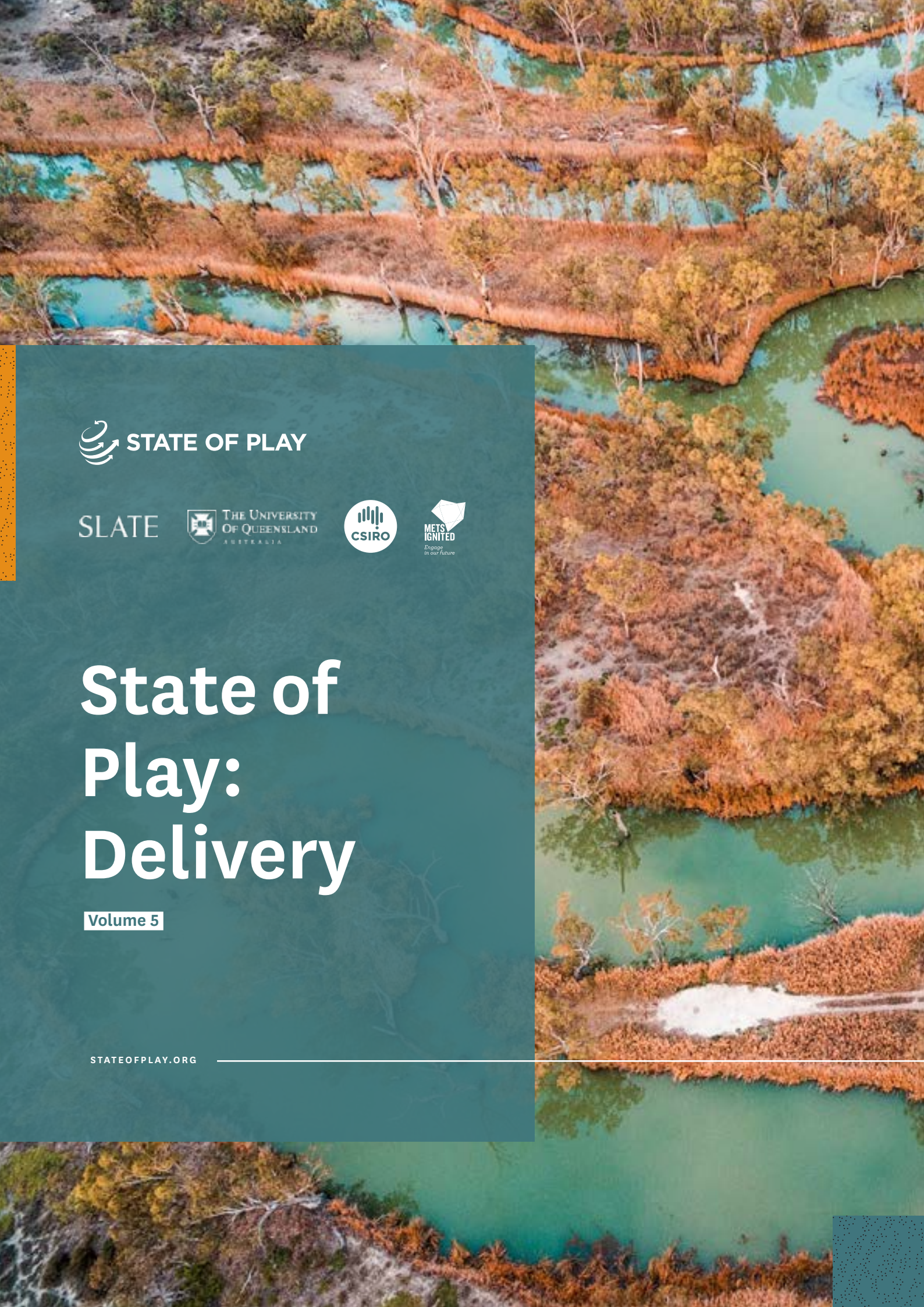

STATE OF PLAY

SLATE

The University Of Queensland
AUSTRALIA

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METS IGNITED
Engage in our future

# State of Play: Delivery

Volume 5

STATEOFPLAY.ORG

# About State of Play and major sponsors

## About State of Play™

The State of Play™ platform was initiated in 2012 and is now the largest mining survey in the world. The ambition was to create a platform to support industry discussion of innovation and performance at a strategic level, macro-level insights into the industry ecosystem, and more effective strategy execution and business design for competitive advantage.

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

This is our fifth 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 featuring a majority of respondents from executive of 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: **stateofplay.org**


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## About our major sponsors

**SUSTAINABLE MINERALS INSTITUTE, UNIVERSITY OF QUEENSLAND**

As society seeks to create a sustainable future, the global demand for minerals will continue to increase. While the resource industry is working to meet this increased demand, it is also reshaping itself to reduce its impact on communities and the environment. SMI are creating change through research discovery and collaborative global initiatives and consortia. SMI are working collaboratively with industry and research partners bringing both depth and breadth of expertise to their research and consulting work. SMI are training the next generation of industry and community leaders through Higher Degrees by Research and through a growing number of professional development programs.

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### METS IGNITED

METS Ignited works with Australian suppliers to the mining industry, global miners, research organisations and capital providers to improve the competitiveness and productivity of the Australian METS sector. Its five areas of strategic focus to help strengthen the global competitiveness of the Australian METS sector are: a shared vision; strengthening collaboration in the mining innovation system; addressing gaps in the ecosystem; raising your profile; and promoting world class clusters.

Adrian Beer, CEO

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### CSIRO

CSIRO is Australia's national science agency and innovation catalyst.We solve the greatest challenges through innovative science and technology. Our collaborative research turns science into solutions for food security and quality; clean energy and resources; health and wellbeing; resilient and valuable environments; innovative industries; and a secure Australia and region.

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Slate provides strategic advice to businesses operating in natural resources, energy and infrastructure. It applies unique industry data and analytics, innovating continuously. Slate's clients range from large multi-national enterprises to entrepreneurs building new industry offerings

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# Foreword

Nearly a decade after our first survey, we are proud to deliver State of Play's fifth biennial report, holding true to the original aim of helping natural resources businesses better understand strategy and innovation in their industry.

This report is being released at an inflection point for both the industry and our business. Covid-19 has condensed 15 years of change in work practices into one. The use of artificial intelligence to automate value chain decisions is poised to revolutionise the industry as datasets from across the value chain coalesce. In summary, the long-promised impacts of digital transformation are poised to impact the industry with uncertain outcomes.

Renewable energy is now cheaper than diesel, and economic options for storage are arriving sooner than many appreciate. The potential for zero carbon energy supply will underpin the full electrification of mines. Electrification across industries will in turn drive growth in battery minerals which could make previous minerals booms look pedestrian. The supply paths for sourcing these minerals is unclear, which will naturally accelerate innovation in extraction. As the relationship between Western nations and China becomes more challenging, global supply chains will be reformed and may fragment along political lines.

As the industry changes apace, State of Play will also need to evolve how it conducts our business. We will become a standalone, self-supporting entity, enabling us to focus exclusively on our core remit. We will move to a more interactive engagement platform where participants can readily contribute to and access the rich set of data that has been assembled over the past decade. Importantly, State of Play will retain its fierce independence and intent to uncover deep insight that helps industry leaders more effectively design their strategy for sustained business success.

Finally, to all those that have responded to surveys, interviews, and have given generously of their time in wide-ranging conversations, we say thank you. You have all contributed to making the industry a bit more aware of what it faces, and the huge opportunities that these futures present.

**Graeme Stanway**
Chair of State of Play

# Introduction

As one of humanity's oldest industries, human progress has often relied on the next advance from mining to send civilisations forward. From the development of bronze alloys, a couple of millennia ago, to large scale coal mining to power the industrial revolution, to the rapid development and urbanisation of China through expansions in iron ore production, to the coming energy transition and electric vehicle revolution being powered by the expansion of minerals such as copper, lithium, nickel and cobalt. Since its inception mining has innovated and expanded, enabling great leaps in living standards and human capability.

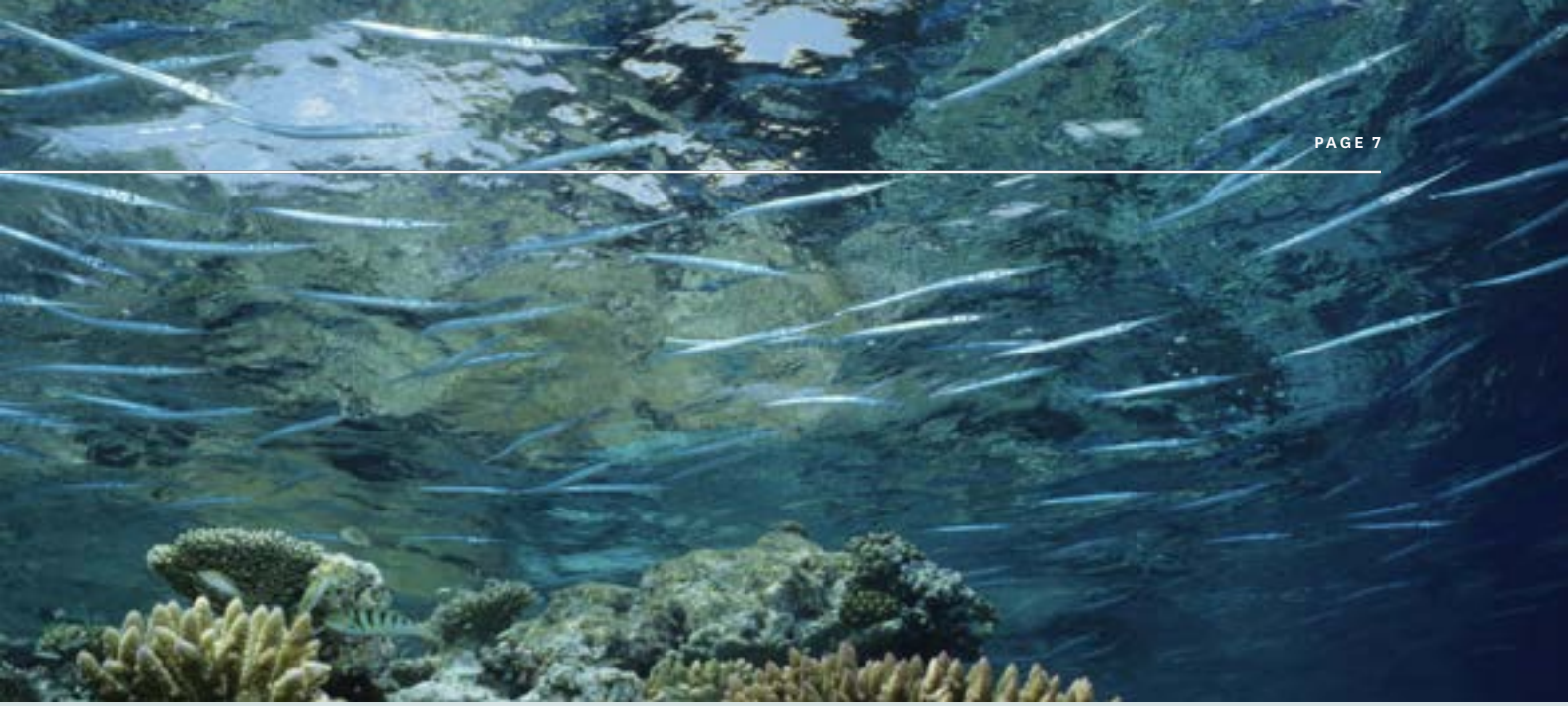
The change that has propelled mining to the next level each time has not come easily. Humans are most comfortable with inertia, choosing the path of least resistance to achieve a goal. It is one thing to design a new way of operating, another entirely to deliver the change with minimal disruption or value loss. People change and technology change each present different challenges, together they present formidable assignments for company leaders. These factors present headwinds for innovation in any industry, however the added necessity for stability and predictability in mining, especially in operations, can constrain large-scale change relative to other industries.

Sometimes an abrupt shock can snap people out of inertia. For over a year now, the world has been responding to a deadly, global pandemic. Covid-19 has shut down international trade routes and confined human movement, leading to some of the largest demand shocks some industries have ever seen. Tourism, aviation and retail, to name a few, have been decimated by the restrictions of travel and leisure. Upending these industries has had flow-on effects to input industries, with the oil sector in particular facing questions about recovering demand. Mining by contrast has been less affected, and stands to benefit from covid-recovery stimulus, especially out of the US.

The pandemic has also disrupted the internal operations of the mining industry. The requirement for many workers to work remotely initially placed significant stress on existing digital technology and communications infrastructure. However, facing extreme need, the industry has rapidly accelerated its digital capabilities together with the rest of the world. Communications infrastructure is secure, fast and normalised within corporate cultures. Data collection and flows to multiple off-site locations has created a virtual operating environment which promises far more transparency and adaptability from off-site locations. Most of all, the rapid development of technology that was initially expected to mature over the next 5-10 years means that the development of technology further afield has also accelerated. Greater data, communications and virtual representation of assets may bring forward the possibilities of artificial intelligence, smart autonomous systems and true end-to-end integration. Today's mining industry was not expecting to deal with mature capabilities in these technologies for at least another decade. They are now around the corner.

While Covid-19 has unsurprisingly dominated news headlines, the shutdown in trade has belied a greater shift in economic and political power globally. From a purchasing power parity point of view, China has already surpassed the US as the largest economy globally and is expected to grow at a healthy 5% over the next decade. By 2030, India is expected to accelerate at a rate of 7.8%, to clinch second spot with Indonesia growing at over 9% to reach fourth. Asia's total proportion of global GDP is expected to reach 35% in 2030, compared to just 20% in 2010.[1] The mining industry was well acquainted with China's initial boom, yet is set to face a new surge in demand that will be unpredictable and multi-polar.

1 IMF, Standard Chartered, Oxford Economics, Brookings



While the Asian demand story is well known, there is a significant risk that strategists assume Asia's influence is limited to an end-market. Asia's growth in political, economic and technological capability is set to have enormous impact on the industry, particularly in the realms of services and investment. China is home to over 300 high-profile electric vehicle (EV) start-ups, each of which will look to the mining industry as a supplier for battery minerals and other commodities, and to fuel the boom in EVs in the industry as the pace of electrification quickens. Services companies are set to face stiffer competition as new entrants are backed by increased capital availability and cutting-edge technology (especially in artificial intelligence (AI)).

The expected growth in electrification of mining assets is a theme throughout this report. It underscores the astonishing rate of technology development in renewable energy and storage. The generation game is over. Renewable energy is now cheaper than alternative sources of generation from a total cost perspective. Storage technology is not yet mature enough to compensate for the inherent volatility in energy capture, however the pace of battery technology development suggests this threshold is just around the corner.

As we have seen with Covid-19 and the faster development of digital technology, will there be a similar acceleration in energy technology? Could a catastrophic climate event or massive groundswell social movement spur further investment in storage options, and accelerate this shift? In any case, legacy energy systems are set to be outmatched and replaced with new technologies which will force a complete rethink of what next-generation assets will look like, and how to adapt current assets for the new energy world.

This report looks at the practical impact of the external world's unpredictability and how the industry continues to push forward. There is a combination of technological change, new ways of working or the inclusion of new people and companies in the innovation system. It draws on deep longitudinal survey data, in-depth interviews with a wide cross-section of the mining industry leaders, and specialist research, presenting a number of different flashpoints of change within our industry that merit attention from mining leaders.

The abrupt shift towards virtual work practices in response to Covid-19 has accelerated the development of true virtual, remote operating environments. Built on a backbone of digital infrastructure that collects and disseminates more data than ever, the geographical locations of workers and decision-makers reduces in importance compared to their interconnectedness with assets and each other. In a true virtual working world, we may see a global dispersion of people and talent, reshaping the nature of mining workforces and work practices in the process.

In contrast to the continued, rapid development of technical capability on-site, the design, construction and delivery of projects remains stubbornly resistant to change. High risk, complex commercial relationships, less proven technology and global dispersion of talent all limit the pace of innovation in project delivery. However, we are starting to see an acceleration in innovation. Digital technology is enabling more simulation and testing at greater levels of accuracy, while delivering project construction more accurately, quickly and cheaply. The general trend of scale reversal impacts both equipment and assets – on-site sampling and improved orebody knowledge is leading to faster turnarounds on studies and design, while modularisation could lead to dynamic asset designs with planned obsolescence and adaption of plants to different stages of the mine plan.

While the main focus of electric vehicles globally is on consumer markets, the promise of electric haulage and servicing vehicles in an industrial sense offers significant potential. Mining is no different, and offers unique benefits and challenges separate to the rest of the global trend. Notwithstanding the impact on carbon emissions and cost (especially once onsite generation is established), electric vehicles could drastically improve safety, especially in eliminating diesel particulates underground. However, the current lack of like-for-like replacements of existing haulage vehicles in particular increases difficulty in piloting and mine design of existing assets. More collaboration will likely be required to overcome some of these challenges.

In the midst of the greatest boom in start-ups the world has ever seen, spurred on by the rapid development of digital business models in particular, mining has been left out. While venture capital firms and corporate venture funds have turbocharged innovation in industries such as consumer technology and retail, physical industries such as mining are not as fertile ground for start-ups. Corporates looking to access the incredible innovation potential of small companies have struggled to establish the right engagement mechanisms and have stunted the potential of start-ups to rapidly change our industry. A more bespoke approach to venture investing that focuses on the specific needs of the mining industry is required to deliver the same payoff seen in other industries.

Like most other established industries, decision-makers in mining generally come from similar demographics. While much work has been done to increase the levels of diversity of gender and race in particular, our data has demonstrated an unheralded element that may offer more value than realised to design, innovation and strategy teams: age. Different age demographics are shaped by different factors, especially in their view of long-term trends and their experience with historical events.

We hope you enjoy it.

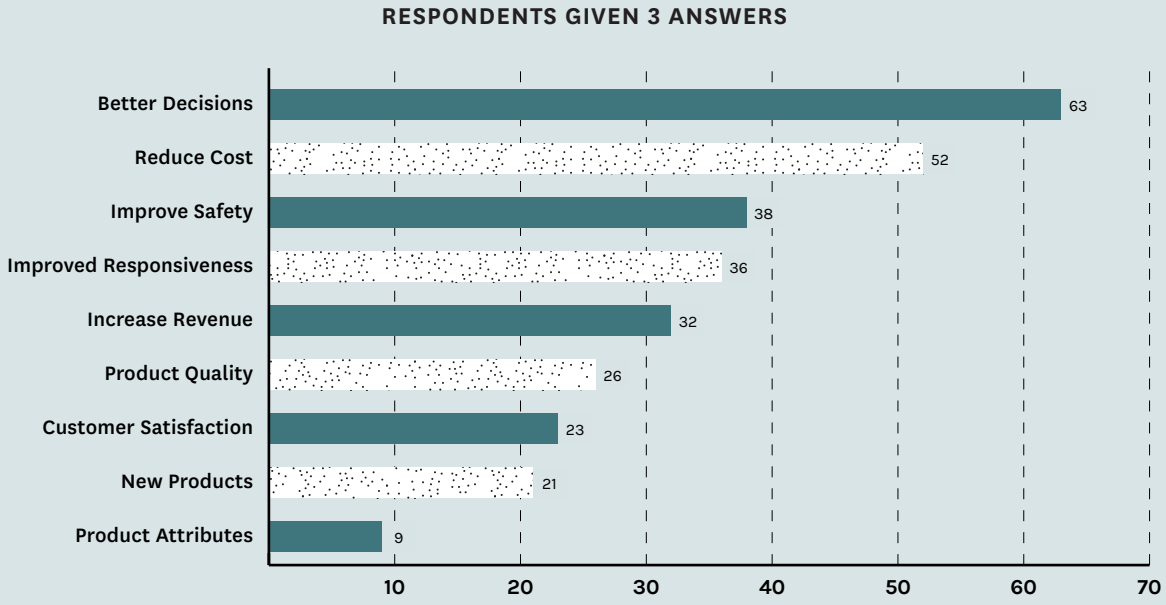
**THE STATE OF PLAY TEAM**

Xavier Evans
Paul Mahoney
Madi Ratcliffe
Graeme Stanway

# Virtual operations: It's coming home

Science fiction has long anchored stories around the concept of eliminating distance from our lives. From seamless communications across galaxies to hive minds for complex decision-making, the concept that people could communicate and interact without the tyranny of distance has always captured the human imagination. We have always wanted to talk to anyone, access anything and control everything from wherever we are. It has driven us to develop communications infrastructure and increasingly sophisticated remote-control technology. However, with the global Covid-19 pandemic, remote working became a daily reality and companies invested heavily in their ability to operate virtually. In doing so, it accelerated technology development, collapsing time horizons and showcasing different, more decentralised operating models in a more interconnected and technologically mature industry.

## How could digital technologies create business value for your company over the next 5 years?



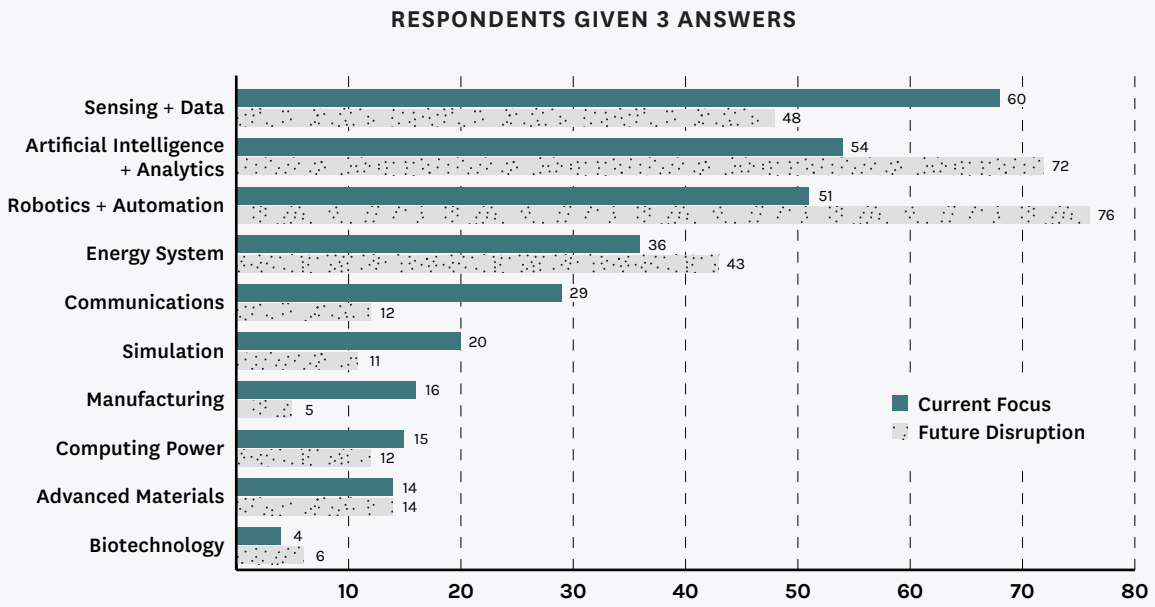
## It starts with ones and zeros

The development of digital technology has been the topic of significant focus across most major industries. Mining has been no exception, with the digitisation trend driving many technology development agendas in the industry for at least the past decade. Working virtually has placed increased focus on three main technology areas. The development of these technology areas has not been sequential, but has evolved in parallel, at a different and often inconsistent pace.

First, gathering data and providing a tangible visual picture of assets and operations has been key to making decisions off-site. With an influx of data flooding the system collected anywhere from drilling sensors, plant monitoring or waste stockpiles, the question is less about getting the data and more knowing what it means. Humans are visual creatures, and a tangible, visual demonstration of real-time activity can be key in bridging the gap from data to understanding. Already, companies like Reality Check that specialise in virtual reality visualisation of mines in real time, are growing rapidly.

Second, more data collection and visualisation options open up possibilities for simulation and modelling of future states. With better data, miners can have a better view into the impact of new or different inputs into their asset and its impact on the system. Service companies can effectively trial new delivery methods virtually, without the impost of ring-fencing pilot sites until a proven method has been simulated. Companies like TI Mining are providing a video-game-like interface with which to simulate physical assets.

**What are you currently focusing your innovation on? And what will have the greatest disruption to the industry over the next 15 years?**



Third, data gathering and analysis has required a significant upgrade in communications infrastructure. Network connectivity, communications between sites and office, and home office connections have all received an urgent boost in investment. Our data shows that this is a standard progression of innovation investment; leaders are ahead of the curve having invested in the required infrastructure and now investing in analytics, AI, robotics and automation to reap the rewards.

> **"Absolutely have to invest in edge computing, without it the system is overloaded"**
>
> **FORMER MINING EXECUTIVE**

As the technology readiness of these communications technologies grows, it also accelerates other, more futuristic technology developments that rely on a viable digital infrastructure backbone. In particular, sophisticated artificial intelligence programs require large datasets to be effective and with the wealth of data now accumulated by miners, explorers and services companies, are becoming increasingly valuable. Simulations are progressing apace as well, both in presenting a virtual value chain (albeit at a certain level of abstraction) to specific, detailed visualisations of specific components of the mining process.

63% of executives see better decision-making as the primary benefit, so bringing together analytics and simulation technology, decision-makers can utilise a realistic simulation to game out decisions in response to dynamic, algorithmically driven scenarios based on historical events. Future price-swings, terrorist attacks, trade wars, armed conflicts or pandemics can be inputted into the simulated system and planned for. Already, many governments are engaging in this work in the wake of Covid-19, determined to be more prepared for the next unexpected shock – miners are sure to follow as the data becomes increasingly available at an asset level.

## Stay at home operator

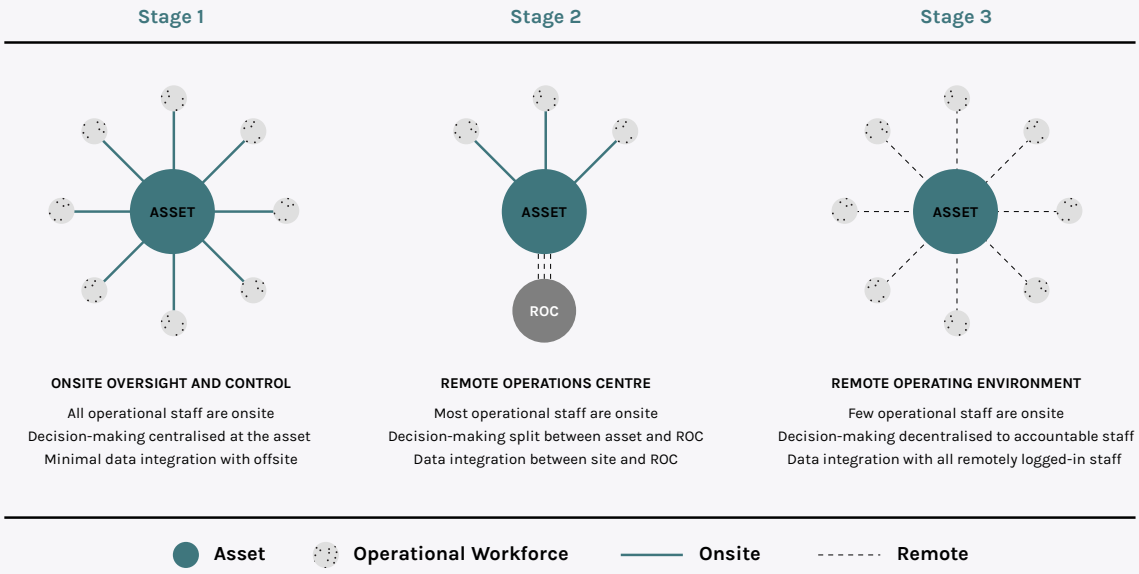
The development of more advanced communications and information technology has given rise to a long-burn trend of bringing people offsite. Automation development enabled people to work away from safety risks, the resources super-cycle increased demand for skills which had to be sourced in part remotely and a concentration of people in urban locations reduced the willingness of people to move to site. Remote workforces also reduced travel costs and encouraged more collaboration, generally through remote operations centres where key decisions can be made without being geographically proximate to site.

The next stage of this trend manifested during the Covid-19 pandemic as travelling was strictly limited and mining companies were surprised at their ability to maintain effective operations with fewer people onsite. Indeed, the greatest impact of Covid-19 on the industry is likely to be remote working (58%) and workforce models (49%). Given the proven technical viability of more remote operations, and the significant cost savings and reduction in safety liability it delivers, this trend is likely to continue, eventually moving from remote operations centres to fully remote operating environments (ROE).

> **"Get the technology right, then make decision-making independent. That's generally the best way to go"**
>
> **MINING COMPANY EXECUTIVE**

In an ROE, autonomous or remotely controlled equipment and vehicles conduct the operations of a site. A blanket of sensors would collect all the relevant data for decision-makers, inputting it into a live digital twin of the asset that can be viewed anywhere in the world, so long as there is an internet connection. Onsite staff are limited to skeleton crews and planned maintenance specialists. Suddenly, all operational staff are office workers.

## Stages of Virtualisation



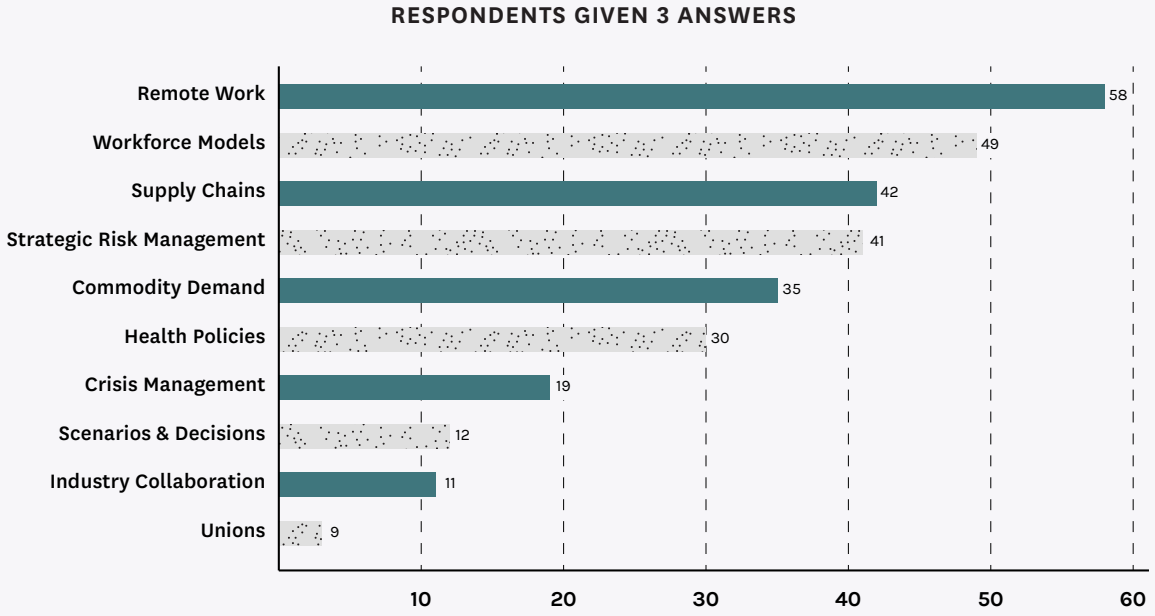

## Job location: anywhere

But what does that office look like? Driven by the relative success of working from home, the argument for allocated corporate offices as a necessary condition of doing business no longer seems to hold water. Depending on the role, many people are able to either partly or fully transition to a virtual working arrangement. The two holdouts appear to be in collaborative teamwork and social benefits from co-location, especially for junior staff development. Beyond this, virtual work is viable and in many cases beneficial, especially once routines are settled and people understand how to make the environment work for them.

Now that virtual work practices for current employees have been embraced, companies are now starting to hire with a virtual mindset. Potential workers don't necessarily need to be in the same physical location as the rest of their team (time zones notwithstanding), nor do they have to necessarily fit a traditional work schedule. This opens up the door for new workers to thrive in the mining industry, be they regional or international workers or groups such as women for whom flexibility is relatively more important. If remote work remains a strong trend, we may eventually see a decline in the importance of cities as a necessary agglomeration of workers, and instead see a revival of regional areas, especially in heavily urbanised geographies.

Realistically, roles which are 100% virtual will generally trend to low-cost centres globally, assuming time zone and language alignment. In Australia for example, the current strength of the mining industry does not come close to matching the giddy heights of the mid-2000s iron ore boom, thanks to a dispersion of services roles such as engineers and technology providers to the global mining industry diaspora. Governments in rich countries may look to counteract this trend with investment or incentives, however this is yet to play out.

## Where will the Covid-19 pandemic have the longest lasting impacts on the industry?




From a top-down perspective, the nature of leadership changes when companies embrace a virtual operating model. Traditional symbols of power (such as dress, large offices, and private floors) are less communicable virtually. Around the world, employees have experienced their bosses calling in from their homes in more casual clothing and experiencing the same workspace interruptions as everyone else. Embrace the t-shirts and put the kettle on, working from remotely is here to stay.

> **"You go to a mine site and they'll show you a KPI board that's 30 metres long and 5 KPIs deep, and they're very proud of it, but no one knows what it means"**
>
> MINING COMPANY EXECUTIVE

# Projects: The world of development

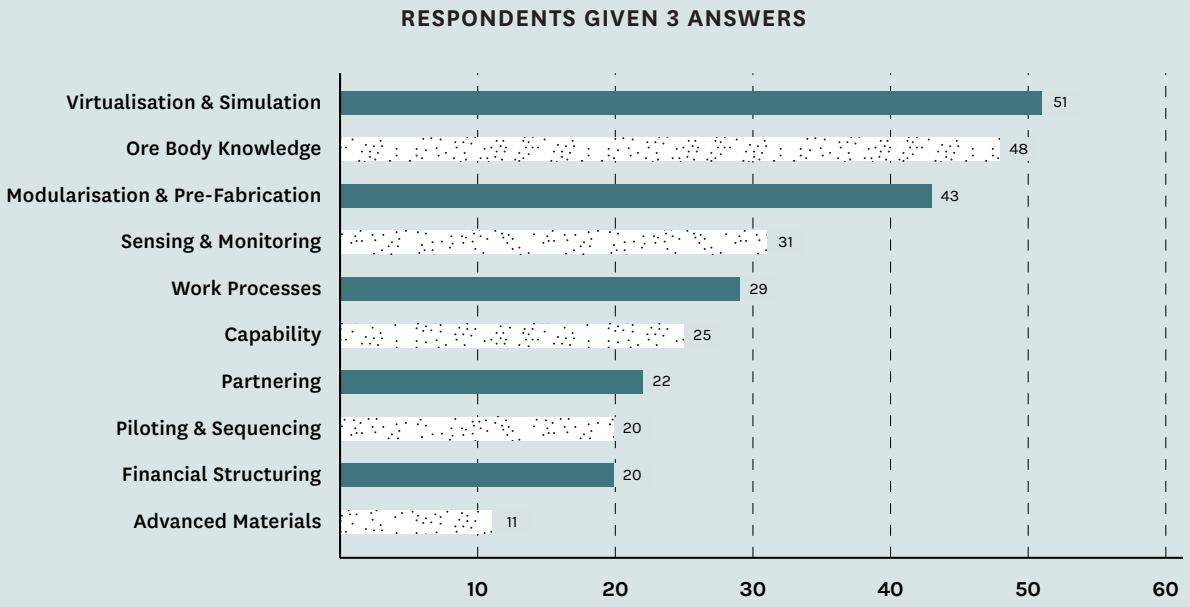
Of all the areas of the value chain set for a significant transformation enabled through technology and innovation, project design and delivery can fly under the radar. It is generally opaque, risk-averse and very capital cost conscious. Projects feature complex commercial relationships, with many players, unclear risk ownership, outsourced work and compressed timelines. Relatively few executives are willing to take any major risk in asset design (20%) or asset development (26%). The predominant culture is conservative, preferring frequent, incremental innovation efforts.

Given an inherently cautious culture, project innovation is unlikely to manifest as a sudden step change. However, the increasing pace of technology development offers a remarkable view of what the future may look like. Better understanding of newly discovered orebodies will enable detailed, tailored asset designs and mine planning. Advanced simulations will enable rapid testing and trialling of new asset designs to develop stranded or uneconomic assets. Investment decisions will be made with simulated futures and advanced analytics support that encompass total asset value and reduce life-of-asset risk. Projects will be constructed with a more solid foundation to manage change. Operations will begin with a smooth transition from construction, leveraging existing technology to deliver step-change improvements in output from Day 1. The pace with which all these technologies will be developed is still unclear and unlikely to be uniform, however when stitched together, represent a compelling transformation of the way the industry develops and delivers its products to the market.

> **"More money has been blown up historically through overpriced M&A than bad project delivery"**
>
> **MINING COMPANY EXECUTIVE**

Our data shows three main technology focus areas for the delivery of major projects in the mining industry. First, virtualisation and simulation (51%) will be able to leverage the ever-increasing depth of data collected about orebodies, mine development, operations, equipment, supply chains and markets. The development of virtual reality and simulations will enable better integrated decision-making, both for studies managers and developers in designing and delivering a project, but also for investors and boards in making investment decisions and managing risk. Second, better sensing and processing equipment that is smaller and can be transported easily will deliver faster and cheaper methods to learn more about prospective orebodies (48%). Instead of sending a small number of samples to laboratories hundreds of kilometres away (if not further), explorers and studies managers will be able to test samples on site, significantly lowering the time and cost of project design. Third, modular assets and pre-fabrication in manufacturing (43%) makes construction faster, cheaper and with fewer errors. Modularised construction also enables more creative approaches to extracting assets with varying grades across a given deposit. Modular models are already evident in energy infrastructure such as 5B and Solpod delivering relocatable solar projects.

**What innovations will have the biggest impact on project delivery?**




## Studying hard

At the studies phase the focus is on designing an asset that will yield the most value and minimising the risk of an asset failing to deliver returns above the cost of capital. The main benefit of the next wave of project innovation is in reducing the overall cost of delivered assets. Cheaper, faster methods of analysing deposits, building models and testing design options reduces total cost as well as improving certainty and the quality of designs. Once widely adopted by the industry (which may take time given the inherent cultural conservatism in project investment), these technologies promise to make investment decisions faster and easier. Modularised assets open up more creative design options, for example multiple plants that are optimised to process different grades and geological compositions in the deposit, which can be modelled more effectively with breakthrough technology. On the other hand, with better orebody knowledge, less contingency is required in the design of assets to deal with unknown orebody characteristics, again saving cost.

As the technology develops, it may tip the scales with previously uneconomic assets becoming viable. With smaller, more optimised plants specific to a better understood orebody, stranded assets may become viable. Improvements in orebody knowledge particularly prized for mining companies (57%), who have the added benefit of improving the economics of currently held tenements.

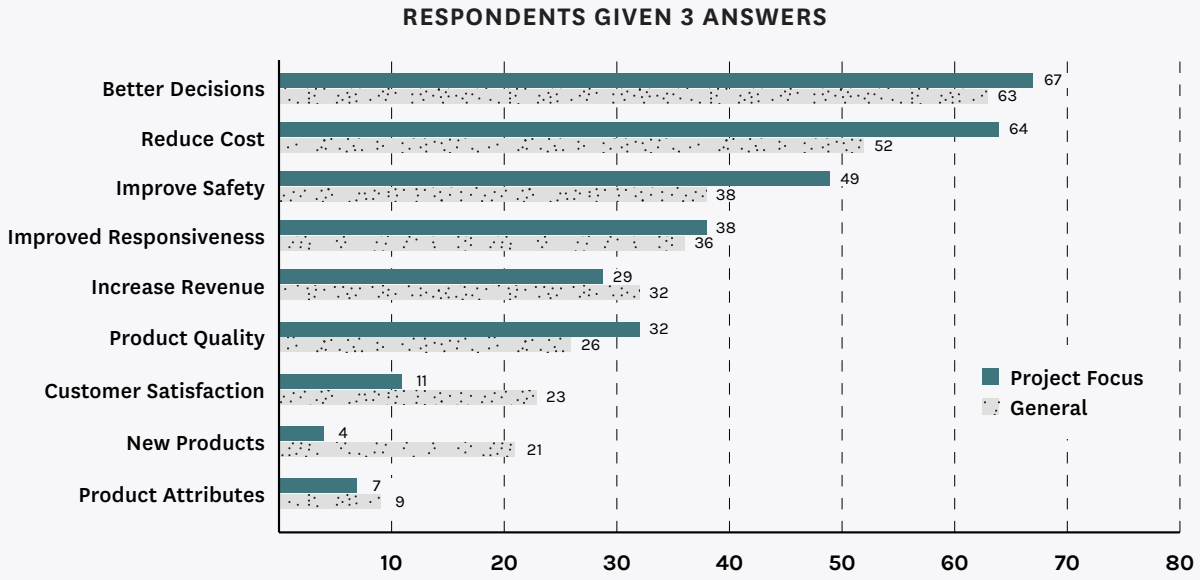
> **"We're looking at designing smaller, more modular assets that adapt more effectively to temporal changes in the market"**
>
> MINING COMPANY BOARD MEMBER

## Build it and they will come

The main focus of project innovation in the construction and commissioning of assets is to both planned and unplanned costs. Whilst most industries and other phases of heavy resource industries have undergone significant focus from Lean methodologies, project developers are yet to. There are opportunities to use technology to achieve the aims of streamlining the value chain and reduce bottlenecks, schedule delays, and inaccurate equipment inventories. Look to Latin America who have been pioneering this innovation and who tend to focus on digital technology to enable their lean methodologies, particularly in virtualisation and simulation (61%) and sensing and monitoring (48%).

Miners who are willing to take measured risk in their asset design and development tend to see digital technology as a safety enabler and cost reduction tool according to our data. Better visualisation of assets as they are designed and built enables engineers to design out safety risks. The virtual design and construction of assets promises to both reduce total cost and project risk during the delivery phase.

**How could digital technologies create business value for your company over the next 5 years?**

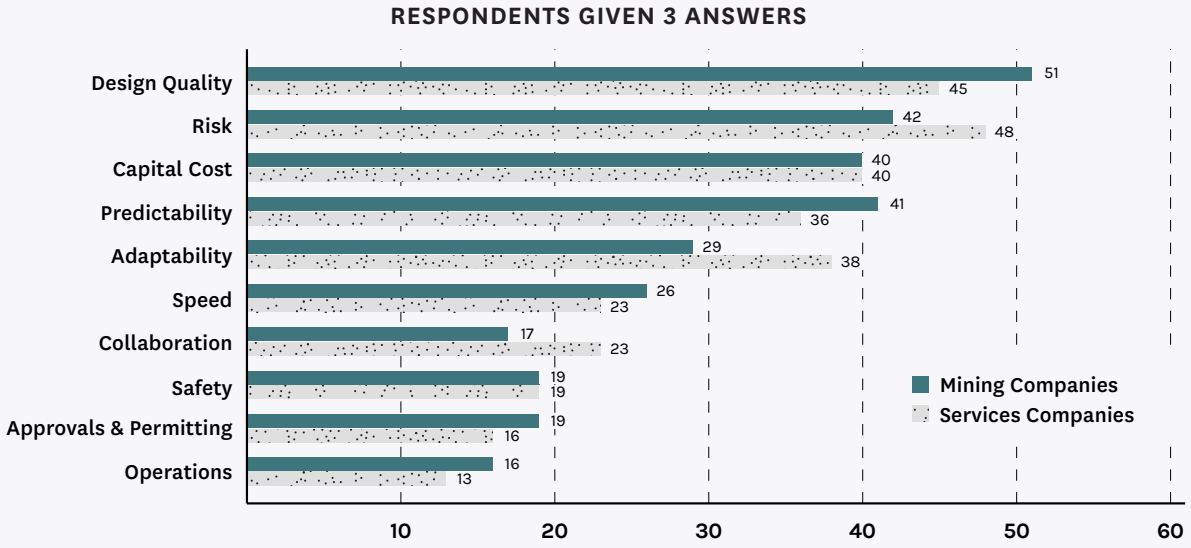


## Power of inertia

Project innovation is orientated toward making the design and construction of assets more effective and there are significant flow-on benefits to operations. If projects are delivered with a high diffusion of digital technology such as sensors, visualisation methods and data-driven decision-making models, these technologies remain into the operations phase of the asset. Better built assets combined with more data will likely reduce the overall maintenance and sustaining capital cost requirements. Assets will be more reliable, but when there is a failure, more data will predict the failure and address the issue with pre-emptive maintenance. With better simulation, decisions are more likely to be made with a whole-of-asset lifecycle view, which could save costs in the future.

Culturally, change is most difficult when inertia is strong. The most effective way to deliver digital technology improvements to assets is to both design them in and reinforce the right culture from the start. Practically speaking, this means more people can see more data, with better views of future impacts, and so can make informed decisions. Decentralised decision-making enables the marginal innovation improvements required to keep incrementing the performance of assets from a bottom-up perspective.

## What are the major benefits of adopting virtual design and construction approaches?




New assets with embedded digital technology and a cultural affinity to leveraging digital technology could help solve the perennial challenge of transitioning between construction and operations phases. Historically this has been poor and has generally impaired the commissioning efforts as a result. Delivering projects using virtual design and construct techniques means that the transition to operations is smooth without the loss of important institutional information as the teams change over.

## Follow the leader

Mining can look to other industries to see the evidence of the successful implementation of virtual design and construct (VDC) technologies. Commercial buildings in heavily populated areas operate with strict spatial constraints and interconnected systems such as electricals, air conditioning and sewage. Similarly, hospitals have complex systems as well as a higher level of need with regard to sequencing the build with large pieces of specialised equipment, with substantial risk in the case of failure. The Sutter Medical Centre in Castro Valley was delivered using VDC methods 30% faster than expected and below budget, bucking an industry trend of cost and time blowouts. Naturally, mining has many areas of uniqueness too. Very few industries have such variability and uncertainty when investing this much capital in a particular area, but this is just a characteristic, not a dealbreaker.

> **"The sleeper is pre-concentration and ore sorting – increasing throughput without increasing plant capacities"**
>
> MINING COMPANY EXECUTIVE

# Electric vehicles: Power up

The mining industry sees decarbonisation as the second highest transformation imperative for the industry (59%). There is a sense of inevitability that carbon neutral operations will become a requirement within the next 15-30 years, as supported by a number of commitments already made by countries and companies around the world.[2] As electric vehicles continue to penetrate consumer markets at an exponential rate and the price of renewable energy surpasses fossil fuels, it appears the transition is well on its way. However, for this to come to fruition in mining, the technology and operating models must overcome the challenge of delivering effective heavy electric vehicles onsite.

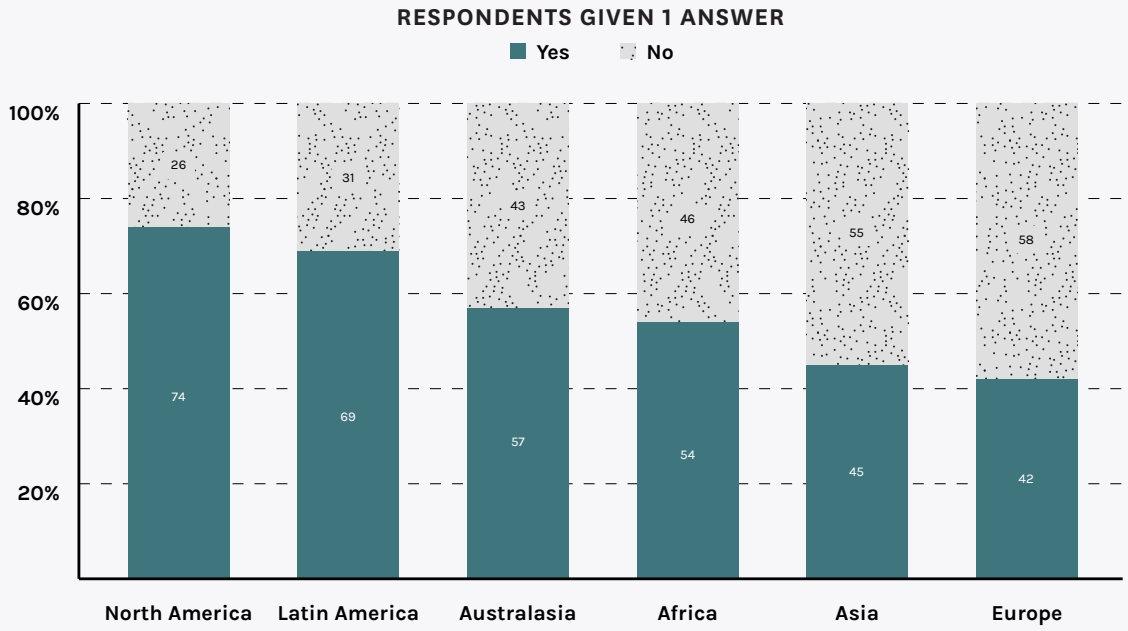
## Heavy load, heavy impact

Heavy vehicles (drilling, ancillary, load and haul equipment) produce the most carcinogenic particulates and utilise the most diesel, therefore having the largest impacts on health and emission production. In an underground environment, mitigating these impacts will have both economic and health benefits. Diesel is expensive, with electricity from renewable sources offering considerable cost advantages. With less diesel particulate matter emitted, underground mines are safer, and less ventilation may be required (a considerable capital and operating expenditure).

> **"Even existing haul fleets can struggle to be as efficient as they were hyped to be, so electric vehicles face a cultural and risk barrier in development"**
>
> MINING COMPANY EXECUTIVE

2 See FMG, Rio Tinto, Sibanye, Norgold among others

## Will the next generation of mines all be electric?

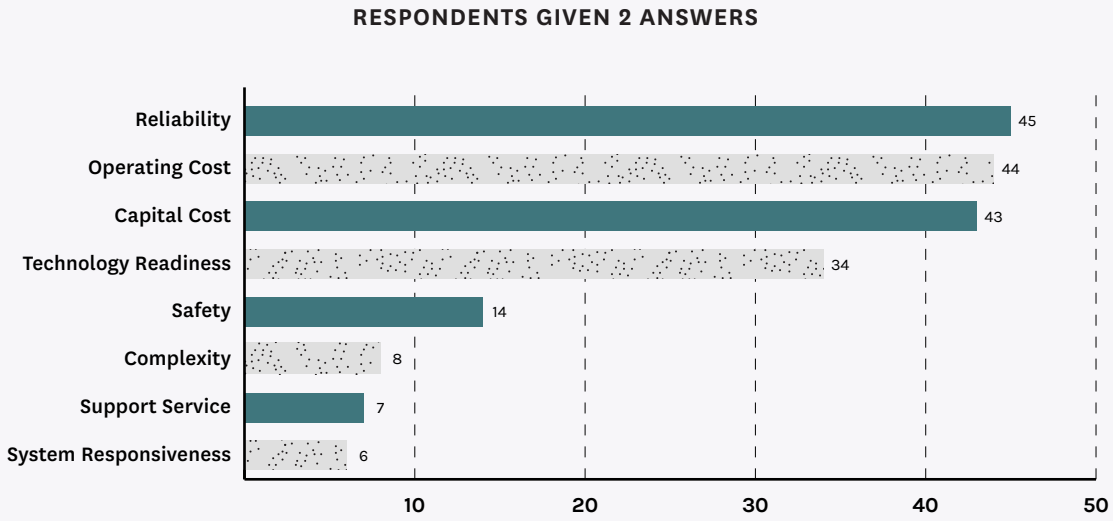



Commercial availability, technical understanding and economic viability lie at the crux of this challenge. Canada remains the leader in the adoption of such equipment, with a number of mines moving towards full or partial electrification in recent years (Borden, Sudbury, Creighton to name a few). Shaft mining, which is more common in Canada, lends itself to smaller load and haul equipment, of which a number of the major OEMs have already developed and sell at scale.

For those using stope or decline mining methods (particularly at depth), the uptake of electric vehicles has been hampered by the lack of availability of equipment at the scale required to meet productivity targets (current electric vehicles are approximately 20% too small for many current assets according to anecdotal reports). The industry's highly concentrated and dominant suppliers are not offering them at scale (and until recently not building them at all) and have not yet been sufficiently challenged by companies to do so. The issue is not as simple as asking the OEMs to just build larger electric trucks. The battery density to support such scale is not yet advanced enough to ensure technical duty is met. Whilst a number of OEMs such as Epiroc and Sandvik have announced larger options are coming to market in the next few years, there is still significant uncertainty around when these options will be mass produced and readily available.

> **"The saline levels in gold mines can be 10x higher than the ocean – if that comes into contact with electric equipment it can cause a lot of problems"**
>
> MINING COMPANY CEO

**What are the most important considerations when making electric technology choices?**




## Humble beginnings

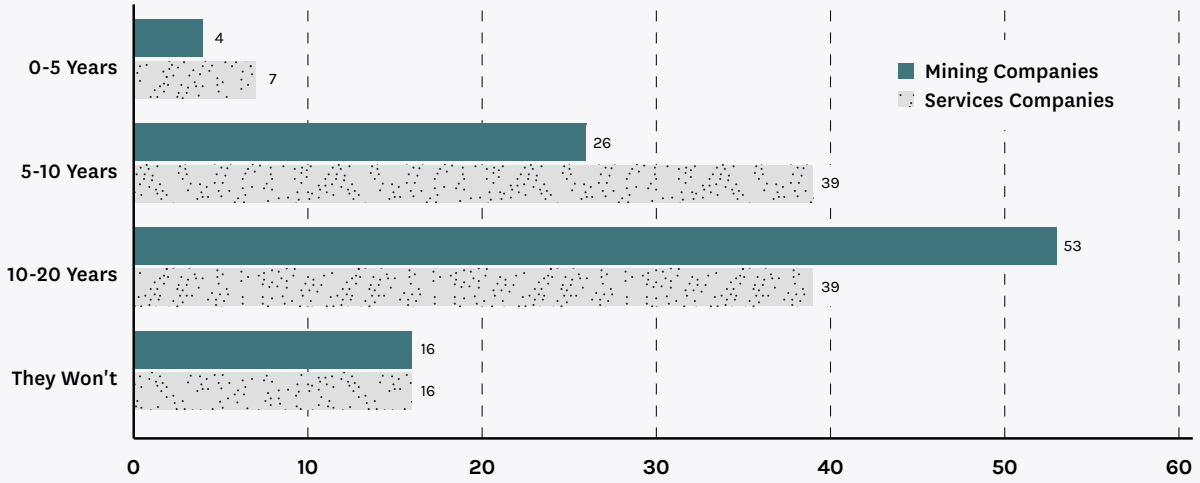
A potential solution would be to adopt the smaller scale equipment – however without mine design changes or parallel advancements in automation, this would likely sacrifice productivity. Furthermore, a lack of well-established performance benchmarks, which miners' contract on the basis of, creates another barrier to adoption. As OEM business models are currently built around a parts and servicing model, the relatively long-life and reliable electric equipment has the potential to eviscerate their current revenue streams. Convincing these incumbents to adapt to a leasing or servitisation approach will require significant, industry led effort that will re-define total life-cycle cost of the equipment.

As a niche application, heavy vehicles do not receive the same amount of global investment to help drive economies of scale, placing a much larger burden on the mining industry itself to drive development. The expectation that OEMs are to wear the upfront capital costs of developing new battery electric equipment in transitioning to a new model is unrealistic. Efforts will require the mobilisation of policy makers, miners, service companies, investors and researchers in order to achieve the scale, capital and influence to drive success.

As a relatively immature technology, there are still many technical and operational uncertainties. The best charging approach for these vehicles has not yet been solved. Battery swap-out, fast-charging, trickle and on-board charging methods are all potential options, with varying impacts on a site's power reticulation network. Commonly known as risk averse customers for equipment, a lack of knowledge regarding a wholly new piece of equipment, coupled with unknown changes to infrastructure requirements has to date made the case for change difficult to push internally.

**Over what time horizon do you expect most existing mine sites to electrify?**

RESPONDENTS GIVEN 1 ANSWER



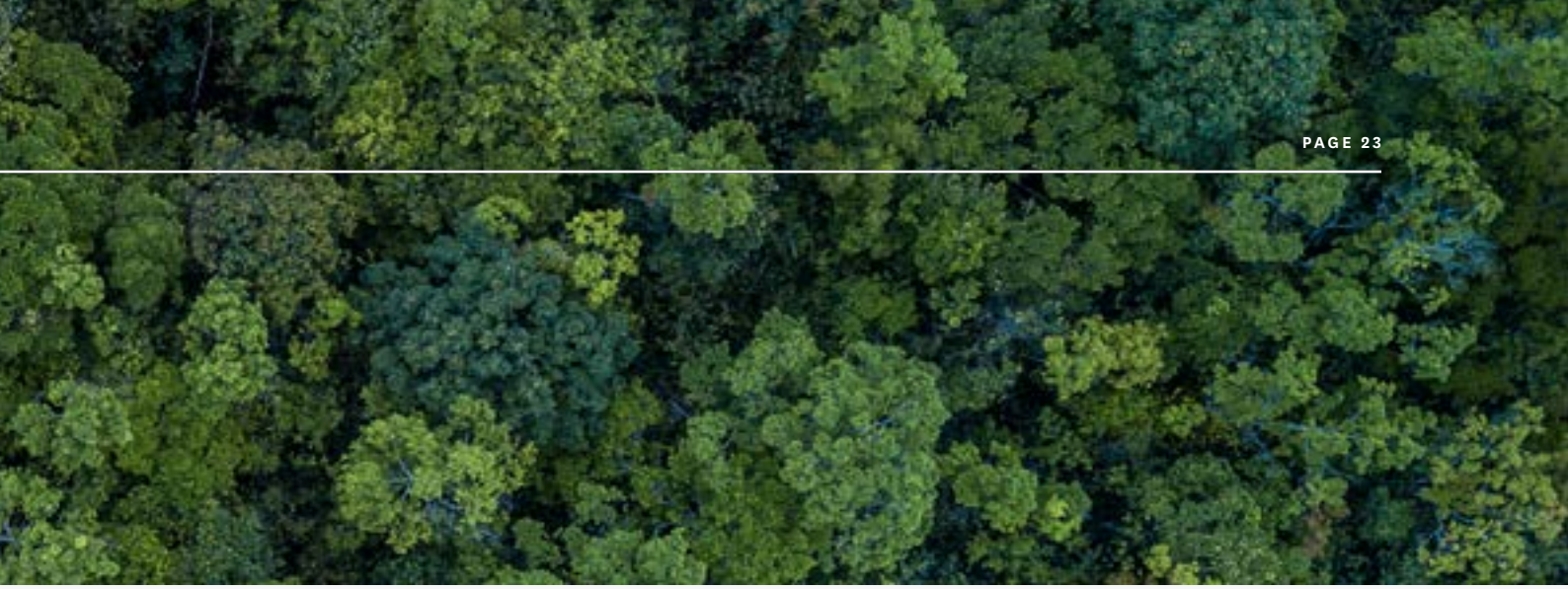

## Charging ahead

So how can the industry overcome these barriers? Whilst diesel hybrid options are currently perceived as a fall-back option, they still emit carbon and particulates and will not disrupt current servicing models and infrastructure to propel the transition. Successful adoption will require new, innovative approaches to the delivery of power.

In underground mines, 60 tonne electric haulage vehicles are getting close to active duty, but improvements in battery technology are still required to achieve productivity with long declines. Electrifying large open-pit haul trucks with nominal payloads of above 300 tonnes requires more technology options. Hydrogen fuel cells may function as batteries, but until battery chemistry improves for the scale of equipment required or mines are designed in a way that supports electrification, combined power options like tethered or trolley assists will need to be used to support battery cycle times.

The advancement of regenerative breaking technology for load and haul equipment travelling down declines could do the same. Ubiquitous, standardised and modular charging points could create the opportunity to 'slow-charge' while a piece of equipment is working at the face (such as drilling and ancillary equipment), solving some of the power delivery issues. These design changes indicate that the miners will need to be deeply involved in the shaping of future technology developments.

> **"You could achieve a 5-10% improvement in energy costs just through optimisation of the network. How EVs play into this is an open question"**
>
> MINING COMPANY BOARD MEMBER



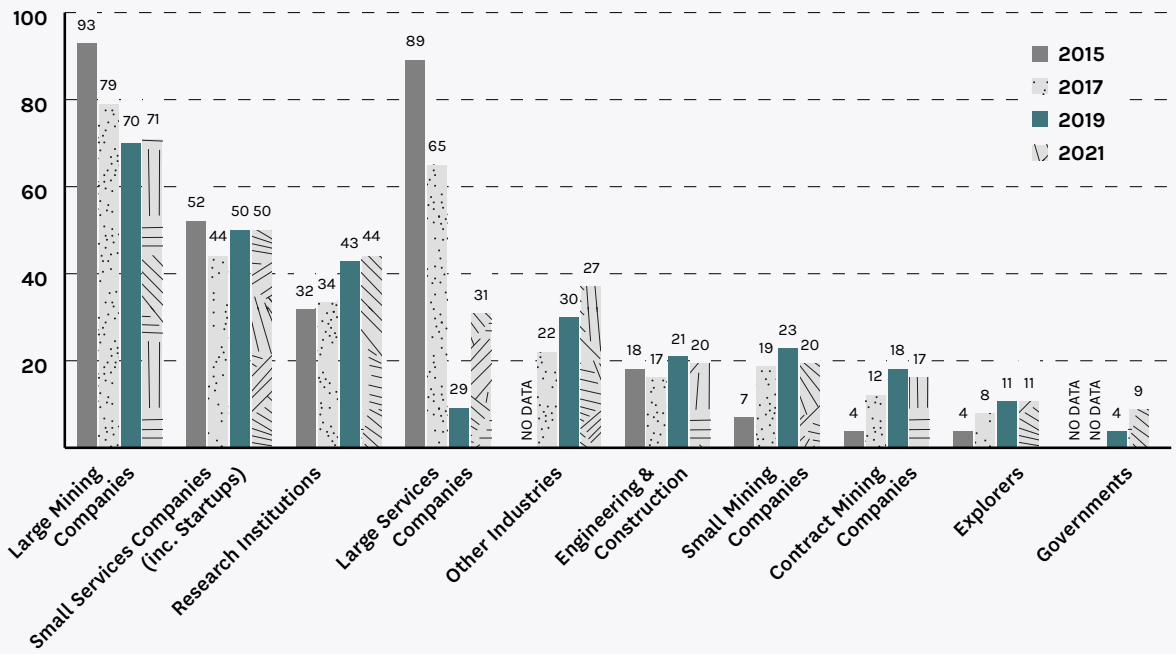
## Power policy

Beyond the miners and suppliers, regulation and policy will play a crucial role in accelerating adoption. There are currently few government incentives relating to mine electrification forcing the shift to full electric across many key mining jurisdictions. Canada, the leader in mine electrification, has adopted more stringent regulations on diesel particulate matter exposure. Other countries following suit in this area, which would include updating ventilation requirements and could be further supported by emission reductions mandates, would likely force the ecosystem to advance.

The electrification of heavy vehicles is well placed to create real value, not only for the mining companies themselves, but for the broader community too. The issue is both technical, economic and cultural and will require effort from the full ecosystem for mass adoption. Suppliers need to develop their equipment and technology faster, the miners need to embrace and begin to understand the impacts of the new technology and government needs to assume its role in developing skills, policy and standards to support the transition. Heavy battery electric vehicles are the keystone for the electrification of the industry. If adoption cannot be achieved, then electrification cannot be achieved. If it is successful, then everything else will fall into place.

### Who is driving innovation in the mining industry the most?

RESPONDENTS GIVEN 3 ANSWERS



# Consortia: Collaboration in competition

Consortia have a long history of application in a wide range of different industries. Broadly defined, a consortium is a group of two people or companies who work together to achieve a common objective. As innovation becomes increasingly paramount to the success of mining companies, the question arises whether there is scope for an industry consortium to collaborate and share ideas.

Firstly, companies are competitive entities, and altruism is more the domain of community organisations. Therefore, any consortium will only be successful if there are compelling and aligned objects that bind the members together and the achievement of these objectives hinging on a collective effort.

Of course, some companies may choose to join a consortium for the reason of information sharing, brand projection, or even philanthropy. However, if these are the predominant reasons for members, the consortium is likely to fragment or stagnate early on.

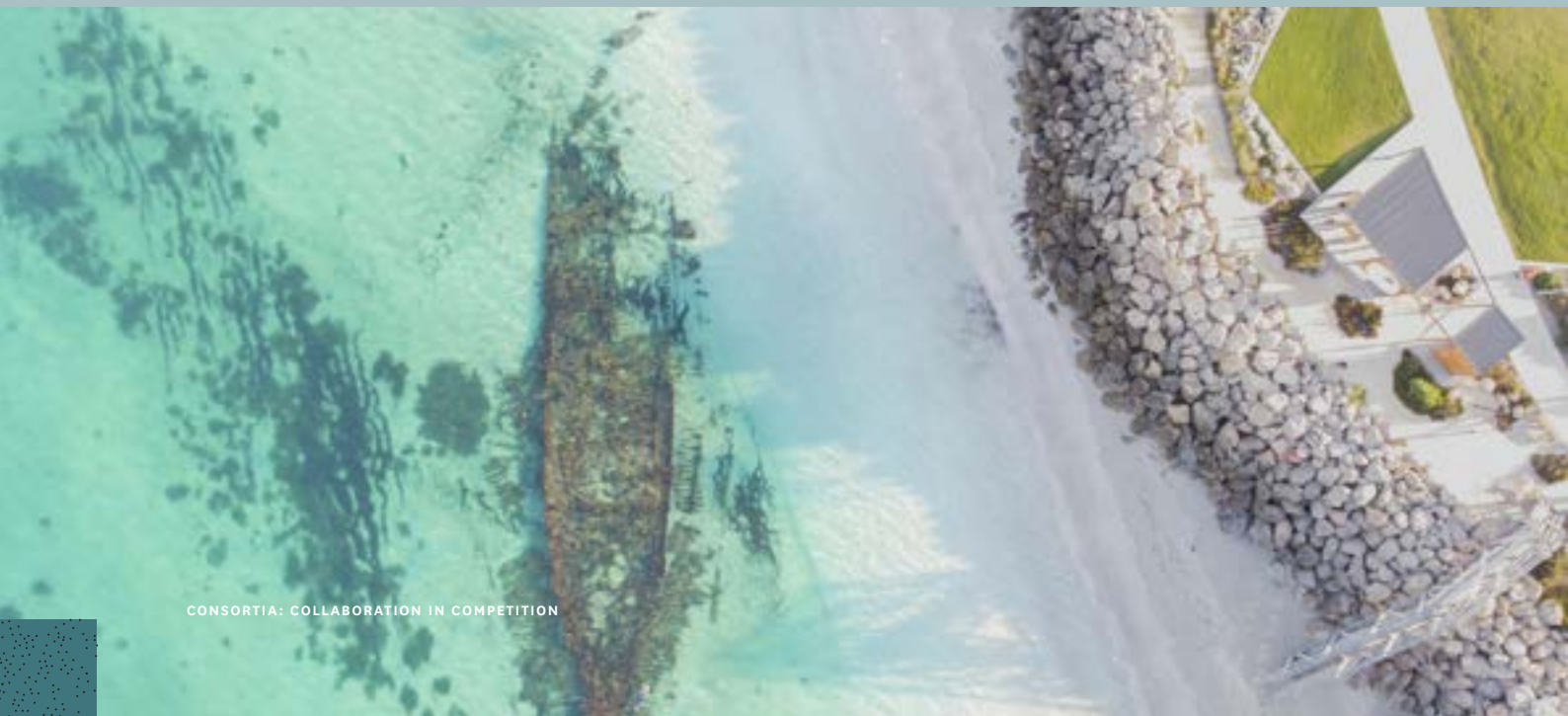
So why would mining companies do this, and who are the candidates?

Predominantly, companies will form a consortium where there is a major opportunity, threat or both. Participants recognise the need for a critical mass of industry partners to wield stakeholder influence, create project scale, spread risk and create alignment which facilitates change.

A seminal example is the US Semi-Conductor Industry Association (SIA). 5 microelectronics pioneers came together to strengthen US leadership of semiconductor design and manufacturing by working with government and key industry stakeholders to "encourage policies that fuel innovation, propel business and drive international competition". The initiative was a response to international competition and used the collective influence to enable the US to retain industry leadership throughout the subsequent four decades.

MMISAC, the mining industries' North American response to cyber threats is another practical and effective consortium response to an industry imperative that directly impacts companies. In 2017, six mining companies agreed to form a community to share threat and response information, with the objective of protecting members.

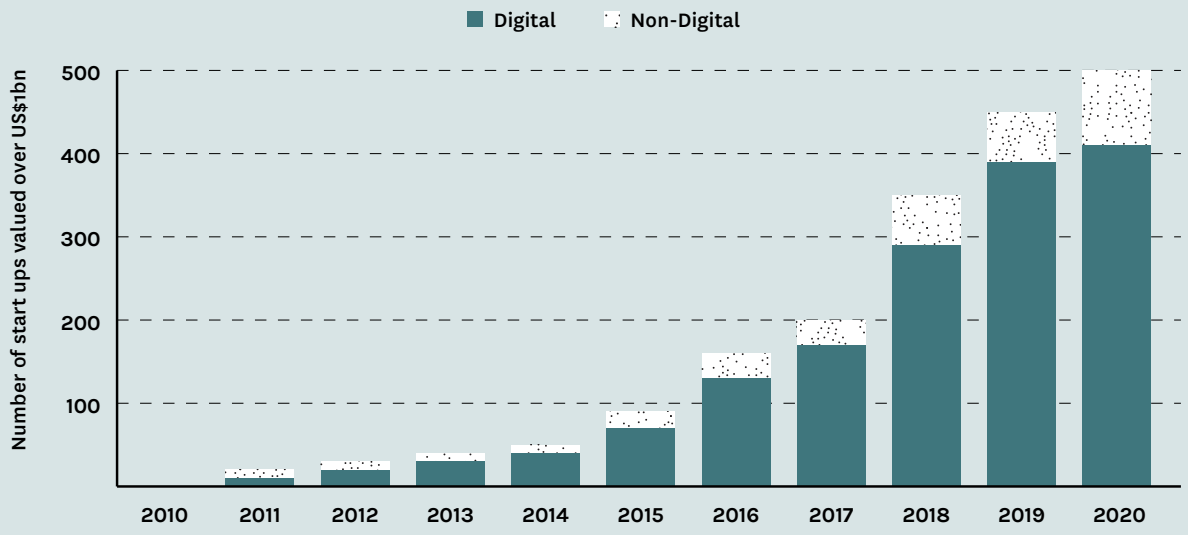
More directly, *State of Play* has been involved in facilitating the "Electric Mine Consortium", with the objective of accelerating full mine electrification, ultimately leading to more efficient mines that produce zero emissions. The consortium originated from five mining companies who collectively have the scale to both influence stakeholders and support the level of technical pilot programs required. In this example, the members are unified not only by the direct economic and health imperative, but also by a desire to lead in the delivery of clean minerals.



# Venture investment: Venturing into the unknown

Throughout popular culture, unicorns have always represented the impossible. Magical, mythical, and incredibly rare, they are a representation of precisely what we are incapable of creating. When this moniker was attributed to privately held companies with a valuation exceeding $1bn, it was certainly intended to convey the same meaning in Silicon Valley, Tel Aviv and Shenzhen but has lost some of its rarity. Instead, start-ups globally have seen the unicorn status as a marker for success rather than unattainable status. For every one of the world's 500 unicorns, thousands more are raising capital, trialling concepts and attempting to fundamentally transform their industry.

**Number of global unlisted unicorn start-ups (valuation $1Bn+)**




Looking from the outside in, large established companies look almost enviously at the innovative potential of start-up ecosystems that are unconstrained by legacy businesses and backed by the deep pockets of venture capital investors. Our data shows that after large mining companies, the overwhelming and persistent perception is that start-ups are the greatest drivers of innovation in the mining industry.

> **"The benefit of a venture fund is pace – if we can accelerate innovation development we're ahead"**
>
> SERVICES COMPANY EXECUTIVE

Understandably, large corporates want in, generally through venture investing of some sort. Start-ups are perceived to be on the bleeding edge and reviewing proposals for funding gives corporates an idea of what disruptive technology is around the corner. If there are nascent companies that fit the long-term business model for a corporate, they may look to acquire and leap forward generally by buying and adopting new technology. Some start-ups represent a threat to existing business models or offer an opportunity for a long-term pivot. Corporates may look to acquire to shift business models, say by acquiring an AI-based exploration company that shifts exploration focus away from traditional geology to algorithmically based patterning. Alternatively, start-ups may be developing technology that requires the product of a particular miner, and venture investing is designed as a market-development tool. Anglo American are currently investing in a number of hydrogen cell businesses that require platinum inputs. Or it may be a case of looking to capture direct returns through traditional venture capital, however this is generally the mandate of investors rather than corporates.

## The old guard

Three broad models exist for corporates to tap into this pool of creativity and capability. Direct, ad-hoc investments in specific companies that offer significant value require little formal structures and can add value almost immediately. BHP's recent investments in SenseOre technology to unlock further brownfields nickel development and in Boston Metals to increase exposure to zero carbon steel making were both not part of a formal venture structure yet align with the overall business model vision of the company. Alternatively, in-house corporate funds can be established with clear mandates, such as Occidental's Oxy Low Carbon Ventures which attempts to shift the oil & gas giant's business model away from traditional fossil fuels. If in-house funds are inadequate, many corporates invest in external funds such as South32 investing in Chrysalix and Anglo-American spinning off its investment arm as AP Ventures. These models are not necessarily mutually exclusive, rather they have different use cases depending on context.

While the models exist and are well established, and the view that start-ups are big drivers of innovation in mining, there is a striking lack of emphasis on venture capital as an innovation vehicle. Some of the underlying reasons for this are universal across the industry, others specific to the miners and services companies respectively.

> **"Disruption is largely going to come from start-ups, get ready"**
>
> **SERVICES COMPANY CEO**

## Getting to the nuts and bolts

Mining is fundamentally a physical business, it drills, breaks processes and moves things in a highly energy intensive system. When it comes to digital technology, most new technology in mining is either very specific to the mining process (and therefore faces a limited market) or is a direct port from other larger industries and adapted to the mining process. The lack of size in digital innovation in mining means that purely digital technology focused venture capital struggles in mining alone, and generally focuses on other industries.

Venture capitalists could branch out beyond just digital technology (where they've generally enjoyed the most success), but physical industries present several problems. Physical technology requires more capital, both in the upfront development and testing as well as in high marginal capital for each additional unit produced in scale-up. It also requires a longer timeframe to develop and prototype, which can stretch the investment horizons further than most venture capital funds (generally around 5-7 years). Physical technology is generally more complex than its digital counterpart. The development process requires the design, construction, and management of supply chains, manufacturing processes, and inventories. Products are more niche and tailored to an operational context, so struggle to have outsize growth across industries. It's harder to get customer feedback and compliance requirements are far higher across different regions. Further, the skills required are rarer than in digital technology. Industrial design requires domain expertise, not just programming skills. And it invariably requires digital technology development as well.

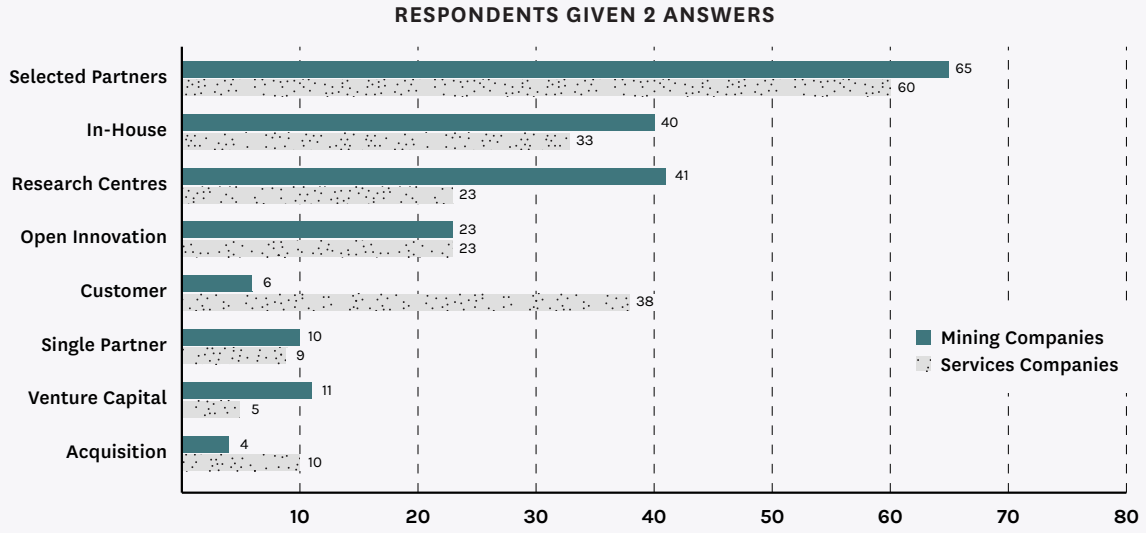
## A case of different identities

For mining companies in particular, one of the main impediments to successful venture investing is a lack of strategic focus. The strength of looking to start-ups for innovation is in their weight of numbers; the maths say that some must have the capability to become winners. However, this strength is also a risk for miners looking to deploy venture capital. Without a clear strategic focus, picking the right companies to invest in for success and growth within a mining company's portfolio is a hopeless task.

Like most companies, miners have a given tolerance for risk within their business. Conventional wisdom in the industry is that risk is generally exhausted either in exploration, acquisition or development of assets. Once this has succeeded, miners are generally risk exhausted and also face comparatively little likelihood of business model disruption. Without a clear strategic need to develop venture investing, miners generally focus on operational improvements through technology and optimisation instead.

Services companies on the other hand have a shorter innovation timeframe focus than miners, with 68% focusing on innovation pay back in the next three years, compared to 49% for miners. Services companies also have a narrow focus on addressing specific customer needs (38%), operating in a relatively insular industry with bespoke use cases for technology and services. These trends are likely a product of their competitive environment, being more prone to business model disruption compared to miners.

**When aiming for a breakthrough innovation, what partnering approaches would you use?**



Combined with relatively skinny margins, services companies generally prefer to acquire more scaled up businesses to address specific customer needs, and that they can implement in their service offerings in the short-term. These requirements are the antithesis of venture capital, which generally requires investment in early-stage companies, with uncertain and conceptual products requiring significant timeframes for growth and development.

> **"Start-ups and researchers are innovating, but are struggling to scale"**
>
> **MINING COMPANY BOARD MEMBER**

## Meet at the crossroads

Despite the challenges, strategic investments with long-term payoff in a crowded market are important. It gives a lifeblood to start-ups with good ideas that can help transform the industry. Venture investing also maintains increased competitiveness among services companies to deliver better products and services. Long-term capital has been behind many great success stories over the past few decades, and mining stands to gain similarly. The question is therefore, how do miners and services companies deploy their capital to grow the ecosystem and gain strategic advantage through their start-up engagement strategies?

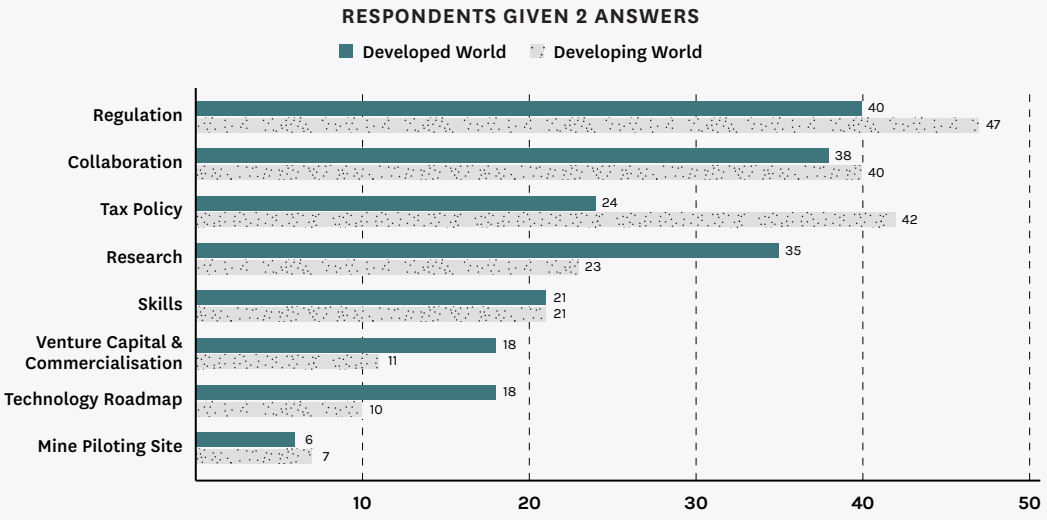
First, embrace the interface between digital and physical technology through mechatronics, IOT and automation. While pureplay digital technology start-ups are well covered by existing venture capital, its application to physical mining technology requires the deep domain expertise brought by mining-specific companies yet offers the dynamic pace of growth required for successful venture capital. More mature companies such as IMDEX are demonstrating the growth potential of this approach, but start-ups effectively exploiting this interface are rare.

Second, target opportunities which present a step-change reduction in capital deployment. Given that mining is such a capital-intensive industry, the value upside is so significant that venturing in technologies such as leaching and electro-chemistry is worthwhile despite uncertain payoff and limited numbers of potential customers.

Third, many of the functions of venture capital can be undertaken without a formal fund. With a scanning function in the strategy team that is manned by experienced operators, engineers, geologists and technology specialists, miners and service companies alike can identify high-potential targets for direct, strategic acquisition.

Fourth, there is a place for government involvement. While governments have traditionally struggled to accurately pick winners, there is a clear economic benefit to having a thriving start-up industry. Israel has demonstrated how agnostic government support for venture investing (e.g., matching every venture investment 1-for-1) can provide more capital to start-ups that have been identified as having significant potential. By addressing the inherent market failure of physical technology venture capital by halving the capital cost, government can stimulate local start-ups and larger companies and create significant strategic advantages for innovation in their countries.

**Where can government best intervene to support innovation in mining?**



# Age: More than just a number

Of all the different ways that we analyse our survey data, by far the most dramatic variation has been in the diversity of respondents by age. Compared to gender, position, experience splits, age had the biggest variance in response trends. Age is a sometimes-overlooked component of considering how diversity of a given workforce can improve its capability in idea generation and decision-making.

In our data, three distinct groups emerge. Younger people (18–29-year-olds), middle-aged people (30-60), and older people (60+) and have often diverged significantly. Some of the disparity can be explained in the roles that each age group assumes within their career. However, there are significant differences even when accounting for different roles. Younger people are generally less biased by personal experience, bringing optimism and long-term approach to complex strategic problems. Middle-aged people often feel the weight of compliance with cultural norms to ensure careers success and bring a wealth of technical experience to decision-making. Older people can generally apply their experience to strategy and are potentially more inclined to offer contrary views in the twilight of their careers, freed up from the pressure to keep climbing corporate ranks. While interesting at a philosophical level, the data primarily holds clues with how to structure teams, the importance of diversity of age and why empowerment of all age-levels within a business reduces risks of blind spots in decision-making processes which are naturally hierarchical with concentrated age groups.

## It's not a phase Mum

Younger respondents to our survey generally represent senior leaders in smaller companies or new managers in bigger companies. 85% were team leaders or juniors, with the final 15% operating as executives in smaller organisations. Younger respondents are therefore the representative sample of the on-the-ground workers, generally implementing and operating rather than making management decisions.

Younger respondents generally think in the longer-term, having accepted mature trends such as transparency, community expectations and flexible work arrangements as a given. Our data shows that they focus on longer-burn strategic trends such as the long-term development potential of Asia and a reorientation of economic power away from the West, as well as the opportunities afforded by new frontiers in mining such as space. From an innovation standpoint, younger respondents are generally implementing new innovations and operating assets. They are by far the most concerned about safety, looking to digital and electrification technologies to fundamentally improve safety onsite. Younger respondents are far more likely to attribute technology failure on complexity and lack of readiness, suggesting that they have an acute awareness of whether or not large technology deals struck at more senior levels of their company are implantable and value adding or not.

> **"One of our biggest challenges is young talent, traditional sources such as mining schools are dwindling right when we need capable young people more than ever"**
>
> **MINING COMPANY CEO**

## One eye on the prize

Middle aged respondents to our surveys represent a diverse spread of roles. 20% were CEOs or board members, a further 36% were executives, with the rest classifying themselves as team leaders or juniors. Middle-aged respondents are in full swing of their careers (often facing family and financial commitments) spanning from leadership through to the more operational and implementation staff.

These respondents have been in the industry long enough to see at least one major economic cycle come and go and make strategic assumptions based on experience. The experience with the China boom leads to relatively fewer middle-aged respondents to identify Asia as being a disruptive driver from the present day onward. These respondents generally focus innovation efforts on extrapolation from the current. Precision extraction is the next step in the current mining paradigm, so is valued more than more step-out mining frontiers such as deep sea or space mining. Likewise, middle-aged respondents are the most confident on the opportunity for solar power to transform mining. Once they see the trend, they back it hard.

> **"Diverse teams lead to real change, mix up your team and you'll start to see real change"**
>
> **MINING COMPANY CEO**

## Been around the block

Older respondents to our survey are generally more senior. 36% were CEOs or board members, a further 40% were executives, with the final 76% either retired or comprising team leader roles. Decades of experience lends itself to a different perspective – they see beyond the next step, looking to disruptive technologies such as deep-sea mining and new operating model practices such as community equity of assets as sources of change. Additionally, as they generally comprise of executives, they are also focused on reducing structural costs from their business, looking at long-term innovation rather than incremental improvement. Personally, they have generally moved beyond short-term financial, career and personal goals and are more comfortable sharing unvarnished views that may run contrary to common industry wisdom.

> **"At their best older people in the industry can break free from the system and have clarity over future trends and strategy"**
>
> **SERVICES COMPANY CEO**

## Age Profiles

### Younger People

**Age -30**

**DEMOGRAPHICS**

10% Executives
90% Non-Executives
34% Onsite
66% Corporate

**PRIORITIES**

1) Long-term innovation
2) Asian development
3) Safety-focused
4) Technology practitioners

### Middle-Aged People

**Age 30-44**

**DEMOGRAPHICS**

38% Executives
62% Non-Executives
22% Onsite
78% Corporate

**Age 45-60**

**DEMOGRAPHICS**

72% Executives
28% Non-Executives
14% Onsite
86% Corporate

**PRIORITIES**

1) Medium-term innovation
2) Renewable energy
3) Growth-focused
4) Technology customers

### Older People

**Age 60+**

**DEMOGRAPHICS**

77% Executives
23% Non-Executives
12% Onsite
88% Corporate

**PRIORITIES**

1) Short-term innovation
2) New mining frontiers
3) Cost-focused
4) Technology investors

## Green is the new black

The overwhelming difference in age-based responses was the approach to environmental pressures. All age groups saw the environment as a key focus for innovation - 61% of young people, 58% of middle-aged people and 62% of older people saw that environmental pressures was one of the biggest impact trends on the mining industry.

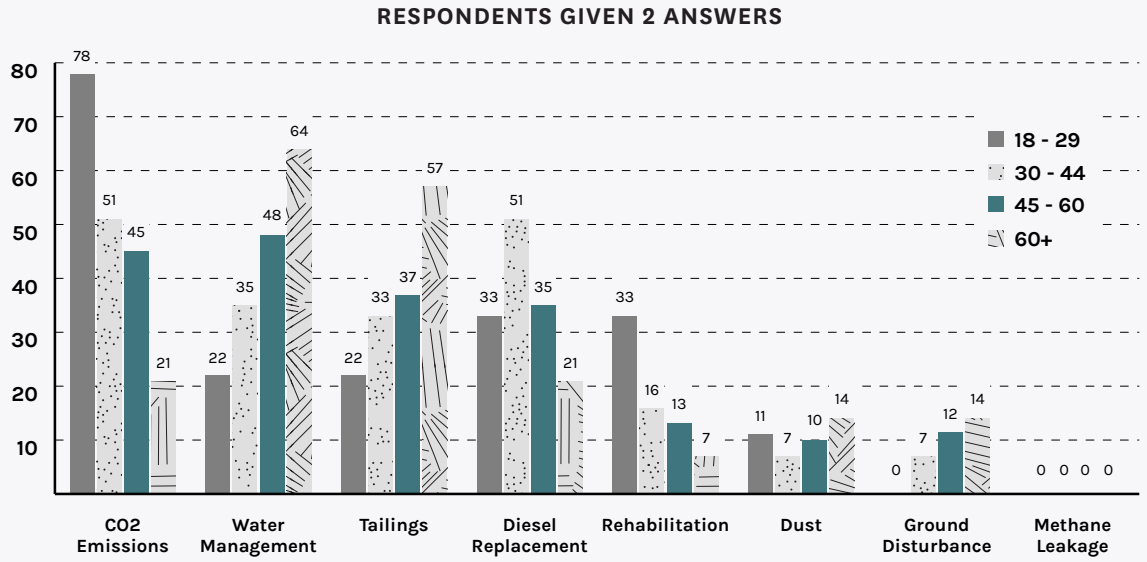
The diversity came in the response. Here we see a significant divergence based on perspective. The options and areas of focus can accurately be divided into three broad areas. Horizon 1 focuses on immediate concerns that pose a direct risk to operating assets. This was relatively prioritised by older respondents, with 64% and 57% focusing on water management and tailings reduction respectively to remove short-term risk.

Horizon 2 of the environmental response focuses on investing in disruptive technologies over the next 5-10 years. These approaches were prioritised by middle-aged respondents, looking to see change roll out over the course of the rest of their careers. In particular, diesel replacement was identified as a key leverage point (42%).

Horizon 3 centres around the long-term fundamental impacts of environmental damage, which was the primary concern of younger people. In particular, reducing CO2 emissions (78%) and rehabilitation (33%) were relatively far higher than other age groups. These concerns will take the most time to mature yet will undoubtedly have the biggest impact on the industry and world at large. Unsurprisingly, younger respondents are most bullish on aspirational technology that can transform the emissions profile of the industry such as renewable energy, hydrogen and biotechnology. Ultimately, mining's impact on the environment is complex, however the inherent time differences in the maturation of environmental risks means that different age groups have significantly different priorities.

> **"Young people challenge assumptions and develop solutions before we old people even get to frame the question"**
>
> SERVICES COMPANY EXECUTIVE

**Where could innovation have the greatest environmental benefit in your business?**



## Show me the money

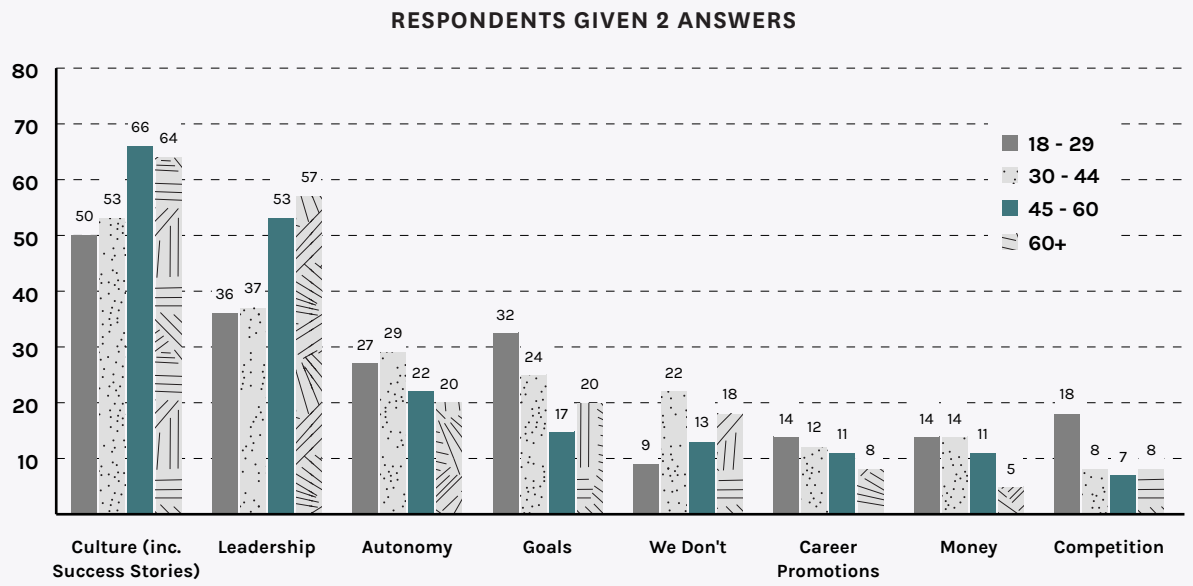
Designing the right system that encourages innovation is difficult. All individuals generally prefer systems that advantage them the most. Our data demonstrates a fascinating dissonance in how different age groups would design optimal innovation systems and their perceptions of their company's own approaches.

Leadership is often valued as a key component of encouraging innovation, and yet it is leaders themselves that are most interested in this mechanism. 57% of 60+ respondents and 53% of 45-60-year-olds see leadership as a primary innovation incentive within their own company. This is 40% higher than the younger cohorts, suggesting that leaders have a distorted view of their own influence on innovation within the company.

Conversely, the much-emphasised impact of culture on innovation is felt most by younger people, given their inexperience in professional contexts. This idealism sadly dies off as people enter the middle stages of their careers, however, as people get older they appreciate the value of the culture being created and realise its value to the innovation capability of the company. Young people are the most encouraging of diversity as a mechanism to improve innovation (27%), especially compared to older people (11%).

More tangibly, younger people are generally the most supportive of incentives and metrics, given them the opportunity to valorise innovation contributions they make. The other side of metrics is competition, which is keenly felt by younger respondents at a far higher proportion compared to any other age group. The data contrasts with middle-aged respondents who are more resistant to tangible measures, likely given their currently higher salaries and the high stakes on not meeting metrics. Older respondents, generally in leadership positions agree with younger respondents, likely because they themselves are driven by incentives in leadership positions and impose metrics to increase performance and output from their staff.

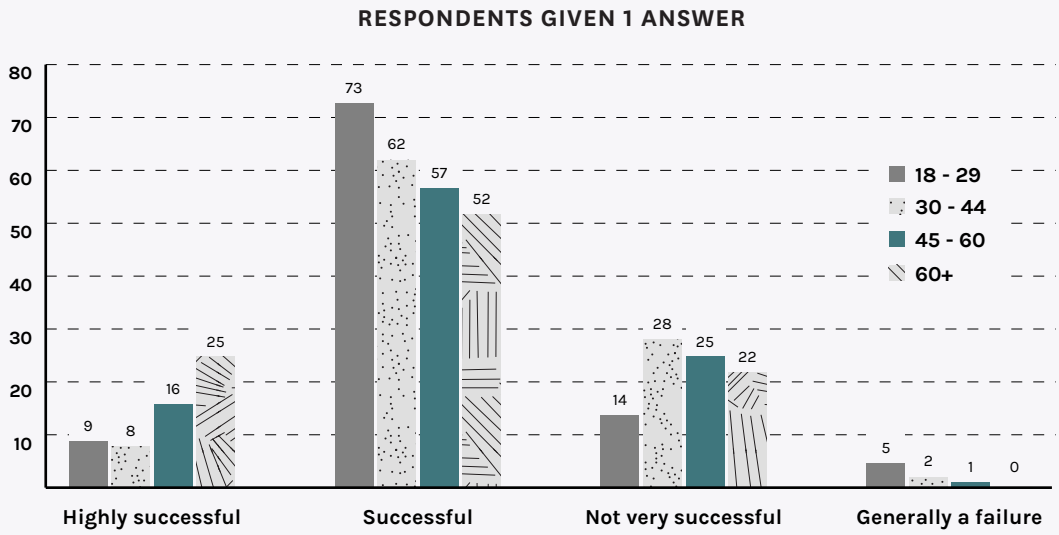
**How do you incentivise your workforce to innovate?**



## Talkin' about my generation

Making sweeping generalisations about the capabilities of individual people based on age is unfair and generally incorrect. However, our data demonstrates enough differences in age-based analysis to suggest that age-based diversity is a key requirement for a broad view of the industry. Younger people are bullish (if perhaps a bit naïve) on long-term strategic options, while being close to the ground and having an intimate understanding on how innovation can be tangibly delivered. Middle-aged people have the experience and technical expertise in current technology to effectively manage business units and extrapolate from the current capability of the industry. Older people may struggle to catch up with the rest of the industry with regard to new norms around diversity or the valid reasons why mining is poorly perceived in society yet have the clearest strategic view on long-term options for change and transformation in the industry.

**How successful have introductions of new innovations been into your business?**



# Conclusion

Innovation is generally characterised by brilliant ideas, bringing together different elements to do something new. Everything from ground-breaking scientific discoveries and industry-disrupting start-up unicorns, all the way through to operational improvement and new tools or equipment - it all begins with an idea. However, the success of innovation is generally about bringing these ideas into the real world. As this report demonstrates, delivery of innovation is complex, with some underlying principles giving way to bespoke approaches to unique contexts.

State of Play research has always maintained a strong focus on implementing innovation precisely due to its inherent complexity. Leaders must consider both the rapid advancement of technology, the changing expectations and capabilities of their workforce and how to integrate the best of each.

The best innovators identify technologies early and look at sourcing mechanisms in each case. Where core to competitive advantage, miners can look to develop technology in-house. Explorers are beginning to operate at the bleeding edge of analytics and surveying to identify potential deposits ahead of competitors. Project developers are looking at how to acquire orebodies at the right price from explorers and implementing new technologies such as VDC to deliver projects under budget and ahead of time to realise as much value as possible from transactions. Operators understand that they compete on efficiency and stability, investing in technology to make the value chain more predictable, from advanced orebody knowledge and real-time optimisation, to operating in a virtual environment to connect people, data and assets. Traders look to advanced market knowledge tools to time purchases and sales and capture the margin opportunity that the uncertain and volatile market presents.

People present a different challenge and opportunity. Overcoming a bias for inertia and stability is difficult, as any change manager can attest. Diversity is a key starting point for the introduction of new ideas and perspectives to any innovation process. Decentralised decision-making paired with direct incentives aligns people around the goals of the whole company and enables real change to often happen at a faster rate than top-down change programs. Having the right people stretches the possibilities for innovation programs, be it through bringing in different partners, having different goals or overcoming difficult challenges and quietly revolutionising the way that work is done.

Delivering breakthrough innovation often takes more than just one company. Whether it be venture investing the best innovators of the start-up ecosystem or working with big established players to co-develop breakthrough technology and equipment, partnering is essential in innovation. We look forward to seeing who the next big disruptors of the industry will be, and the changes they will wreak on mining globally.

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