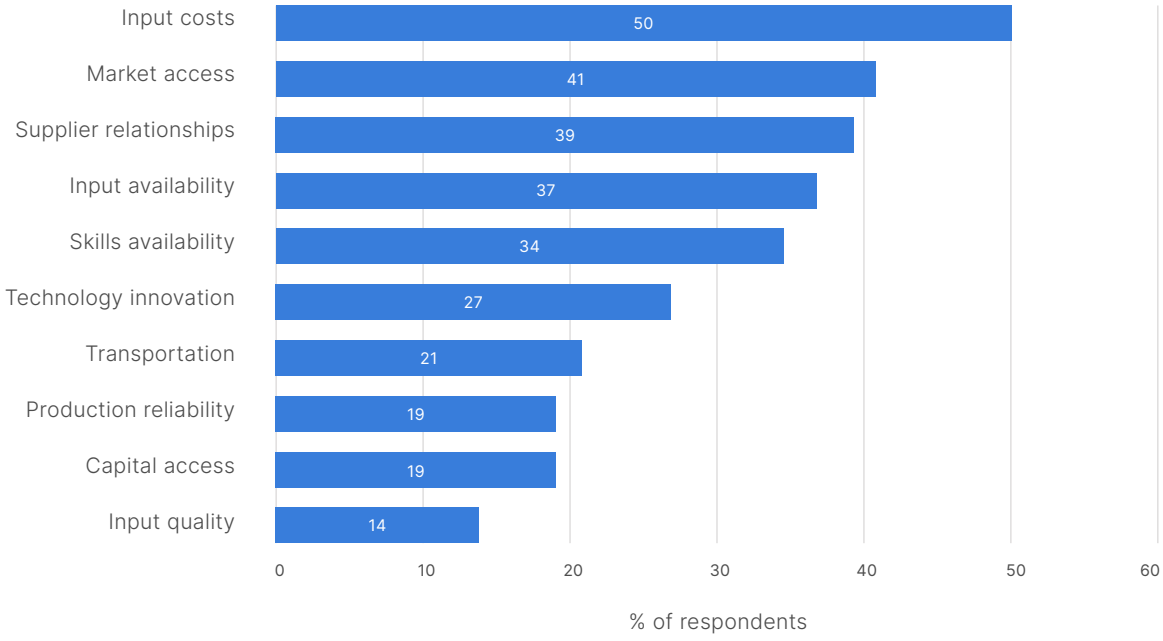
De-globalisation will have numerous supply chain impacts, many of which are yet to be felt.

"There's a growing narrative that globalization is going to change shape. At one end, you've got extreme commentators saying that not only you're going to de-globalize, we're going to de-civilize. Because a lot of what we have in modern day society relies on supply chains that are so intertwined with every political boundary or geographic boundary around the world."

CEO, Mining Services Company

QUESTION **Where would de-globalisation of supply chains impact your business most?**

Respondents given 3 answers.



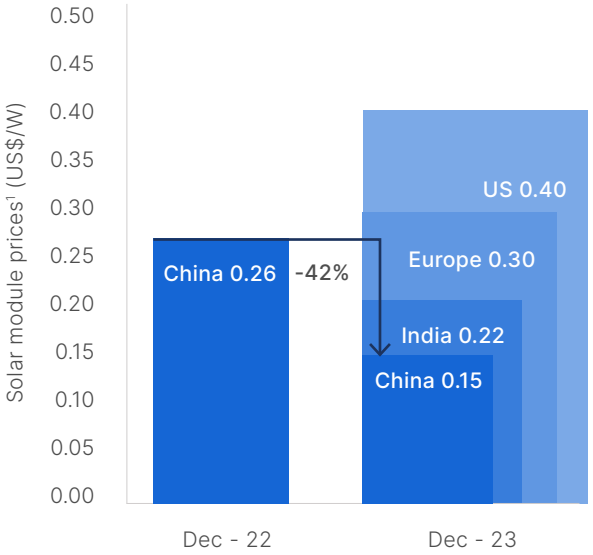
A restriction in viable operating locations impact input costs according to 50% of our respondents. As trade barriers increase, so will the direct costs of goods and equipment – a result of increased supplier costs and the introduction of tariffs on global trade. China, for example, already have the lowest solar module costs at US$0.15/W, making it extremely difficult for regions, such as Europe and the United States, to be able to compete on price.[50]

We are already seeing the difficulties play out, as countries typically not involved in downstream processing attempt to develop a new industry. From an access to minerals perspective, Australia is the perfect location to push downstream, provided it can maintain its energy cost advantage as it moves to renewables. When compared to its competitors, however, Australia can be a high-cost environment – a result of high labour, construction and transport costs. Another emerging player in the battery production sector is Germany. It suffers a similar fate to Australia, however, with factors such as higher land, construction and labour costs potentially making the establishment of an Lithium-Iron-Phosphate battery facility in Germany up to one-third costlier than in China. Innovation in operating methods that use new types of equipment and materials could prove key in adapting to the new economic environment.

From a services perspective, a return to the local empowers a greater diversity of services companies to adapt to a new operating environment for miners. Local services companies may find a competitive edge in their smaller geographical footprint, adapting to supply miners that lose the ability to arbitrage contracts at a global level.

50. Wood Mackenzie

Solar module prices by manufacturing location



1. Module type: M10PERC. All prices are ex-works prices from the factory in the region in question. Source: Wood Mackenzie

The missing link

If disruption is expected in certain fields, one could expect that these topics would be a high priority when it comes to defining the current focus on innovation, strategy, and investments. But our data shows that this is not the case.

A third of respondents believe that supply chains will be a future disruptor to the mining industry, however just over 20% are currently focussing their innovation efforts on it. The complexity of supply chains may be the reason for this. Despite being a vital part of a mining companies' success, supply chains are notoriously out of direct control, influenced by many factors we've already mentioned, such as weather, geopolitics and regulations. Regardless of this, it is still hard to comprehend that given the perceived disruption they will cause, so few companies are finding ways to be innovative in their approach to their supply chains.

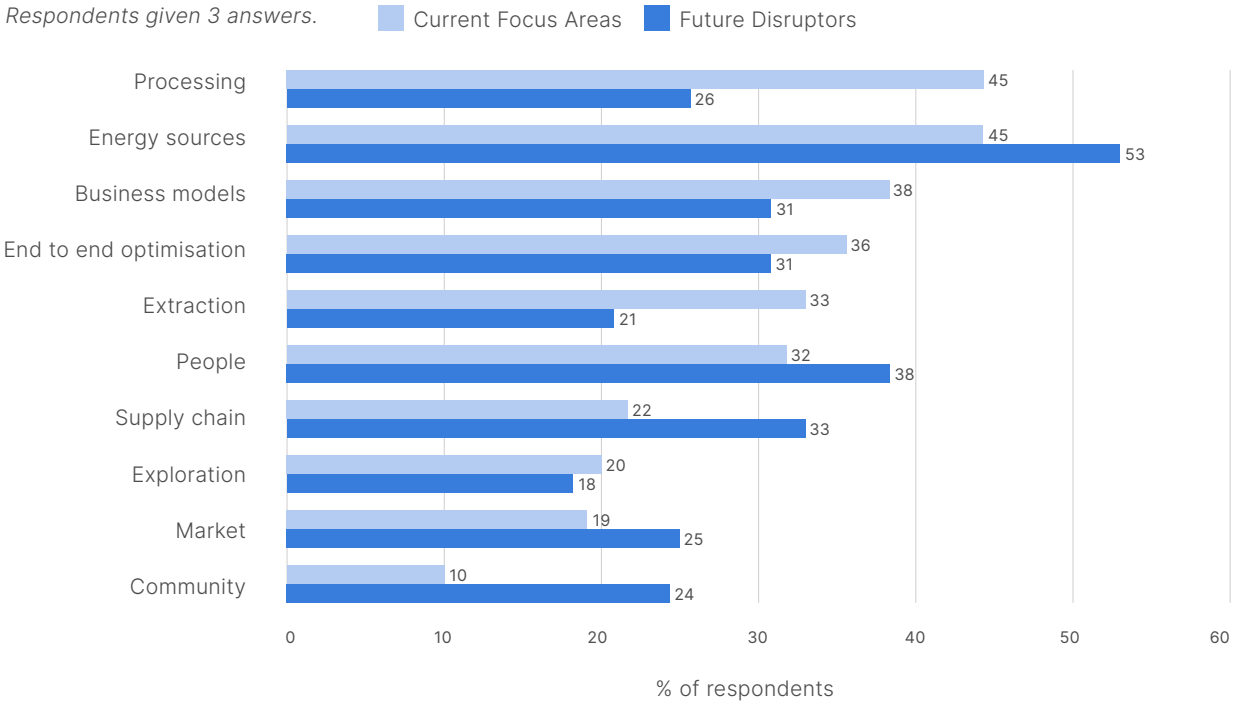
So, what could companies do to insulate themselves from these risks? The one major trend we are seeing is an evolution on the interconnected operating model we have become so accustomed to. As supply chain risk increases, and energy calculations shift (see Energy chapter), companies are finding that increased localisation of the value chain in one geographic area can not only reduce risk, but also prove a more valuable operating model under certain conditions.

"There are all of these things that don't bear scrutiny. We say all these things about geopolitical uncertainty and the possible disruption to supply chains. And we are planning with blinkers on."

CEO Mining Services Company

QUESTIONS **Where along the value chain is disruption in the mining industry most likely to occur? x Where in the value chain are your innovation efforts primarily focused today?**

Respondents given 3 answers.



The European trailblazer?

Governments are getting increasingly involved in supply chain designs. One of the most progressive, and powerful, forces in this space is the European Union (EU). The recently proposed Critical Raw Materials Act (CRMA) increases onshoring and supply diversification requirements for European industries. The regulation sets targets for 10% of critical mineral supply to be mined in Europe, 25% to be from recycled sources within Europe, and 50% of critical minerals processing to occur in Europe. Finally, no more than 65% of any imported critical minerals are to be sourced from one country. It remains unclear how this will be enforced, but the objective is clear.

In parallel, the EU is considering a new law on supply chain due diligence, the Corporate Sustainability Due Diligence Directive (CSDDD). The Directive builds on previous German legislation that requires companies above a certain size to be fully accountable for their supply chains under European law, even if alleged infractions occur outside of the EU. The law would allow stakeholders to take individual companies to court for non-compliance by other parties who service the European company.

What do these types of legal approaches mean for industries who operate within a global system? The EU is both requiring greater diversity of sources of materials, while also requiring greater oversight of supply sources. Naturally, the best way to comply with EU rules is to bring production onshore to both meet import requirements and to operate in a stricter regulatory requirement to reduce audit liability – the obvious intention of the law.

Public regulation and incentives, particularly for critical minerals adds a further factor into the already complex strategic landscape of supply chain design and management. The EU has often been a trailblazer in policy development, with other countries following their suit. Particularly considering these regulations are zero-sum – excluding other countries to advantage the European bloc – we may see a rise in retaliatory regulations looking to safeguard domestic operations in other countries. If these types of regulations become more common, mining companies will need to adapt to the new future. For companies who have taken ESG topics seriously and built them into their core culture, these trends can prove to be competitive advantages, as competitors will scramble to comply.

From compliance to opportunity, this environment is likely to increase risks in the medium-term as these laws take effect and drive change at a corporate level. Two new opportunities for innovation will be in major asset development and in recycling and urban mining. Take major asset development – miners may increasingly need to change

their value chain designs and portfolios to de-risk their operations in compliance with provenance regulations. We may see an increase in spin-offs and decentralised operating models to increase the amount of value add that can occur locally and reverse a trend of specialisation for each step of the value chain. A change in the supply chain environment changes the economics of new major assets, with uncertain outcomes. Will all-inclusive hubs that produce a more refined product become the norm? Will projects relying on offshore processing struggle to attract finance? Speculation only takes us so far, but companies willing to adapt, learn, and manoeuvre in the new operating environment will have a structural advantage.

New operating environments do not just add risk, they also create opportunity. One topic which should be on the mind of strategists and innovators here, is the increasing necessity for urban mining, where mining companies could get an opportunity to diversify into the recycling industry, while still being able to contribute core knowledge around logistics, processing, material handling, etc. Some research suggests that there are around 7 million unused phones in Switzerland alone, with USD $10 million worth of gold embedded in them. While the value of the metal within the phones is unlikely to offset the recycling costs, the environmental impact of this approach is significantly less than sourcing the metals through a traditional mining method.[53]

53. Van der Merwe et al. 2023

Playing the long game

The speed of change and the amount of external and internal demands will further increase. Companies and leaders are struggling to escape the short-term rat-race with a focus on quarterly financial growth metrics. These short-term pressures for results can significantly weaken long-term prospects, especially for mining companies which need to be able to play the long game.

How much should companies focus on business as usual vs. their approach to value and supply chains? What does it mean to be proactive in the face of uncertainty? Ultimately, at some point change will come and then companies who have done their homework and ensured everybody is pulling in the same direction will be the most resilient and agile.

It is primordial to ensure monetary gains are invested in the long-term survival of the company with healthy assets, motivated and qualified employees and a thriving surrounding community, elements too frequently neglected. If employees know that in the next crisis the first reflex will be a dismissal wave to save costs, it is unlikely that they will give their best in the current job. Science indicates that disruptions will come, and soon. Geopolitical, natural, economic and social equilibria are shifting. Some changes will be gradual, others will be non-linear. Many of the senior executives interviewed agreed that there needs to be breathing time to understand the risks and opportunities and have time and energy to address them properly in line with company values.

So, are we any better prepared for upcoming disruptions? In a limited way.

While the answers can be different for every company, bringing back some long-term thinking in the whole value and supply chain, from geological exploration to the final product considering criteria will be key. There is momentum in the local and global value chain (re)design, it is time now to get employees, communities and governments to think together, ponder options and prepare for the best possible future with risk awareness, an aligned vision, strategy, innovation and execution.

Perceptions

Written by Lisa Harwood

The relationship between human development and mineral extraction industries has a complicated history. Mining has spurred economic growth and new jobs, but in the process has caused major environmental disasters. As early as the 1960s, there were reports of protests against mining developments, however the industry is also responsible for providing the raw materials to produce many of society's basic needs. This complexity has resulted in mixed perceptions of industry, compounded by an increasingly negative sentiment towards those contributing to climate change.

"And yet you look around the place... everything was either grown, mined or pumped. Everything society needs... you can't have any of that without mining. I think there's a massive disconnect between the public's perception of mining and the reality."

Partner, Investment Firm

This negative sentiment has further been fuelled by a growing level of distrust between the general public and the mining industry. Safety issues, such as the 2019 collapse of the Brumadinho tailings dam in Brazil that killed 270 people, environmental negligence such as the 1984 OK Tedi waste disaster, and cultural heritage incidents such as the 2020 Rio Tinto Juukan Gorge incident, have all tainted the mining industry's public perception. Given the industry is responsible for up to 7% of global greenhouse gas emissions, the amount of scrutiny received will only continue to increase, as efforts to curb climate change ramp up.[54]

Negative perceptions have the power to disrupt the progression and development of the mining industry, impacting the way the industry operates, accesses capital, and attracts talent. In some instances, this is already a reality. Rio Tinto's lithium project in Serbia has been put on hold in the face of intense anti-mining protests, meanwhile the Peruvian Tia Maria copper project has been paralysed for the last decade as a result of ongoing community outrage and ongoing protests. This chapter will explore industry's understanding of society perceptions, the impact these perceptions have and potential next steps.

54. PWC
55. Euractiv

A look in the mirror

The industry understands that there is work to be done when it comes to perceptions – 73% of mining respondents believe the industry is viewed negatively by society.

The negative sentiment is particularly clear across the areas of historical legacy, local environmental impacts and climate change. None of these should be a surprise, especially in light of the previous examples of environmental destruction provided at the beginning of this section.

Climate change is a topic that has come to the forefront of discussions over the last decade, with scientists stating global heating as the single most dangerous problem facing the human race.[56] 2023 saw 28 individual disasters (ranging from severe storms and flooding to drought) exceed the billion-dollar cost mark in the US. To put that into context, the average number of US billion-dollar disasters per year from 1980 to 2023 was 8.5.[57]

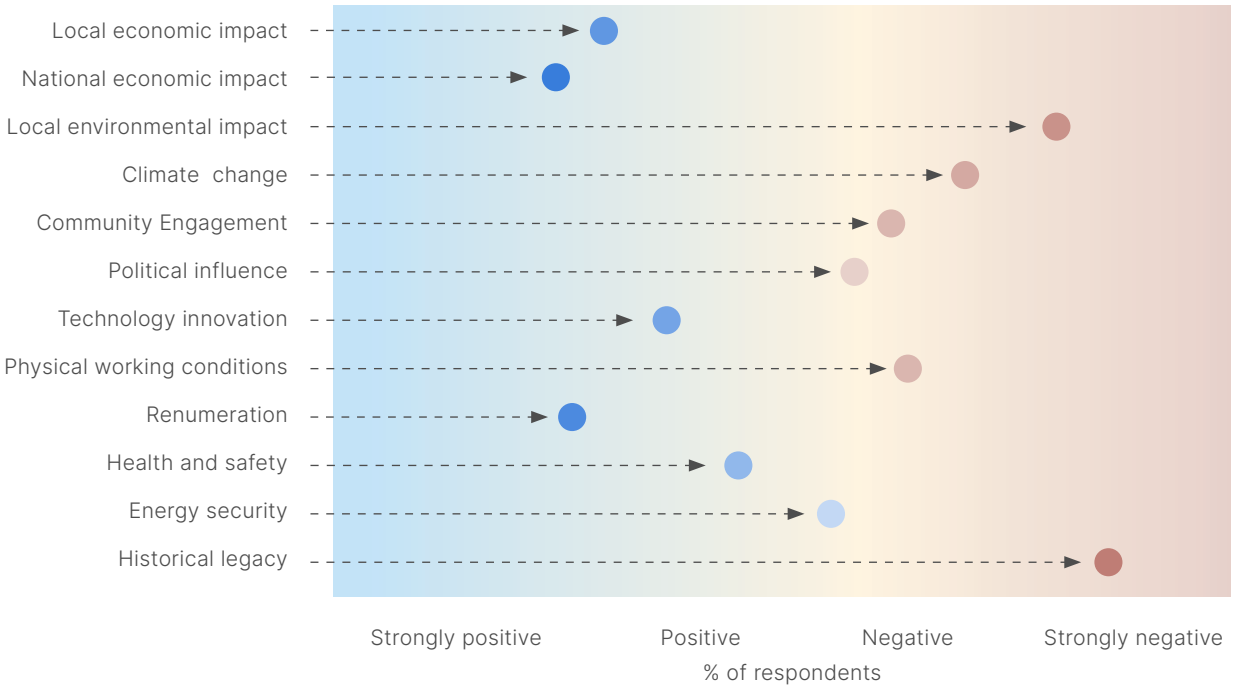
With the increasingly severe weather events, more eyes are turning to some of the world's largest emitters and pressure is mounting for them to address their part in the problem. Mining has fallen into this category given its direct energy intensity in operations and its role in coal mining, and consequently there are sweeping changes happening across the globe. Under the European climate law, EU countries must cut greenhouse gas emissions by at least 55% by 2030. Australia's newly reformed Safeguard Mechanism see the baseline for annual emissions fall by 4.9% each year so that industrial facilities contribute to Australia's targets, while Canada has a carbon tax across all its provinces and territories.

Its clear change is happening, and we all play a role. What we are yet to see is how industry will take responsibility and implement change to address society's negative perceptions.

56. SBS
57. Climate.gov

QUESTION **How is mining generally viewed by society in each of the following areas?**

(Approximate centre of gravity of respondents)



The double-edged sword of mining in Australia

Mining contributes approximately 14% of Australia's output and 63% of all export revenue for the nation.[58] It is therefore understandable that industry perceive their impacts on the local and national economy as a net positive. There are however unintended economic consequences of relying on an industry which is cyclical by nature. Large fluctuations in population, housing stock and expenditure can all have impacts on the cost and standard of living for those located in small mining towns. In Karratha and Port Hedland, house prices fell by 65% over a five year period in 2017 following the end of one of the large mining projects in the region, resulting in many workers who had moved there for work or invested in property, struggling to make payments or sell their assets.[59] Fast forward to 2023 and the latest mining boom is driving up the cost of living, with an influx of workers and mining companies buying up local real estate. The cost of renting a residential property in the Pilbara jumped approximately 20% in the September 2023 quarter, and the Kimberly and Pilbara having the highest cost of food and beverages in 2022/23.[60] [61] The boom and bust industry cycle can have disproportionate impacts on residents, with those working in the mining industry more likely to be able to absorb the cost of living increases due to higher wages, leaving those other residents not working in industry, struggling. There is no easy fix to this, however recognition of these unintended consequences is important, as are plans to mitigate the negative effects where possible.

58 RBA

59 The Guardian

60 Business News

61 WACOSS

What's the need for change?

Industry recognise that people, operations and technology are the three spaces in which they generate a competitive advantage. But whether they are fully aware of the impact perceptions may have on those maintaining those advantages is another story. What has become clear more recently, is that there are consequences to negative perceptions, and these exist in the spaces of talent attraction, maintaining operations without disruption and accessing financing for the deployment of new capital.

"Change comes from have two main sources. You need a crisis or a scandal. You need real stress and that tends to drive change. Everything else is just lip service. Not many companies are good at creating pivots or redirections, or commitments to new ways of working in the absence of a crisis."

CEO, Technology Company

Talent attraction

As people become more engaged with environmental and social issues, there is a growing expectation for their employers to do the same. Globally, 69% of employed adults want their company to invest in sustainability efforts, including reducing carbon and using renewable energy. This sentiment becomes even stronger for the younger generations.[62]

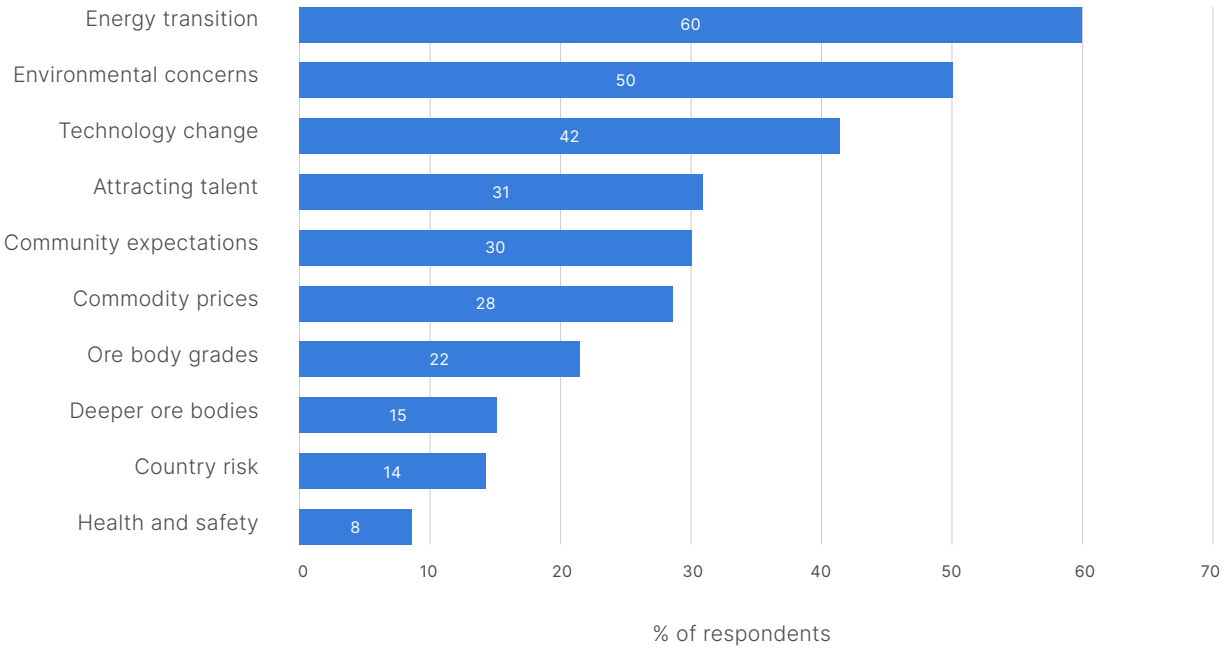
Many industries are experiencing some kind of skills shortage, and the mining industry is not immune to this issue. In Canada, the job vacancy rate was 4.6% in June 2023 compared to 2.4% in 2018. In Australia, the number of mining vacancies were four times higher in May 2023 when compared to May 2016.[63] This issue is further exacerbated by the energy transition – it's predicted up to 168,000 workers will require training in skills specific to renewable energy industries, including design, engineering, manufacturing, construction and maintenance of wind, solar, hydrogen and storage infrastructure.[64] Where these workers will come from is the question no one seems to be able to answer.

Our data suggests that sentiment towards the industry plays a significant role in talent attraction, a reality the mining industry is aware of. 31% of survey respondents listed talent attraction as an industry trend which will have the biggest impact on mining over the next 15 years.

62. Deloitte
63. Mining.com
64. ARENA

QUESTION **Which of the following industry trends will have the biggest impact on mining over the next 15 years?**

Respondents given 3 answers.



The reason this issue exists is twofold. Firstly, recruiting the younger generation to join the mining industry is becoming a more difficult task. Approximately 59% of Australian students between the ages of 18 and 29 were reported to know nothing about mining careers, and when career advisors were asked what the top three STEM careers were that they would recommend to their students, only 2% stated mining.[65] [66] As students' progress to university, there has also been a decline in enrolment numbers for mining related degrees. Undergraduate geoscience enrolments in Australia declined by 70% from 2013 to 2021 and enrolments in mining engineering programs in the US has fallen by 45% since 2015.[67] [68] There is no doubt that industry's environmental problems, in addition to a growing focus of younger generations on sustainability and equality, has played a role in their desire to engage with mining. In many ways, mining's historical legacy has tarnished its future prospects.

Secondly, in lieu of an increase in the number of new entrants from university to the workforce, the industry must attract talent from other industries. Attracting talent, particularly those in jobs who can transcend industry depending on the conditions, pay and values they are looking for, makes it increasingly difficult for mining to bring on board the number of people they need. There are increasing employee expectations of company action on climate and sustainability, with a quarter of respondents in a recent survey stating they had considered switching jobs to work for a more sustainable company.[69]

65. Youth Insights
66. Youth Insights
67. Australian Geoscience Council
68. Real Clear Energy
69. Deloitte
70. Jurist
71. Mining Technology
72. Balkan Insights

Social licence to operate

Its commonplace these days to read about mining protests taking place across the globe. While industry may find it easy to brush these off as a nuisance, there are increasing examples of the impact that social licence to operate (SLO) is having on mining operations. In 2022, protests in India over a proposed mine site extension that would see large scale deforestation take place, resulted in the project being put on hold.[70] In 2023, the project restarted, as did the protests. In Panama, First Quantum's mine has experienced significant delays and suspended production due to protestors.[71] In Serbia, production was temporarily suspended at Zijin Copper's Novo Cerovo mine due to villagers blocking the road.[72]

At the core of a company's SLO is the community's perception, level of trust and an understanding of the project's impact. Transparency is important. Despite this, only 26% of the respondents listed transparency and social expectations as a global trend that will have impacts on mining innovation over the next 15 years. Given the role expectations and transparency play in determining perceptions, and thus SLO, it's hard to see how it won't have an increasing impact going forward.

Access to capital

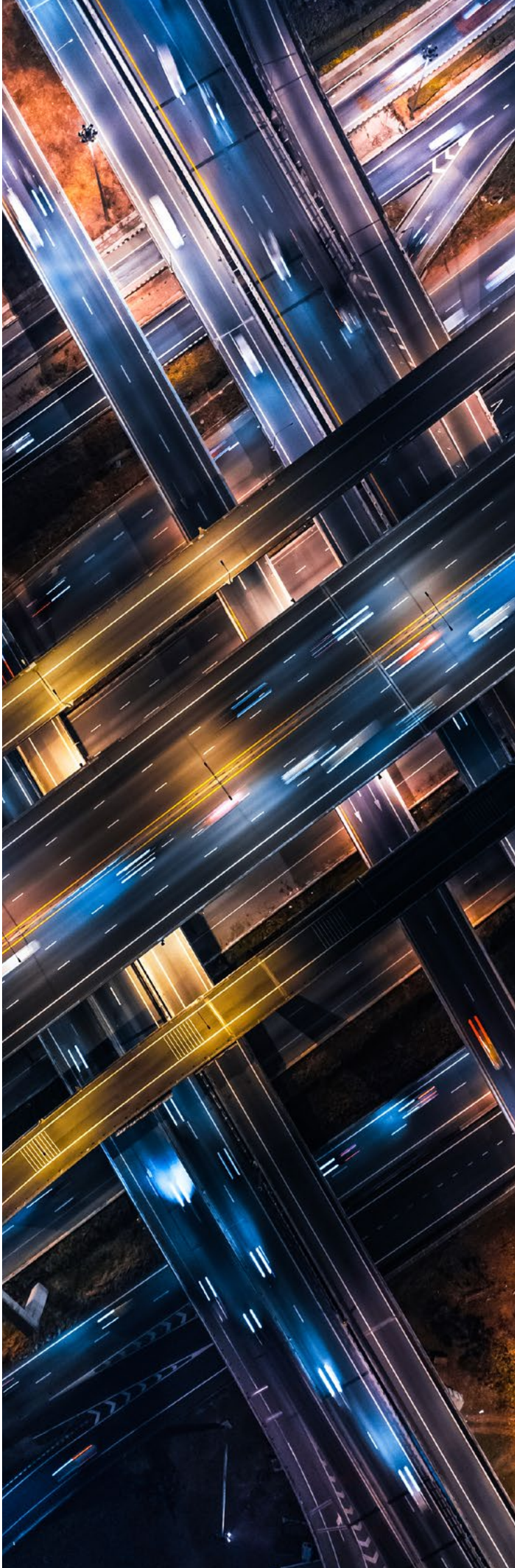
Capital availability is make or break in the execution of mining projects. Large amounts of capital are required to get a mine, and associated technology, in operation. Given the race to decarbonise, the imperative to access capital, and fast, is an increasing priority for mining companies. Previous State of Play research into the critical minerals sector identified that 44% of respondents thought cost of capital was the largest barrier to investment in critical minerals projects, with 65% of respondents listing investors as the

industry stakeholder who was able to have the most impact on the acceleration of critical minerals supply.

More recently, several banks have publicly announced their plans to be more conscious of their investment decisions in mining projects, as well as setting decarbonisation targets for themselves. NAB has stated they are not taking on any new thermal coal mining customers, BNP Paribas no longer provides financing to projects dedicated to the extraction of metallurgical coal and Deutsche Bank has published a Transition Plan for achieving next zero.[73] [74] [75]

Whilst we are slowing starting to see some banks more willing to fund critical mineral projects, these legacy perceptions of industry have resulted in unintended consequences. Claims of overly burdensome ESG related red tape has resulted in financing delays in the EU and in Australia its claimed that banks' institutional knowledge of mining projects has been reduced, an unintended side effect from reducing their exposure to mining projects more broadly.[76] [77] As a result, many banks are risk adverse to critical minerals projects, especially those more niche metals, as they don't fully understand the project complexities and future demand profiles. This is requiring many miners to seek funding through non-traditional sources.

73. NAB
74. Reuters
75. Deutsche Bank
76. Mining.com
77. AFR



Ok, so now what?

The industry can continue down the path they have always trodden, however the consequences of perceptions will have long lasting impacts. Industry needs to take a step back and think about it from a customer perspective to determine what's next – what are they continuing to do (or not do) that is leading to these perceptions, and how do they go about building back trust?

Communication and relationships

Nothing breaks trust like a lack of communication and inconsistent messaging. Community engagement that is genuine, and not just seen as a tick box exercise, is critical for both SLO and ensuring the delivery of optimal local economic and community development outcomes. This requires engaging with community, local businesses and local governments on an ongoing basis, building engagement into project timelines (not throwing it in at the last minute), and genuinely taking feedback on board and adjusting processes where appropriate.

When an incident does take place, communicating both broadly and at a grassroots level is equally important. Sandfire's recent announcement that they waited a year to communicate the destruction of Aboriginal artefacts at its Australian copper mine to the community is an example of what happens from a lack of communication, as it has now resulted in a breakdown in trust between the company and Indigenous community groups.[78]

There is also a question as to how the industry should position and promote themselves as part of the energy transition. The absence of clear market segmentation between coal and critical minerals miners, for example, makes it difficult for more progressive companies to effectively advertise their positive role in the transition, or their efforts to actively reduce emissions. While miners are beginning to include more comprehensive ESG metrics in their sustainability reports, these documents are perhaps better suited for auditing and credibility than as general promotional material.

This reveals a new opportunity for the industry as a whole. Simply stating that mining is at the heart of everything is not working (and will likely never work), so as a first step industry players should work together to develop a promotional strategy for the sector. To be convincing, this effort must be supported by an uptake in transparent and open communication across the board. Such approaches have been deployed by other industries, including the plant-based and regenerative food industries who sponsored documentaries on major streaming services to get consumers interested in the facts behind the industry and steal market share from the meat industry (US veganism has grown over 30x in the last two decades).[79] We are beginning to see this approach attempted by campaigns such as the European Union's "Responsible Mining in Europe" documentary, but it is yet to achieve mainstream saturation.

ESG

The growing importance of Environmental, Social and Governance (ESG) considerations is obvious to most in the industry.

Embedding ESG considerations into how miners operate is a simple first step. Actually, acting on those considerations and making change is when you will get perceptions shifting. Projects such as Accenture's Diversity an Inclusion 360 program, which has seen 100% pay equity for women and men in

78. ABC

79. Food Revolution

every country they operate, or Apple's ESG initiatives, which has seen them reach carbon neutrality since 2020, provide examples on how to shift the dial. Imagine the impact they could have if they were being applied in the mining industry on a global scale.

The social component of ESG is more often overlooked, however it plays an equally important role in building trust and shifting perceptions. Social issues like health and particulate exposure, child labour and diversity, equity and inclusion all have impacts on investor confidence, social licence to operate and company operations. 2023 saw reports of children working in illegal gold mining in Venezuela and child labour and treacherous conditions being used in the Congo to keep up with cobalt demand.[80] [81] In a recent Australian survey, over half the respondents said they experienced some form of gender inequality, ageism, bullying, racism, homophobia or sexual harassment in the last 5 years. Women

50% of respondents stated environmental concerns as the industry trends that will have the biggest impact on mining over the next 15 years.

were more likely to experience these issues (73%) than men (40%).[82] Addressing any of these issues is no easy feat, and the range of social challenges will change between developing and developed countries. Having strong policies in place and holding others accountable for their actions are the first steps. Having diversity within an organisation, to ensure that there are differing opinions and approaches to achieving transparency and social expectations is equally important.

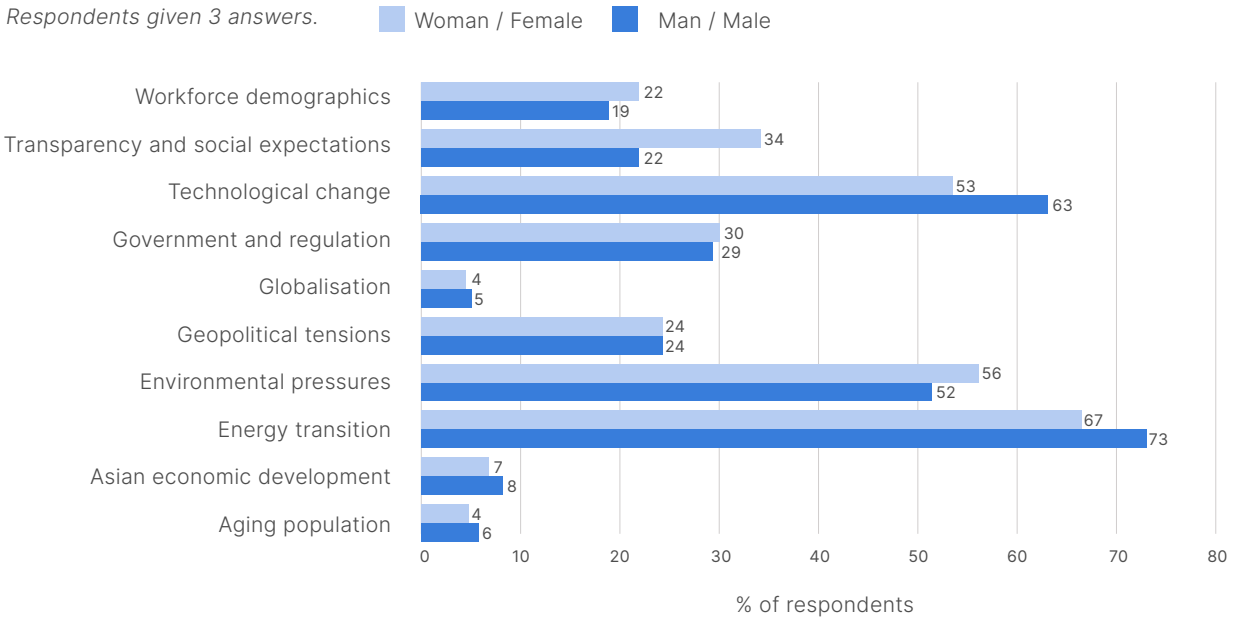
80 Aljazeera

81 Washington Post

82 AusIMM

QUESTION **Which of the following global trends will have the biggest impact on innovation in mining over the next 15 years?**

Respondents given 3 answers.



ESG is not just a question of compliance, but a genuine business model opportunity. Sustainability related bonds and other financing mechanisms are providing mining companies with new sources of capital – the total issuance of global green bonds (including by government) reached US$423 billion in the first three quarters of 2023.[83] Companies such as Hastings Technology Metals are establishing green financing frameworks where green loans or bonds can be issued due to their ESG credentials on their Yangibana rare earths project.[84] Business models with a strong ESG component could also deliver higher shareholder returns.[85]

Transparency and reporting:

As ESG pressure increases, so does scrutiny on ESG claims. Greenwashing can lead to brand damage, greater regulatory scrutiny and the risk of fines, and companies are already feeling the impact of their claims. Black Mountain Energy had to pay several fines as a result of misleading net zero claims in relation to its natural gas development and Mercer Superannuation is likely to pay a fine resulting from the allegedly false claims that it excluded companies that were involved in carbon-intensive fossil fuels from its funds but then heavily invested in 15 stocks from the sector including AGL Energy, BHP, Glencore and Whitehaven Coal.[86] Accountability mechanisms are not yet uniform, however companies are still better placed to take credit for genuine action rather than risk regulatory or reputational ramifications of greenwashing.

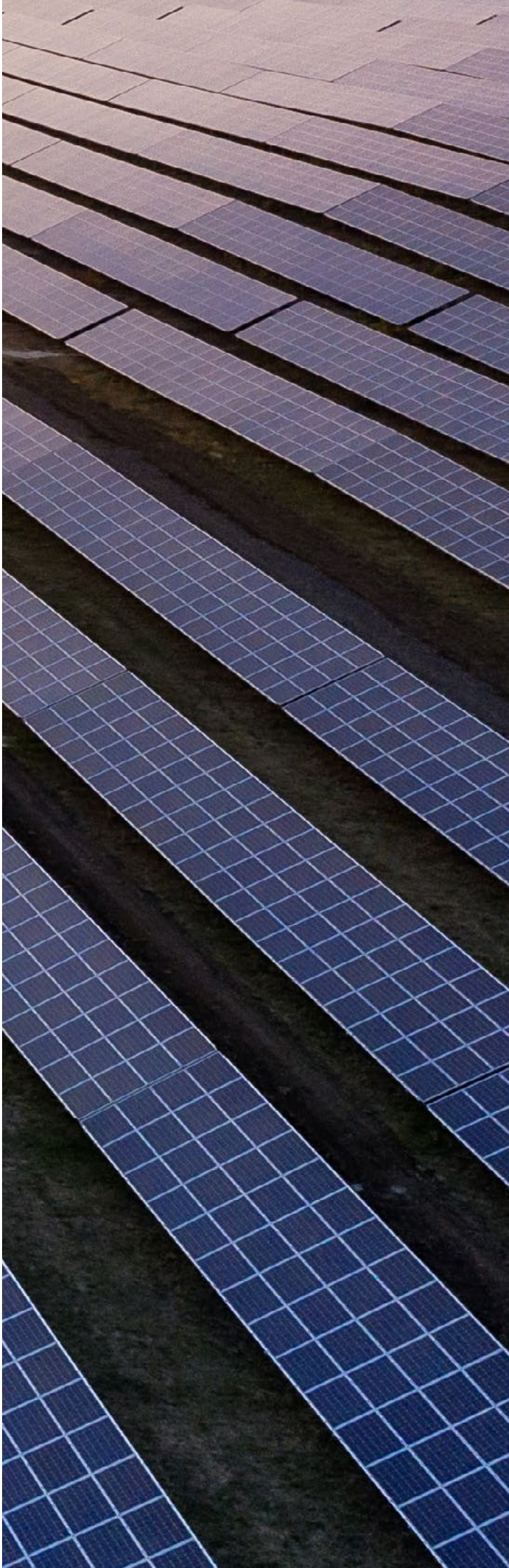
To start the shift in perceptions, businesses must be transparent and open in the targets they are trying to achieve. 18 out of 20 of the world's largest mining companies (by market capitalisation) have carbon reduction targets, however to date, reporting requirements on climate impacts and decarbonisation plans vary across the globe. This has resulted in various levels of transparency and disclosure from companies. Global recommendations such as the International Sustainability Standards Board's IFRS S2 requires an entity to disclose information about climate-related risks and opportunities that could reasonably be expected to affect the entity's cash flows, its access to finance or cost of capital over the short, medium or long term. When it comes to the Taskforce on Nature-related Financial Disclosures, their recommendations are related to the disclosure of nature-related issues.

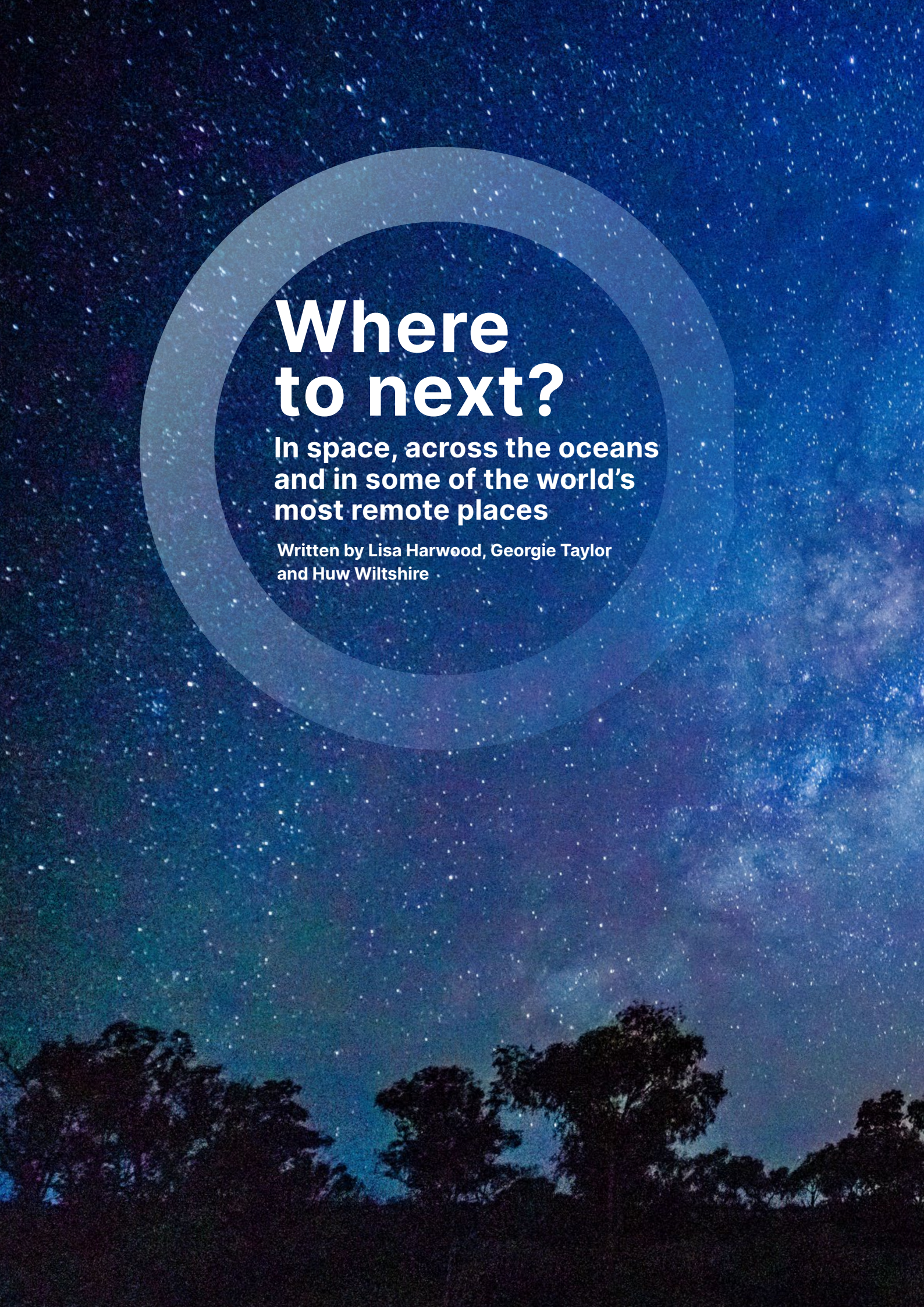
More recently mandatory reporting has been announced in various countries. In New Zealand climate-related disclosures were made mandatory for large publicly listed companies, insurers, banks, non-bank deposit takers and investment managers in 2023.[87] In Australia, large companies and financial institutions will have to disclose information about how they plan to decarbonise and the impacts of climate on their business and ability to operate from July 1, 2024.[88] In Canada, climate related reporting will be mandatory from 2024.[89]

Whilst this reporting may seem onerous to mining companies, it should be seen as opportunity to promote their environmental efforts and shift perceptions. These tools not only hold companies accountable, but they are important mechanisms in communicating the change that is underway in the industry.

83. Bloomberg
84. Australian Mining
85. PWC
86. AFR
87. World Favour
88. Renew Economy
89. ESG Today

Attempting to change the perceptions of a society who has spent decades forming certain opinions is no easy feat. But in the face of a global energy transition, increasing demand for critical minerals and a deficit of skilled workers, industry must take greater steps to build trust. Industry understands there is a negative perception problem and work has been done, however in the wake of ongoing protests at numerous mine sites and continued environmental and social disasters, there is still significant steps that need to be taken to ensure they becomes more sustainable, accountable and considerate of the impacts they have on the broader environment and community. More proactive, ongoing engagement with community is one of the keys to shifting these perceptions, alongside further prioritising ESG efforts and transparency. It's no longer enough to make claims around sustainability or social efforts, it's now imperative the mining industry makes building trust, and ultimately shifting perceptions, a strategic priority going forward.





Where to next?

In space, across the oceans and in some of the world's most remote places

Written by Lisa Harwood, Georgie Taylor and Huw Wiltshire

It's a question that has been asked a hundred times before but is yet to have a plausible answer. How do we continue to source enough minerals to power the world?

It's predicted that mineral demand for clean energy technologies will rise by at least four times to meet climate goals by 2040, requiring hundreds of new mines.[90] [91] Realistically, the mining industry will need to mine more than ever over the next decade to support the energy transition. At the same time, it will continue to deal with deeper and more complex orebodies and the growing pressure to mine in a sustainable way.

To achieve these goals, the mining industry will require innovative thinking and new strategic approaches; from where it mines, to how it mines and the technology it uses to mine.

This chapter will explore some of the innovations that could change the mining landscape, the developing countries who are emerging as hot spots for mining and the energy transition, and the unexplored territories which could help to fuel our future.

Mining innovation out of direct view

Innovation is driven by need, which is highly contextual for each region, company and asset and dependent on external factors and pressures. Innovation within the resources industry has historically been dominated by developed countries with a high mining prominence such as Australia, Sweden, the United States (US), Canada and Chile. A strong mining industry attracts investment and enables the development of a technically skilled workforce. In contrast, developing economies typically lack the capacity to invest in infrastructure and development necessary to extract their own natural resources, while geopolitical complexities make investment less attractive. In the race to deliver enough critical minerals, developing countries, which have always had a presence but have never dominated the mining scene, are starting to emerge as major players in the game.

Indonesia

With Indonesia currently accounting for 55% of global nickel output (an increase in production from under 800,000 tons in 2020 to 2.03 million tonnes in 2023), their rise as a key supplier of the world's nickel has been nothing short of meteoric.[92] The Indonesian government introduced an export ban on unprocessed nickel in 2020, encouraging a shift downstream. This shift, coupled with the geology of Indonesian nickel (which typically requires more carbon and acid intensive processing), has seen processing innovation emerge. The two key processing techniques, backed by foreign investment, have resulted in a battery-grade product from low quality raw nickel that was previously only suitable for industrial use.

90. IEA
91. Mining.com
92. Reuters

The first processing innovation involves a new method of turning nickel pig iron into nickel matte, essentially turning low grade nickel into a grade suitable for battery use. While this technique has increased the supply of EV-grade nickel, it is far more emissions intensive that simply extracting from sulfide ores.[93] The second processing innovation is high-pressure acid leaching (HPAL), which involves a combination of heat, pressure and acid to separate cobalt and nickel from other elements.[94] Whilst this technique has been around for a little while now, the support provided by Chinese investment and know how has supercharged the process, which has seen Indonesian HPAL plants come online in a record speed (and at a very low comparable price). The average capital intensity for Indonesia has typically been around US$30-35,000 per annual tonne of nickel. The average for a western built plants sits around the US$100,000 per annual tonnes of nickel.[95] As battery industry leaders such as Tesla, LG, and BMW AG shift to high-nickel cathodes to increase battery density, Indonesia has begun attracting international chemical conglomerates such as BASF and the Mitsui Sumitomo, which have further contributed capital and knowledge.

With a predicted 70% of the world's HPAL project production capacity being developed in Indonesia, and no end in sight to the export ban, the shift downstream supported by these processing innovations are already having implications on the global nickel market.

Indonesia's exports of ferro nickel alloy climbed 38% by volume in the first five months of 2023, with this increase in supply resulting in a subsequent plunge in price.

If demand for cheap nickel continues (and with there being little incentive to pay a premium for a green product), it's hard to see how the rest of the world will be able to compete with Indonesia's dominance in this space.

"I think Indonesia has changed the nickel market. We've got a guy who's just on his way back from doing some site-work and Indonesia has cracked the code on HPAL."[96]

Chief Investment Officer, Resources Investment Firm

An interesting aside to the nickel dominance is the emerging dominance in cobalt that has resulted from the HPAL technology. Cobalt is traditionally a byproduct of nickel mining – just 1% of cobalt mined in 2023 will be the primary product of the mine from which it is produced.[97] Whilst the Democratic Republic of Congo (DRC) will likely remain the largest producer of cobalt, there is a question around how much disruption Indonesia can make in this space. This is particularly true for those companies who are looking to diversity from the DRC, a country which has a history of alleged human rights abuses. Indonesia has plenty of its own sustainability issues, with HPAL facilities being reported to have more than three times the carbon emissions compared to traditional refining methods.[98] They also produce high volumes of waste, with questions around how it will be stored and risk of leakage causing environmental damage. The emergence of HPAL technology is now forcing downstream manufacturers to decide between readily available, low-cost inputs, or those with a higher standard of ESG production.

93. Macquarie
94. AFR
95. Wood Mackenzie
96. AFR
97. Benchmark Minerals
98. S&P Global

Saudi Arabia

Traditionally known for its dominance in the oil industry, Saudi Arabia have recently stepped into the mining industry space. Keen to diversify away from fossil fuels, Saudi Arabia are also looking to capitalise on their reserves of phosphate, gold, copper and rare earths, which are estimated to sit at US$2.5 trillion worth of untapped resources.[99] A USD$182 million mineral exploration incentive programme has been established and there are plans to award over 30 mining exploration licences to international investors in 2024.[100] All of this is underpinned by the new mining law introduced in 2020, designed to make it easier for companies to pursue mineral exploration and extraction. In addition to greater exploration, the country is also looking to increase power generation from renewable sources and develop their own domestic battery sector.

Saudi Arabia has strengths that could see them become a notable player in the global mining industry. The oil and gas sector traditionally spend a significant amount of time and money to understand their asset before they even start the extraction process. They are well versed at directional drilling and using sensors to extract data and model oil reservoirs. The use of sensing technologies to model an asset is still relatively new to the mining industry and is a space in which Saudi Arabia could dominate if they harness their experiences. Seismic techniques, which have been deployed by oil and gas players since to early 1900s, but also have applicability in enhancing the exploration of minerals, is another space in which Saudi Arabia could use previous knowledge to accelerate their new pursuit.

Saudi Arabia also has huge potential for cheap, renewable energy given the abundance of sunshine and vast amounts of land. And whilst it is coming from a very low base of renewable energy source; 99% of the overall power generation of the country comes from fossil fuels, there are multiple large-scale projects in operations or under construction, including the Sakaka Solar PV Park (a 300MW PV solar farm) and the Jubail 3A IWP Solar PV Park (a 45.75MW solar PV power project).[101] [102] [103] It's reported that some projects, such as the Al Shuaiba PV IP solar power plant, could sell electricity for just 1.04 US cents per kilowatt hour in the future, which shows the potential for a cheap and clean energy source for future mining activities.[104]

No doubt there will be interesting partnerships, discoveries and opportunities that will evolve, some of which are already emerging. Australian companies, EV Metals and European Lithium, have announced plans to set up processing facilities to take advantage of cheap energy costs.[105] In 2023, Novonix announced a joint venture deal to build a 30,000 tonne capacity graphite anode materials facility with TAQAT Development. There is also an emerging EV manufacturing sector, with Lucid Motors, a US automaker, announcing it would build a factory in Saudi Arabia.[106] Despite this demonstrated support from industry, Saudi Arabia's push into mining is unlikely to be all smooth sailing. The large infrastructure, water supply, and technical labour requirements will all pose significant hurdles for the nation, requiring long-term leadership and dedication to make it through to production. In the end, only time will tell how Saudi Arabia's foray into mining will play out.

99. Reuters
100. Reuters
101. Energy Monitor
102. NS Energy Business
103. Zawya
104. Live EO
105. AFR
106. Benchmark Minerals

“The oil and gas industry has better collaboration around farm-in agreements, they spend more money upfront, they drill $100 million hole, we drill a million-dollar hole. The reservoir, in their case, is the prize national asset – they understand it intimately before they start cutting it open. They care for it. They want it to last.”

CEO, Mining Services Company

Morocco

From launching the world's largest concentrated solar power plant (at the time) in 2016, to earmarking one million hectares of land for green hydrogen projects, Morocco's focus on renewable energy is both admirable and ambitious. With a large natural endowment in wind, solar and hydropower, the country has reached 20% renewable electricity penetration, predominantly from the development of Concentrated Solar Panel (CSP) technologies combined with thermal storage.[107] Beyond their high renewable penetration however, Morocco's proximity to Europe and established free-trade agreements (it's an EU and US free trade agreement partner), make it well suited for trade under the European Union's Carbon Border Adjustment Mechanism and for capitalising on the US' Inflation Reduction Act. Combine that with a growing demand for green value chains in many developed countries, and Morocco is well placed to develop downstream processing capabilities, and push into electric vehicle (EV) manufacturing.

Morocco has an abundance of cobalt, lithium and phosphate reserves. Its phosphate prospects are particularly strong, boasting over 70% of the world's reserves of this key ingredient in lithium iron phosphate cathodes. From a mere mineral supply perspective, Morocco is well positioned to capitalise on the energy transition – the automotive sector currently represents around 5% of purified phosphoric acid demand, but that number is predicted to jump to 24% by 2030.[108] Add in the benefits discussed earlier along with government progress in establishing appropriate policy levers, and Morocco has positioned itself as an attractive place to set up business.[109] Companies are beginning to capitalise on this environment, with South Korean company LG Chem recently forming a partnership with Youshan to establish a joint EV battery material plant in Morocco. The partnership will see enough lithium-phosphate iron cathode material produced annually for 500,000 entry level EVs.[110] The government also signed a memorandum of understanding with Chinese-German electric vehicle battery company, Gotion High-Tech, to build Africa's first gigafactory.[111]

Shifting further downstream, there is also potential for Morocco to leverage their extensive knowledge in automobile production and shift to EV manufacturing. Morocco already has a cluster of automobile suppliers and original equipment manufacturers which means the country has capability to produce in house versus importing components. Renault, for example, sources more than 60% of their vehicle parts from Morocco.[112] Renault-Nissan and Stellantis have announced plans to expand EV production in the country and Morocco's own automobile brand, Neo Motors, is looking to step into the EV space.[113] Combine the country's capabilities with their goal to produce 100,000 EVs per year by 2025, and there is real potential for Morocco to become a downstream powerhouse.

107. Andreoni and Avenyo, 2023
108. Benchmark Minerals
109. Benchmark Minerals
110. The Assay
111. Financial Times
112. Financial Times
113. Benchmark Minerals

The bigger picture

With the world evolving so quickly, the possibilities are endless when it comes to the next big innovation or dominant country in mining and downstream processing. Beyond what has been discussed above, there are many more examples of innovations happening across the developing world. In Costa Rica, a country where open pit mining is banned, a recycling factory, which has been open for decades, has become a leader in lithium extraction in rechargeable batteries. They call the plant their 'urban mine'.[114] A recent discovery of a large copper site on the Zambian copper belt seemingly aided by artificial intelligence has reignited discussions on the role of AI in exploration. In Kenya, a biodegradable glove from bacterial cellulose was recently developed to address the problem of mercury in artisanal and small-scale gold mining.[115] Only time will tell if any of these countries will step up to challenge the status quo in mining as it currently stands.

114. Tech Xplore

115. Mining Weekly

Moving heaven and earth

Hearing the words "space" and "mining" together might at first conjure up thoughts of Bruce Willis in an astronaut's suit, drilling into an asteroid to secure the future of humankind. While the prospect of extraterrestrial mining has fascinated entrepreneurs for decades, to date it remains the stuff of science fiction – as of 2023, 50+ years of academic interest and more than USD$2 billion have delivered just 7 grams of asteroid material to Earth.[116]

The gap between outer space and mining operations is closer than it seems, though. There are a number of ambitious programs to support off-world industry in the near future, such as the Defense Advanced Research Projects Agency's (DARPA's) 10-Year Lunar Architecture program to explore a lunar economy.[117] Technology drives exploration, both in space and underground. The cutting edge tools and technologies developed to solve incredible problems encountered in the remote, harsh conditions of space could also be applied to create (literally) groundbreaking change in the mining industry. The application of space exploration technologies to Earth-bound use is already far-reaching: a litany of items, from air purifiers and cordless power tools to blue light glasses and nutritional baby formula supplements have roots in NASA R&D. We all rely on space technologies for our weather forecasts, communications, and cell phone cameras. Given the broad trailblazing capabilities of the space sector, closer collaboration may offer an invaluable opportunity for the mining industry to solve some of its innovation challenges, shorten the time span of physical innovation, and achieve a step-change in safety and efficiency of operations. This is particularly critical right now, when our survey data shows that the energy transition (which requires significant physical and technological innovation) is considered a key strategic driver by the majority of the mining industry.

There are obvious similarities between the two sectors. Both operate in extreme environments, requiring durable, precise equipment that can be operated remotely or autonomously, particularly if there are communication lags. Both involve exploring new areas and

116. The combined hauls of the Hayabusa, Hayabusa2, and Osiris-REX projects

117. DARPA

measuring their structure and composition, and both increasingly rely on advanced simulations, modelling, and testing. Both are energy intensive and make use of controlled explosions. Both call for an increasingly low footprint, with high optimisation and a circularity of waste products, and for staffed operations, both have encountered serious issues related to human safety. Perhaps that's why we're seeing an increase in cross-industry business activity. For example, Fleet Space's space-enabled 3D subsurface model technology has already been used for over 250 exploration surveys on Earth (and will be catching a ride with NASA to explore the moon in 2026), Woodside Energy's offshore facilities are being used as a testing ground for NASA's humanoid Valkyrie robot, and FirstMode's team of ex-NASA professionals are providing innovative engineering solutions such as retrofit power systems to remove diesel from heavy industry.[118] [119] [120]

A particular area of interest for mining is the development of remote operations and autonomous systems. Some programs, such as AROSE (Australian Remote Operations for Space and Earth) have already recognised the confluence of application in these areas, working to develop niche solutions "from Earth to Space and back again". AROSE founding members saw the value in the intersection of mining and space industries firsthand in 2021 when the AROSE demonstrator lunar rover feasibility study was completed with mining and METS companies, South 32, OZ Minerals and IMDEX, in order to transfer autonomy and systems engineering knowledge.[121]

There are surely many more successful collaborations between space and mining sectors on offer – especially with efforts such as NASA's Technology Transfer program, which is designed to make space-based innovation available to the public (its website hosts a catalogue of thousands of technologies that can be applied for business usage, and hundreds of free pieces of software that can be downloaded to give businesses a competitive edge).[122] Another silo-breaking initiative comes in the form of the DARPA challenges. For example, the DARPA Subterranean Challenge saw teams from institutes including NASA JPL, MIT, and CSIRO compete to rapidly map, navigate, and search complex underground environments, showcasing novel technology innovation with obvious industrial applications.[123]

These examples demonstrate how breaking industry silos enhances knowledge, capability, and innovation, inspiring mining enterprises to push further into the future. In particular, the space sector offers products on the frontier of hardware, software, and information, including reusable rockets or rockets with increased payload capabilities, ion propulsion technology, advanced electronics that process billions of commands per second, satellite tools and data, filters and weak-signal observation technology, swarming "bugs" in fibre-fed spectroscopes, autonomous rovers and undersea bots, data mining tools, long-distance communications, giant batteries, heat-and-cold-resistant materials, rugged imaging technology, and advanced simulations.[124] The opportunity is clearly there – so who in the mining industry will reach up to seize it?

118. Fleet Space
119. NASA
120. FirstMode
121. AROSE
122. NASA
123. DARPA
124. NASA

Exploring the murky depths

The Seascape

Seabed mining (both on the continental shelf and in the deep sea) presents an opportunity to access mineral deposits that are inaccessible or uneconomical to mine on land. The ocean floor is rich in polymetallic nodules, hydrothermal vents, and cobalt-rich crusts, containing valuable minerals such as copper, nickel, cobalt, manganese, zinc, gold, and rare earth elements. As we all know by now, many of these elements are critical components of the infrastructure needed for the clean energy transition, and as such, are predicted to experience sustained surges in demand. As easy resources are depleted and land-based mining for such commodities becomes more difficult and expensive, many companies are now casting their eye on the watery horizons.

Shallow water resources are generally found atop continental shelves and include mineral rich sands and placer deposits. Many countries mine their shallow water resources – for example, Namibia's offshore diamond mines, Indonesia's tin placer dredging, and New Zealand's ironsand mining operations. This seabed mining is performed by collecting resources on the seabed and lifting them to surface vessels, which either process the materials offshore or transport them back to facilities on land. This process is similar to that used in the widespread extraction of sand and other shallow-sea materials used for construction. The extraction and collection are generally handled by remote or autonomous underwater vehicles, using pressurised water jets or mechanical tools like cutting and collecting machines.

It's estimated to have over 21 billion metric tonnes of nodules that could provide twice as much nickel and three times more cobalt than all the land reserves.[125]

Mineral deposits in the deep seabed (i.e. depths greater than 200m, covering more than two-thirds of the total seafloor) represent the greatest mineral reserve potential, though have not yet been mined. Mining in the Clarion-Clipperton Zone, between Mexico and Hawaii in the Pacific Ocean, provides one of the greatest potentials for mineral deposits that we know of so far.

In early 2024, Norway became the first country to approve deep-sea mining in its national waters, opening 280,000 sq km of seabed (roughly the size of New Zealand) to potential mining operations – though each license will still need to be approved on a case-by-case basis. More broadly, the International Seabed Authority (a quasi-UN body) has until 2025 to complete their regulations on deep-sea mining exploitation in areas beyond national jurisdiction and have already issued exploration contracts to 22 contractors to date.[126]

Much can be learnt from the oil and gas industry, with many techniques able to be adapted for the deep-sea pursuits. Transportation of ore from the sea bottom can use riser technology from oil and gas

projects, and floating production storage and offloading vessels typically used by the oil and gas industry can be used to store the ore before transporting to an offshore facility.[127] Rapid advancements in robotics, autonomous vehicles, sensor technology, and deep-sea exploration techniques have lowered the technical barriers to entry, and will also lower the capital cost as development progresses at scale.

Whilst deep-sea mining shows potential, it is a technically and economically challenging exploit. There are serious operational challenges surrounding the practice of deep-sea mining, including cost of specialized equipment and infrastructure, long development cycles of new processes and techniques, and the potential risks from equipment failure, tidal or weather conditions, and geological instability. The bankruptcy of what was set to be deep-sea mining's first mover, Nautilus Minerals Ltd., is an ominous warning sign for business prospects. Nautilus had been granted exploration licences by the Papua New Guinea government, who incurred significant costs when the project failed to deliver.

125. The Conversation

126. ISA

127. Tjåland et al. 2022

The Big Question

Ironically, the societal benefit gained by supplying energy-transition raw materials through sea mining may be offset by significant environmental damage. As well as being critical to the fisheries industry and global food security, the ocean is the world's largest carbon sink, sequestering up to 25% of all global CO2 emissions through microorganism activity. However, the deep seas are largely unstudied, so we have no idea how much life (and life-supporting systems) deep-sea mining could end up disturbing – as recently as July 2023, 5,000 new species were discovered in mineral-rich areas of the Pacific Ocean that are being targeted for mining operations.[128] In particular, some hydrothermal vents which host mineral deposits (including those targeted by Nautilus's failed project) are categorised as rare ecosystems.

> **"Environmental impact is a prime concern, of course. But beyond that, the logistical challenges are staggering. Just think about the sheer scale – moving vast volumes of material from the ocean floor to extract a significant amount of ore is an immense undertaking."**
>
> **Founder, Mining Consultancy**

Mining operations cause local disruption to the seafloor through altered seabed morphology, destruction of seafloor organisms, and sediment plumes laced with toxic metals. They also affect the quality of more surface waters during the discharge of waste materials, oxygen depletion, and acidification. Studies have found that even at the best of times, the practise can cause harmful noise and vibration, sediment disruption akin to dust on a traditional mine site, light pollution, and decreased animal populations, at the detriment of the ocean's food chains.[129] At the worst of times, mining incidents risk irreversible fuel or chemical leaks, or could trigger the release of the ocean's huge methane stores, causing a catastrophic global warming effect. These factors were compelling enough to cause 24 states to sign a moratorium, pause, or ban on commercial deep-sea mining.[130] They also contributed to public protests against Nautilus's activities, by coastal residents who reported seeing dead fish and excessive levels of sediment during the project's exploration phase.[131]

The very nature of the sea means the risks are more interconnected than on land – ocean currents mean a mining accident in the waters of Norway may easily impact the marine vitality in the rest of Europe, or even further afield. Perhaps the drive for innovative, eco-friendly new technologies to meet the challenges of future sea mining will be a source of sustainable growth for the mining industry more broadly... but perhaps not. We know that we need to find more minerals, however a recent report found that a combination of circular economies, new technologies, and mineral recycling could cut cumulative mineral demand by 58% between 2022 and 2050, eliminating the clean energy transition's reliance on future deep-sea mines.[132] Allowing private companies to tap into this new source of resources may play a crucial role in meeting global resource needs while diversifying the sources of mineral supply, but of course, the question we must always ask ourselves is – at what cost?

128. Oceanographic Magazine
129. Williams et al. 2022
130. Mining Review
131. PNG Attitude
132. Environmental Justice Foundation

> **"I envision a future where trade processes, starting from the mining stage and extending to the end user, are seamlessly integrated. The shift from supply-driven supply chains to demand-driven supply chains will allow end user demand to influence production schedules in real-time."**
>
> Founder, Technology Company

Conclusion

The energy transition will be the central focus of the mining industry for decades to come. The question that remains is what the future of mining will look like given the imperative to decarbonise, the growing need to innovate when it comes to exploration and supply chains, and the growing negative perceptions from broader society.

Will we see new entrants come in and completely disrupt the value chain? Will we see a complete overhaul of current business models? Or will businesses resist change and eventually fail due to a lack of adaption? Only time will tell – we can only imagine the disruption that may take place over the next few years.

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