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Electric Mine Consortium: 2020 to 2024

WHAT WE LEARNT FROM FOUR YEARS OF A RADICAL EXPERIMENT IN CROSS-COMPANY COLLABORATION TO BUILD A ZERO PARTICULATE AND ZERO CARBON MINING INDUSTRY.

"Direction is inevitable, but the speed is up to us."

ELECTRIC MINE CONSORTIUM

SLATE

STATE OF PLAY

Prologue

"We are now not at the beginning of the end, but the end of the beginning."

As a global community, the need to rapidly decarbonise has never been more apparent. We are reaching and surpassing irreversible environmental tipping points. The earth is experiencing its hottest year on record, intensifying the destructive impact of cyclones, fires, heat waves and droughts – and yet the world's demand for fossil fuels continues to rise.[1]

The mining industry is responsible for approximately 8% of global carbon emissions. We have a central role to play in reducing our contribution to climate change and its effects. Across the industry, well over 80% of public companies have released net zero by 2050 pledges, with around 25% also releasing near-term 2030 or 2035 carbon reduction targets. There is broad agreement that we need to operate differently going forward.

Over the past 15 years, there have also been many studies into the impact of diesel particulate matter on the health of exposed workforces. This culminated in the Safe Work Australia consultation paper in 2022 that demonstrated the severe long term lung health effects of prolonged exposure to diesel particulates, a daily reality for our underground mining colleagues. As an industry, we have a clear responsibility to eradicate these exposures.

Our 2020 report, *State of Play: Mine Electrification*, in collaboration with around 50 organisations demonstrated without question that the only fundamental way in which the mining industry can play its part to reduce both our carbon emissions, and our diesel particulate matter exposures is through the electrification of our equipment, supplied by renewable energy.

Twelve of these organisations self-selected to collaborate through a radical new initiative, the Electric Mine Consortium, to accelerate progress towards these goals. The twelve quickly grew to twenty-four as others in the industry sought to learn from the early leaders and push the frontier forward themselves. These leading companies drove the entire agenda of the Consortium.

CEOs of the founding mining companies co-signed a public letter of intent to accelerate their businesses towards electrification in line with the Consortium's goals.

Companies broadly understand the key decarbonisation roadmap steps, and many have studied these in detail. Some have taken courageous steps to drastically reduce the carbon intensity of their energy supply.

But as an industry, there is a long way to go. In Australia, the mining industry has a renewable penetration of less than 10% in aggregate.[2] Outside of processing, the heavy/load and haul fleet make up the majority of a mining operation's direct emissions - yet there are no fully electric pieces of load and haul equipment integrated in Australian mining operations (i.e. not outside of pilot or prototype testing stages).[3] The next stage is serious and sustained capital investment in decarbonisation. Across the Australian industry, there is a clear consensus that the major barriers to progress are the capital cost and the confidence in new electric equipment.

Electric mine benefits

Operational cost savings	Emissions reduction	Diesel particulate exposure
10-30% overall reduction in operating costs	100% reduction in scope 1 & 2 emissions	40+ toxic pollutants in diesel exhausts
Up to 50% energy cost reduction	26% reduction in all emissions	1.2m Australian workers exposed per year
20% maintenance cost reduction	↑ Access to finance	2nd largest Australian carcinogen
30% ventilation cost reduction	↑ Potential for premium product pricing	250k Australians in the mining industry

Source: EMC analysis

1 NASA

2 Australian Renewable Energy Agency (ARENA)

3 Many EMC members have this equipment in various stages of pilot or prototype testing

Mining is a capital-intensive business, and the financial evaluation of investment proposals is a key task. When considering electrification, these analyses must include the full spectrum of potential value sources, including health and the environment, and take account of rapidly evolving technical and regulatory assumptions. Perhaps the simplest question a CEO or board can ask when setting their decarbonisation roadmap is, what would this asset be worth to an acquirer if it were a fully electric operation vis-a-vis diesel? The balance of structural risks of carbon intensive mines, weighted against the value optionality and social license of carbon-free mines, are clear.

Our message to the industry is that the "direction is clear, but the speed is up to us". In the words of one of our most passionate and effective members we need to "just get started".

In September of this year, four years after we began, the Electric Mine Consortium will close. This report will recount the journey and catalogue many of our most impactful collective learnings. covering the external world drivers, the nature of collaboration in mining today, the myriad initiatives, electric mine valuations, the current best practice road map and the processes and assumptions we have today to electrify your mines.

We hope that this can be used as a resource for those looking to attempt similar ventures, and for those looking for inspiration and guidance as you work to push your businesses to decarbonise on an accelerated timeframe. There will be much in here for people across the industry, including from governments, industry bodies, researchers and suppliers, as well as those working in mining companies.

And finally, one of the great benefits we have been lucky enough to enjoy from starting and running the Consortium has been the vast array of people we have worked with and met.

Over the years, we have had more than 200 people actively working, conversing and collaborating in various Consortium working groups, meetings, initiatives, conferences and cross-industry collaborations.

This will perhaps be the legacy of the Electric Mine Consortium.

A new and exciting network of professionals committed to modernising the industry and realising the dream of all-electric, high-tech, safe and low impact mines. What made this group special was the trust, friendships and collaborative nature of the people within it.

We would like to thank all those who participated in the Consortium over the past four years, both as active members but also to the many we met across corporates, suppliers, traditional owners, government, research and the not-for-profit sector.

It is also important to recognise up front the central role played by the organisations who supported the initial State of Play report that led to the Consortium being established. These are FBI-CRC, METS Ignited and Project 412

From all of those who have worked on the Consortium team, thanks, and see you around.

The EMC team

Graeme Stanway
Paul Mahoney
Michelle Keegan
Simon Prebble
Madi Ratcliffe
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Georgie Taylor

Electric Mine Consortium participating organisations

3ME Technology
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Barminco
Bellevue Gold
BHP
Blackstone Minerals
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METS Ignited
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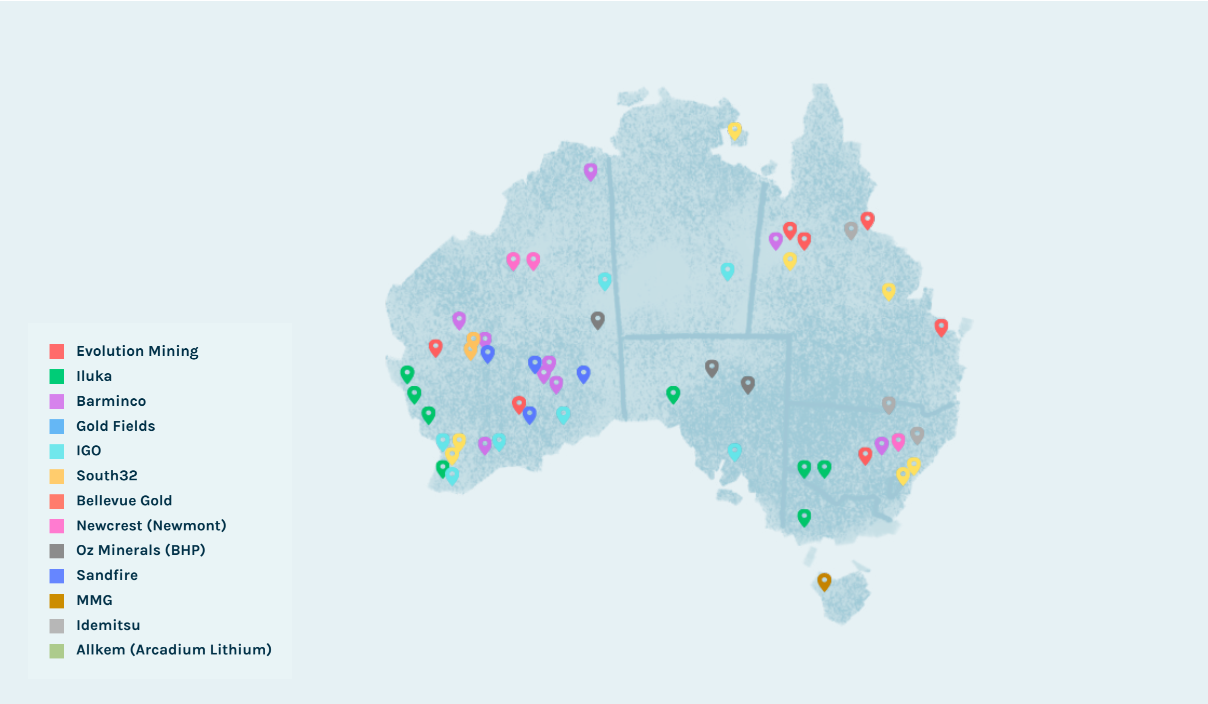
Safescape
Sandfire
Sandvik
Slate Advisory
South32
State of Play
VivoPower
Zenith Energy
ZERO Automotive

And the organisations we worked closely with as non-commercial partners

Allion Partners
Australian Automation and Robotics Precinct (AARP)
Australian Renewable Energy Agency (ARENA)
Clean Energy Finance Corporation (CEFC)
CSIRO
Electric Mine Conference
Electric Power Conversions Australia (EPCA)
Energy and Mines
Energy Policy Western Australia (EPWA)
Future Battery Industries – CRC (FBI-CRC)
Global Mining Guidelines Group (GMG)
International Mining
MathWorks
Model Answer
Project 412
Tjiwarl Aboriginal Corporation

EMC participating organisations (2020-2024)

Participant assets



Mining companies

14 Members participating in the Consortium	17 Countries with member entity operations	22 Commodities represented by member entities	100+ Assets owned by member entities
43,400 $ktCO_2e$ Aggregated volume of member Scope 1+2 CO2 emissions (similar to countries such as Norway, Ireland & Austria)		43,800 People employed by member entities.	$95bn Combined market capitalisation of member entities in AUD

Services companies

15 Partners participating in the Consortium	100+ Countries with partner operations
450,000+ People employed by partner entities	$890bn Combined market capitalisation of partner entities in AUD

Calculated assuming AWS represents approximately one-third of Amazon's total employees and market cap.

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Contents

Chapter 1: State of the transition

"Electrification is inevitable, but the pace is slow – take me to your leader."

Mining electrification is the opportunity of the century

The way the mining industry generates, stores and harnesses energy around the globe is undergoing a period of major change. A rapidly warming planet combined with decreasing costs of clean energy technologies, has led to a global race to shift the industry towards full electrification. The best path to reducing the carbon emissions of mining assets is through a combination of clean energy and electric equipment. These two factors will reduce carbon emissions by over 80% for most mining businesses.

The opportunities that this cheap, near ubiquitous energy provides to the mining industry are many and varied. Established relative values of ore bodies and operating assets are likely to shift, new business and operating models will become established at all levels of the industry and traditional diesel supply chains will be relegated.

Electrified systems will generate more information, analysis and optimisation opportunities, becoming a fundamental enabler of full data-based automation of operations. Electrification is therefore at the centre of two of the biggest shifts that the industry has seen: clean energy and digitisation.

At an international level, countries have a clear opportunity to establish a point of international competitive advantage. A race to globally scale leadership in clean mining, underpinned by electrification, has well and truly begun as a wave of global regulation and subsidies attests.

As an industry, we are on the cusp of a generational shift in how we mine and the impact we have on the world around us. The opportunity to be a high-tech, clean, safe provider of the world's metals and minerals is there to be grasped if we are courageous and creative enough to take it.

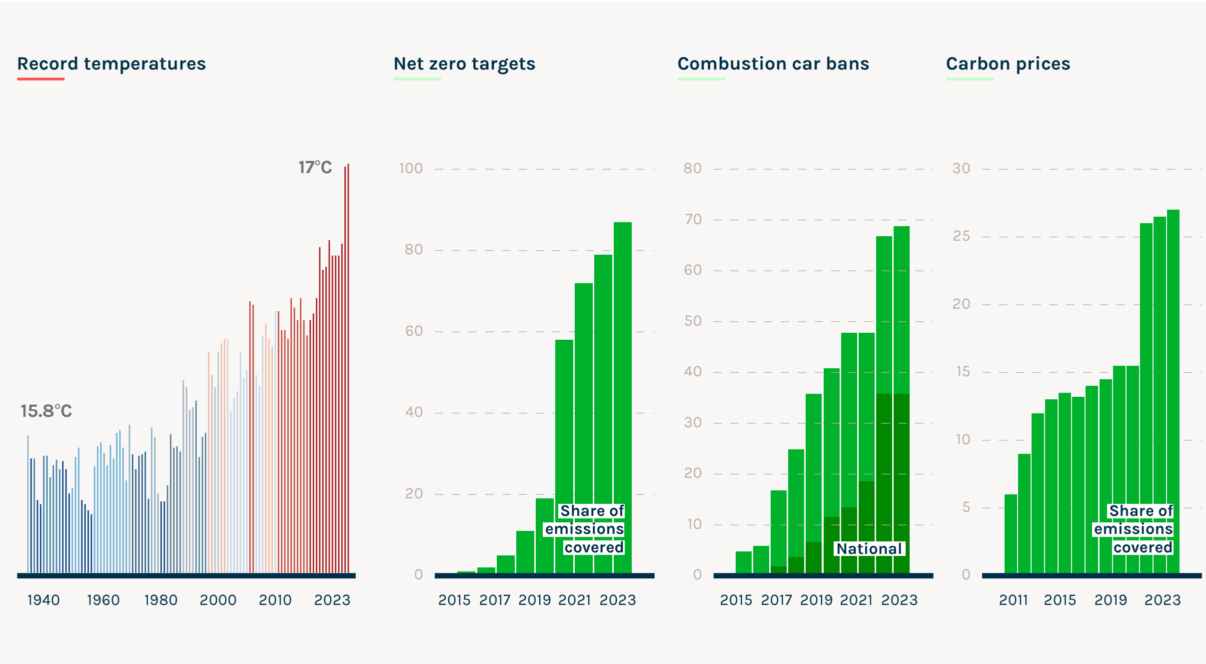
The opportunity of a lifetime for our people and communities

Local communities and workforces also stand to gain enormously through the reduction of carbon and diesel particulate emissions. For many decades, miners have worked in spaces polluted by airborne particulates generated by the fossil fuels that power their workplaces. The opportunity to breathe clean air while at work is their enormous, daily dividend from the innovation and strategic insight of their corporate leaders. Without doubt, workforce health is reason enough to electrify as quickly as possible.

Australia's prevailing government guidance on a 0.1 mg/m^3 diesel particulate matter exposure level is well above the range of "approximate epidemiological exposure estimates that have been associated with an increased risk of lung cancer".[4] Some mines are far below this level, while others are closer to the limit. The only practical way of fully mitigating DPM health exposure in mining is the adoption of electric equipment underground. In 2024, IGO and Adaptus shared modelling in which they explicitly placed a value on workforce health benefits from avoiding DPM exposure for their Cosmos project – the results, based on the quality of life methodology, shifted the project from slightly negative to positive. For the workers themselves, it is transformative.

4 Safe Work Australia

The world warms...so policy pressure will continue to rise



Source: Reproduced from RMI

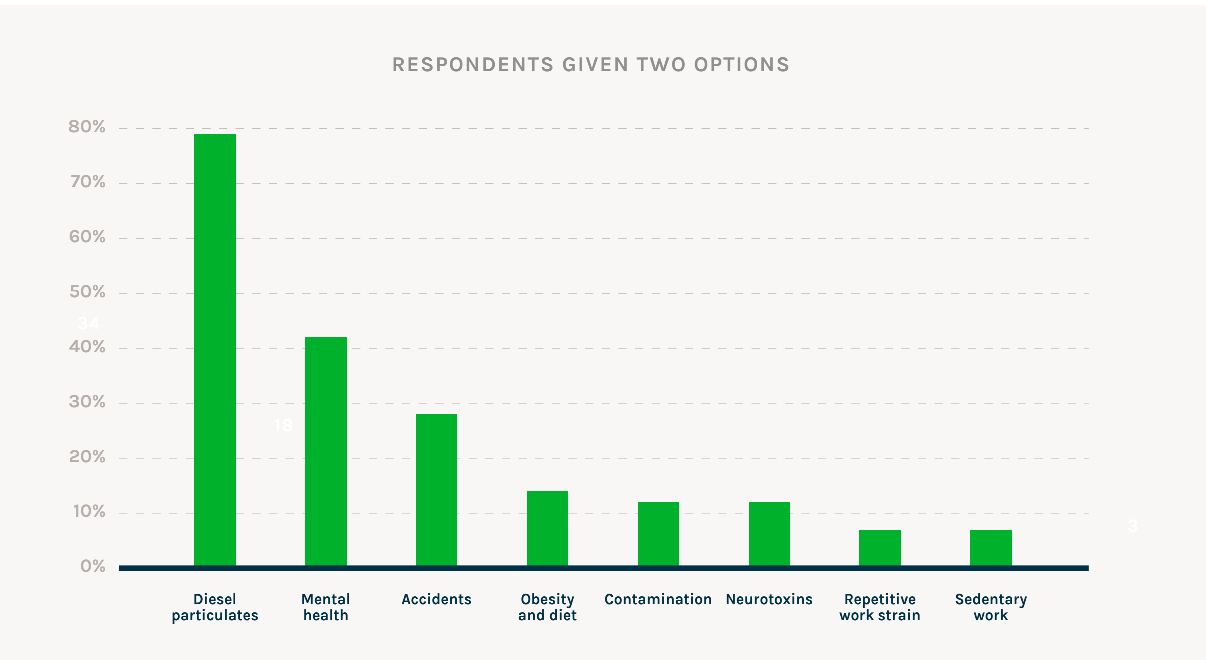
Mine health and safety legislation globally is typically framed around obligations for mine operators to eliminate or control risks "so far as is reasonably practicable" (SFAIRP) – or similar conceptual wording. Operators are required to consider the availability of suitable methods to eliminate or minimise hazards or risks, and the cost of eliminating or minimising risks. Given that electrified equipment eliminates DPM from the underground environment, and that costs are becoming comparable, it is only a matter of time before the SFAIRP argument for electrification becomes compelling. Indeed, companies taking no action may soon be obliged to justify why they are not removing DPM emissions from the underground environment.

The safety of workers underground is another benefit. A single electric energy system enables the acceleration of other technologies such as automation – the number one technology beneficiary of electrification. The view of companies who participated in the Consortium is that the automation of high-risk activities, particularly underground, will drastically improve safety.

Electric mines are also quieter and cooler than diesel mines. Driver fatigue will also be improved through the lower noise and vibration. This is a welcome phenomenon shared frequently by the team at Barminco as they described their reason for joining the Consortium at its inception. Electric equipment has faster response times, due to the immediacy of batteries and electric motors, meaning equipment is more controllable and better able to avoid unexpected collisions – making it far safer for those who work near these machines. All of this ultimately benefits companies through workforce attraction and retention in a competitive labour market.

Whilst automation technology has been a key focus point for the mining industry for many years, its advancement has been hampered by disparate energy systems and the imprecision of non-electric drive vehicles. A singular electric system integrates the sensors and control compatibility required for automation and precise control. Gold Fields and South32, two highly capable multinational mining businesses, are at the forefront of this work.

What industry health risks should receive the most investment over the next 5 years?



Source: EMC Survey 2024

It's all about bucks, Kid. The rest is conversation.[5]

For many companies, the case for electrifying operations is a purely financial decision, whilst the health, safety and environmental benefits are considered additional. Capital is allocated on the basis of economic metrics, such as total cost of ownership (TCO), or net present cost (NPC). This is an openly discussed reality.[6] In the end, even the assumption of a carbon cost may not be included in the final decision evaluation. And so, what is the economic case for electrifying today?

As of 2024, the financial case in Australia using either TCO or NPC is marginal using conservative assumptions (See Chapter 4: Valuation, for a full breakdown of cutting-edge modelling from within the Consortium). In Canada and Europe, their models are largely positive due to public policies that directly impact the financial case. Government tax and regulatory incentives are less balanced towards existing fossil fuel technology, such that over 15% of Sandvik's production and demand globally is now for battery electric load and haul, equipment. In Australia, without this policy support, no battery electric underground haul trucks have been ordered for full operation (there are battery electric prototypes on sites).

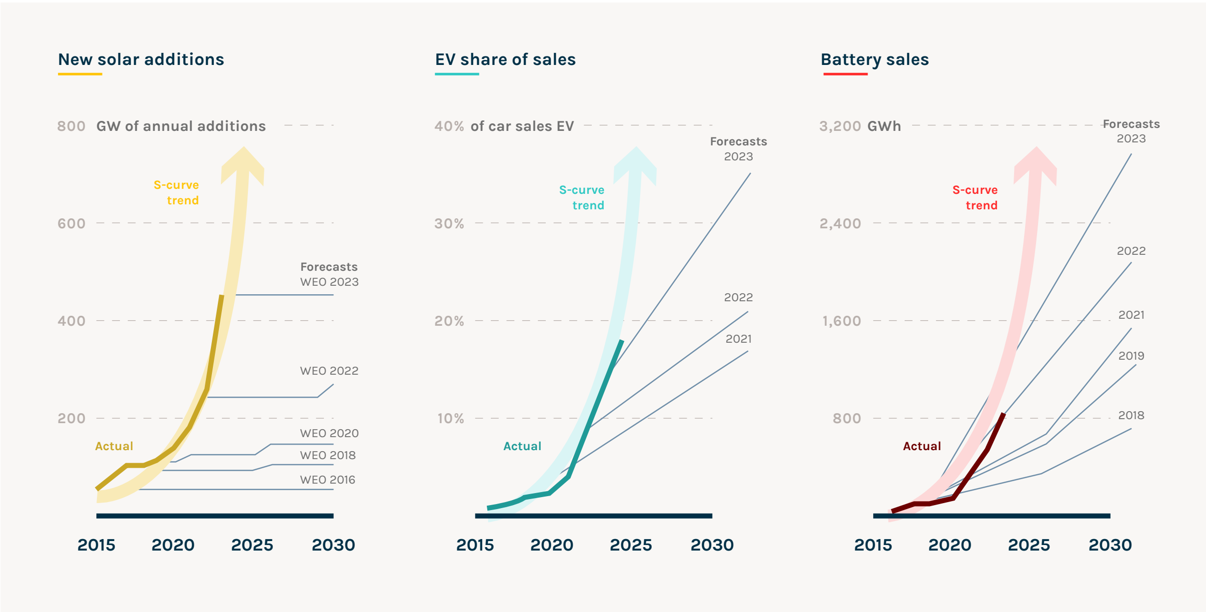
At an equipment level, there are many factors that contribute to the slow uptake of heavy haul equipment. The capital cost for new battery electric haul equipment is up to two times higher than diesel, and without any in operation, it also comes with operational risk. The battery commercial model is also unsettled, with manufacturers offering battery-as-a-service models that are so expensive that they exceed diesel operating costs despite not needing a constant fuel supply. The supporting infrastructure is new, and therefore also expensive. Upgraded electrical reticulation, fast chargers and spare batteries all add costs. Excavating new charging bays with different layouts for battery swaps close to ventilation (for risk mitigation in the event of a fire) also impacts the business case.

Finally, value (or revenue upside) is not typically included in the business case for electric equipment. Therefore, assumed productivity benefits from operating a full fleet of electric equipment have not been explicitly incorporated into the financial models – where it is accounted for, it is done so by altering the number of trucks required. Upside potential for low carbon commodity pricing (green premium) is also not typically incorporated. These line items are considered too uncertain to be included, but even a small probabilistic weighting leads to a large impact. For example, in the EMC case study mine presented in Chapter 4, a 5% green premium on revenue is adequate to offset all of the capital investment required for electrification over the life of the mine.

5 Gordon Gekko

6 The Electric Mines Conference, 2024, Perth – several presentations and panel discussions cited the fact that these projects would not be approved until they are TCO equivalent.

Incumbents have continually underestimated the speed of change



Source: Reproduced from RMI

May the wind always be at your back – the trend is your friend

As one key Consortium participant often says, "the costs for an electric mine will never be so high, and the costs of a diesel mine will never again be so low". Solar, wind and lithium battery costs are dropping exponentially, while investment in new fossil fuel capacity is also dropping through the floor. All the key technology cost inputs for an electric mine are falling inexorably due to global innovation, subsidies and investment in new capacity. To put it another way, "the Stone Age did not end because we ran out of stones".[7]

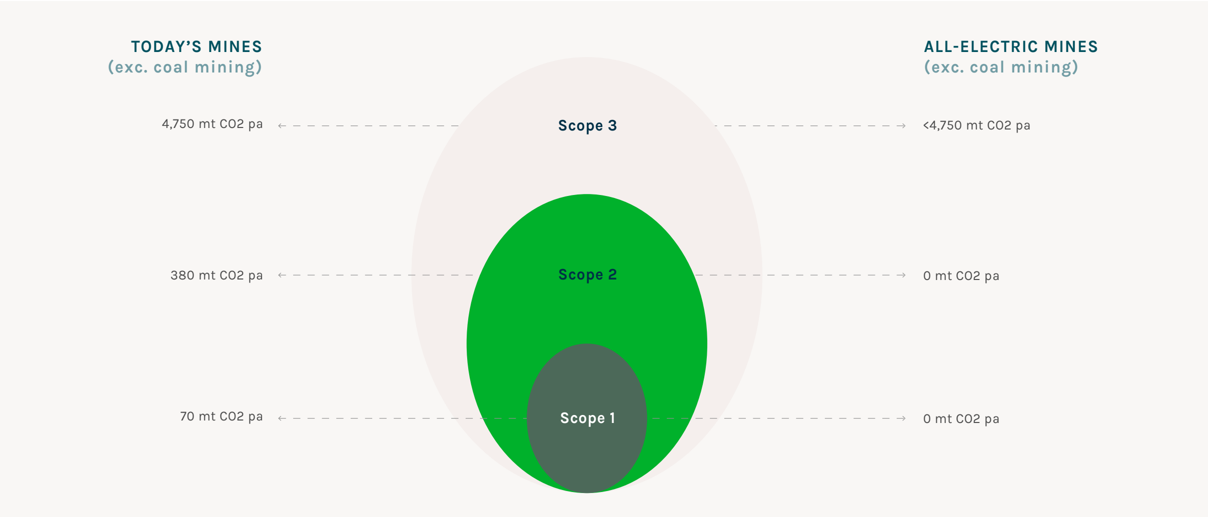
At a global level, battery costs are on a learning curve of 20% – 30%, which is still on the exponential part of the s-curve, as is battery performance – since 1995, lithium-ion battery costs have fallen 99%.[8] All of the investment and innovation in these two things are external to the mining industry – that is, they will keep getting better and cheaper regardless of the actions of the mining industry. Equipment will keep getting better and cheaper. Sandvik's latest battery will have a 36% longer range than its previous iteration.[9]

The same can be claimed by Epiroc, reinforced by their joint venture with European battery manufacturer, Northvolt. Many EMC participants, however, doubt that reductions in battery cell prices will be passed on by the major mining OEMs in the short or medium-term. In a general sense, the pace by which electric mining equipment gets cheaper will be linked to its adoption – a point made on several occasions by these same OEMs.

This equipment also benefits from having 80% fewer parts than a diesel engine and the latest battery cells are lasting over one million kilometres with minimal (less than 20%) degradation.[10] This will extend equipment replacement cycles, drastically improving the net present cost and total cost of ownership of electric mines.

7 Steven Chu
8 BNEF, RMI
9 Sandvik
10 CATL

Industry carbon footprint



Source: State of Play analysis, McKinsey

Electric equipment, clean energy, ventilation, drilling and processing will all be on the same energy system – there will be endless cost optimisation opportunities as businesses handover improvement programs to their workforces. Any additional energy use by electric equipment will be offset by reductions in the energy use of the ventilation systems – as described in detail by the IGO, Perenti and ABB Electric Mine white paper based on the Cosmos mine.[11]

Balancing caution and boldness – Fear is not an option; hope is not a strategy[12]

For mining boards looking at the long term, all the major risks are weighted against diesel mines. Costs in the form of volatile diesel prices, regulated carbon costs, investor preferences and portfolio targets, workforce retention, DPM exposure class actions and social license risks are all functions of the diesel case. A reduction in the Safeguard Mechanism threshold would impact virtually all operating mines in Australia. A difficult market for many mined commodities over the past 12 to 18 months has not helped company boards to take the long-term view. On the other hand, mining is naturally cyclical, and while nickel and lithium miners may have to wait for their moment, copper and gold miners can invest in electrification now.

Strategically creative miners in the Consortium, particularly the juniors like Blackstone Minerals and Bellevue Gold, are establishing electric mining as a central competitive advantage through lower costs, regulatory risks and product value upside via low carbon nickel and gold. Corporate development teams, supported by their institutional investors, are beginning to apply their learnings and assumptions to support acquisition targeting. In addition, following the Ukrainian invasion, financiers are considering asset resilience to diesel volatility in valuation assessments.

Over time, this will shift the relative value of ore bodies as some resources are better suited to electrification than others – the slow movers will miss this value opportunity. A good illustration of this concept is simply the advantages of location; proximity to clean energy leads to cheaper, cleaner energy inputs, low carbon intensity and the strategic optionality to co-locate downstream processing facilities – in the process opening new product lines and new customers. This is already playing out in aluminium and manganese.

The strategic choice mining executives are faced with today is therefore difficult. Interim carbon reduction goals by 2030 can be achieved solely through clean energy via renewables, whether through direct investment or power purchase agreements. However, if equipment is not also addressed when designing new mines, then obsolete infrastructure and a higher, riskier cost base will be locked in for the life of the asset.

When the business case is simplified, and lifted beyond equipment-by-equipment valuation, the economic case for electrifying today is clear.

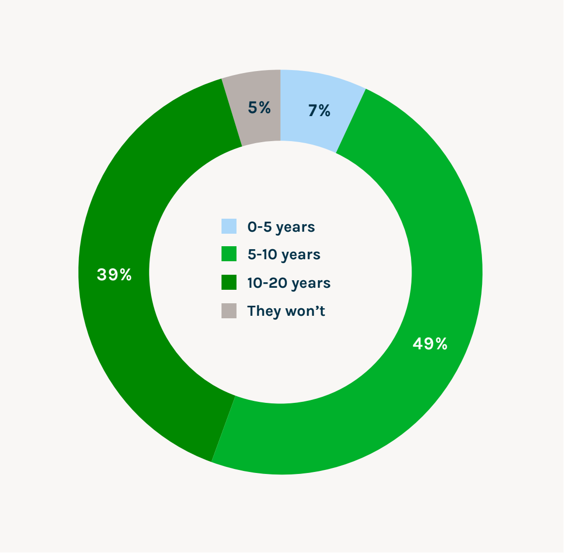
11 IGO, Perenti and ABB: Making electrified underground mining a reality. Lessons from the Cosmos Electrification Study
12 Borrowed (paraphrased) from James Cameron

What is slowing us down

Leaders and managers - Managerial leadership is ok in steady state, which isn't now

Getting started is the responsibility of the industry's leaders at CEO and board level. Unfortunately, technology stability has also created a general form of steady state leadership. What we need now is the courageous leaders with conviction and a long-term view to invest through the cycle in the assets, skills and technologies necessary to thrive in the world we are entering.

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



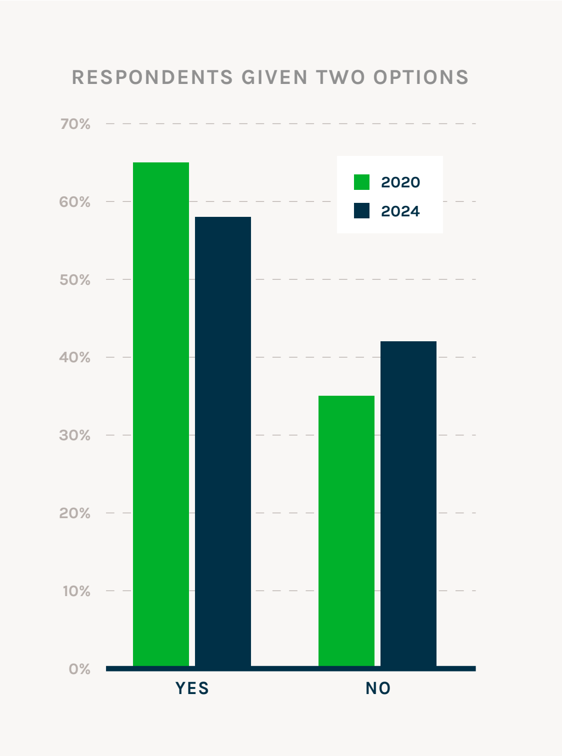
Source: EMC Survey 2024

Undeniably, Andrew Forrest clearly fits the bill. As does Bellevue Gold's Darren Stralow, Gold Fields Australia's Stewart Mathews, Blackstone Minerals' Scott Williamson and, of course, Peter Bradford, who led IGO until his recent death in 2023. These leaders have demonstrated a willingness to invest in decarbonisation and to challenge industry conventions such as mine life and reserve constraints to allow for long term capital investments. Without true leaders, the industry will continue to build the latest old mine.

"Most CEOs in the industry don't think about innovation, they are risk takers, but not innovators."

— State of Play, 2017

Will the next generation of mines be all electric?



Source: State of Play survey 2020, EMC survey 2024

Policy paralysis in Australia – incentives are in conflict and favour the current state

There are several reasons why Australian miners have not adopted battery electric underground load and haul equipment, while around 15% of Sandvik's Canadian and European order book is battery electric.[13] The overriding reason is a lack of clear policy support in Australia. Canada has had clear air quality standards for some time, leading most famously to the Borden mine's first move to electrify. In support of this are a price on carbon, a 30% capital tax write-off for electric equipment and supporting infrastructure and substantial grants to fund early fleet adoption, such as the Canadian Government's funding of AU$12m to fully electrify Glencore's Onaping Depth mine.

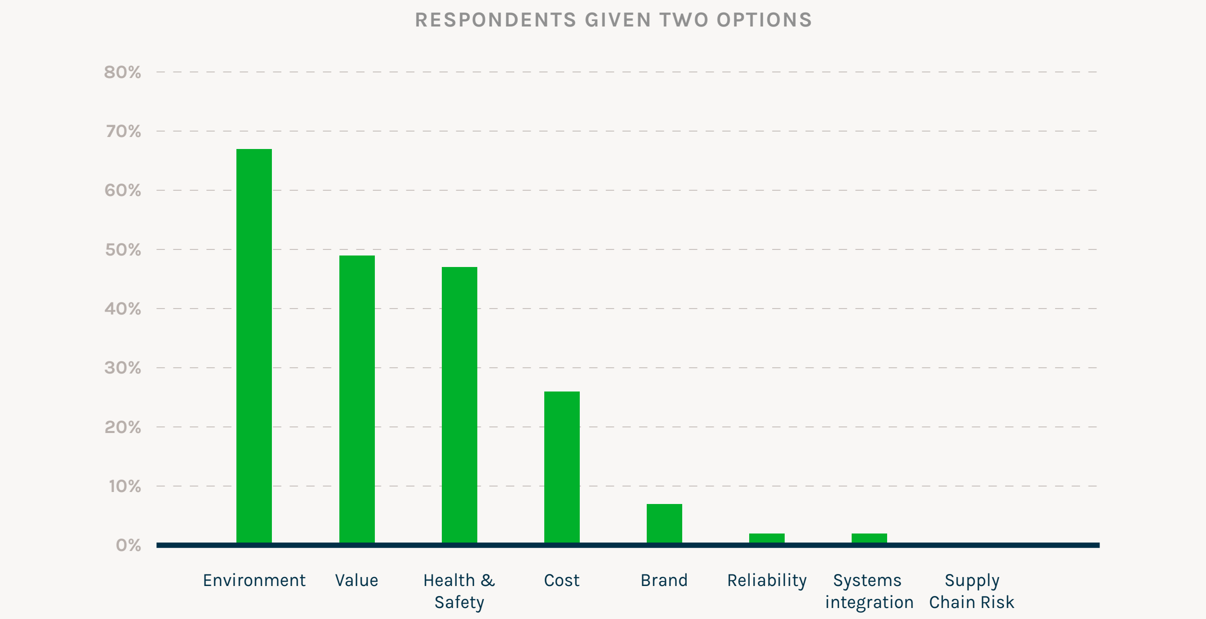
In contrast, Australia maintains a generous diesel fuel tax credit that will cost Australian taxpayers AU$37b between 2024 and 2030.[14] For BHP's iron ore operations in 2023 alone, this tax credit is worth over AU$500m. Unsurprisingly, while BHP has committed to large electrification of its Chilean fleet of 200+ heavy haul trucks before 2030, any electrification targets in Australia are for the period 2030 to 2040.[15] This is seemingly a policy difference laid bare. As of 2024, Chile imposes a tax on diesel for miners (of around US$0.12 per litre), whereas Australia does not.[16]

The Australian mining industry is also not subject to a universal price on carbon, at any price, unlike Canada and Europe. The closest policy instrument is the Safeguard Mechanism, but this covers only 200 facilities in Australia, of which most are coal mines or LNG facilities. At a 100,000 tC02-e per annum threshold, only a small handful of large iron ore mines are captured as well as very large base metals mines like Olympic Dam and Newmont's Telfer gold mine, and downstream alumina and aluminium processing facilities. The vast majority of mines are not subject to a compulsory carbon market.[17]

In a more subtle way, our mining regulations are also a major challenge to electrification. In Western Australia, ventilation regulations do not differentiate between diesel or electric equipment, which means that the ventilation benefits from using electric equipment, estimated to be anywhere from 20 to 40%, cannot be captured.

13 Sandvik
14 Climate Energy Finance, September 2023
15 BHP, Operational Decarbonisation, 21 June 2023
16 KPMG
17 https://cer.gov.au/schemes/safeguard-mechanism

Why would you electrify a mine site?



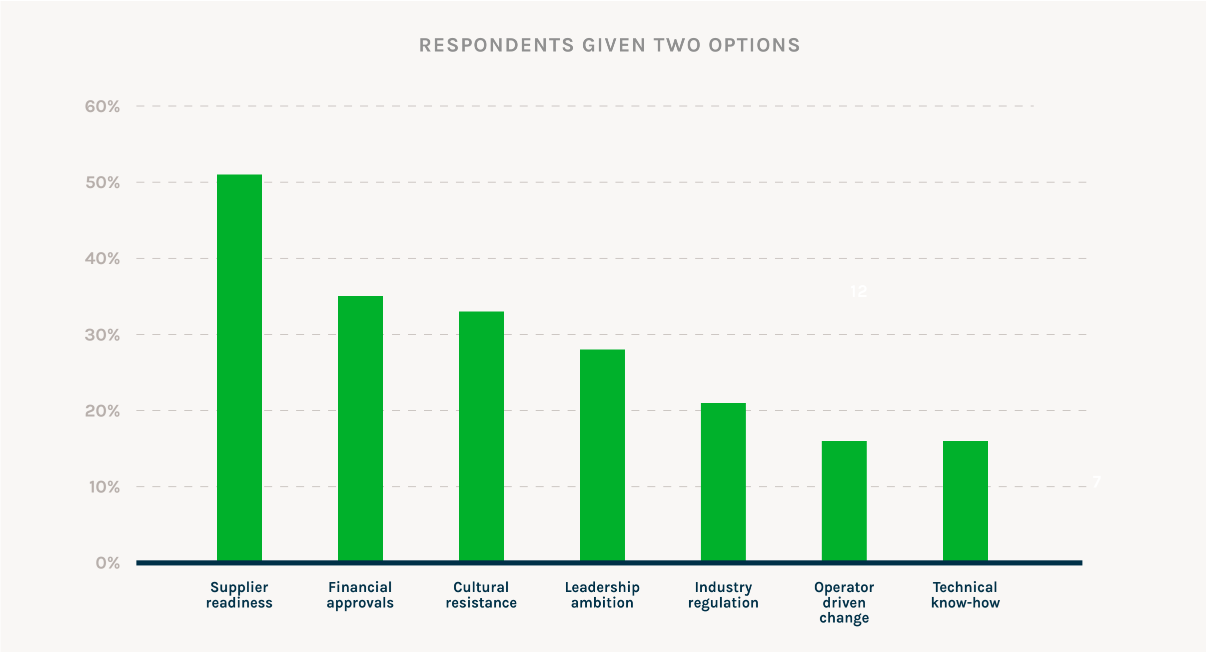
Source: EMC Survey 2024

Needing a fast transition – but getting an OEM oligopoly

There is a broad perception that the mining industry is large, but as a proportion of the global economy, it is relatively small at around 2% – 3% of global GDP.[18] And because it has had relatively incremental technology advances relating to its core process, mining equipment manufacturing is also relatively stable with a concentrated set of key players. In open pit mining, these are primarily Caterpillar, Komatsu and Liebherr, while in underground mining these are Sandvik and Epiroc, with Caterpillar and Komatsu filling smaller niches. There are also several manufacturers of ancillary equipment, such as Macleans and Normet, and a number of light vehicle providers such as ZERO Automotive, VivoPower, 3ME Technology and Safescape.

18 https://www.worldbank.org/en/topic/extractiveindustries

What is the one thing you would change to accelerate electrification in your business?



Source: EMC Survey 2024

Current equipment specifications have remained so stable that the whole contract mining industry is built around their performance, which is written into their contracts. The mining regulators have written their safety codes on the basis of well understood risks. It is a fiercely competitive industry in terms of price and performance within these specs, but there have been few new entrants to drive a disruptive shift of the type seen in the consumer vehicle industry through Tesla and BYD's emergence over the past half-decade. Mining equipment is effectively an oligopoly, and in underground mining, a duopoly.

The result of this has been a relatively slow development and supply of battery electric equipment to the industry, despite a clearly identified and understood need dating as far back as the beginning of the EMC in 2020 – and in most cases, well before that. The conventional 65t underground haul truck size for Australia does not have a vehicle commercially available to be purchased off the shelf today. If a company were to order one, it would be the first one off the production line. The same is true for the conventional 22-tonne underground loader.

Even if an Australian miner wanted to go fully electric today, there would be a 12 – 24 month wait for the equipment to arrive, let alone be commissioned. For an order of more than one, or even a full fleet, this could easily be close to double that time. And so, without clear incentives to move, and a good excuse not to, the Australian industry will continue its inertia in electrifying fleets.

Ore body horizons – Drill, drill, drill

One of the very important, but subterranean, challenges facing an industry looking to decarbonise is the centrality of mine life. Mine life underpins valuations of mining companies, which equates to their share price and market capitalisation. It therefore also drives all reporting to the market. It drives calculations of rehabilitation liabilities. It is the key variable around which the biggest mine design decisions are made – such as, will the mine be accessed via a shaft or decline? The mine life directly impacts the returns from all major capital investment decisions. This convention is entrenched through the Joint Ore Reserves Committee (JORC) code. The Gold Fields team, as early as 2020, clearly identified the value of increased drilling to support the longer-term mine design choices that support an electric mine, and ultimately, higher returns to shareholders.

For underground mines, boards and executive teams tend to aim for a 10-year mine life to get the initial project up and funded. Very few mines, however, last for only 10-years.[19] A continual brownfield drilling program generally maintains a rolling 10-year mine life over a much longer timeframe. Gold mines typically last 10 – 30 years, with some famous ones such as Obuasi in Ghana lasting for over 100 years. Copper and nickel mines can last for up to 40 years. Olympic Dam began in 1988 and could easily last for decades more given its estimated resource.

Miners tend not to drill out their reserve for longer than 10 years because they don't really need to – particularly in Australian gold mines where ore bodies can be more readily accessed via declines. Drilling is expensive, and the benefits of establishing a large reserve are generally not captured in the short term. The conundrum is that the major capital decisions for an optimally designed electric mine demand a longer mine life to justify investment. For example, in many instances, a shaft is considered to be a better mine design for electric mines given the benefits of hauling downhill fully loaded, capturing regenerated braking energy and then going back uphill unloaded.

Bellevue Gold were courageous enough to commit to a 15-year investment in a cutting edge hybrid energy project that extended beyond their 10-year mine reserves. Boards can find substantial advantages for shareholders by taking a longer-term view of the optimal size of their reserve, if they can begin to understand the implications of this for decarbonising their businesses.

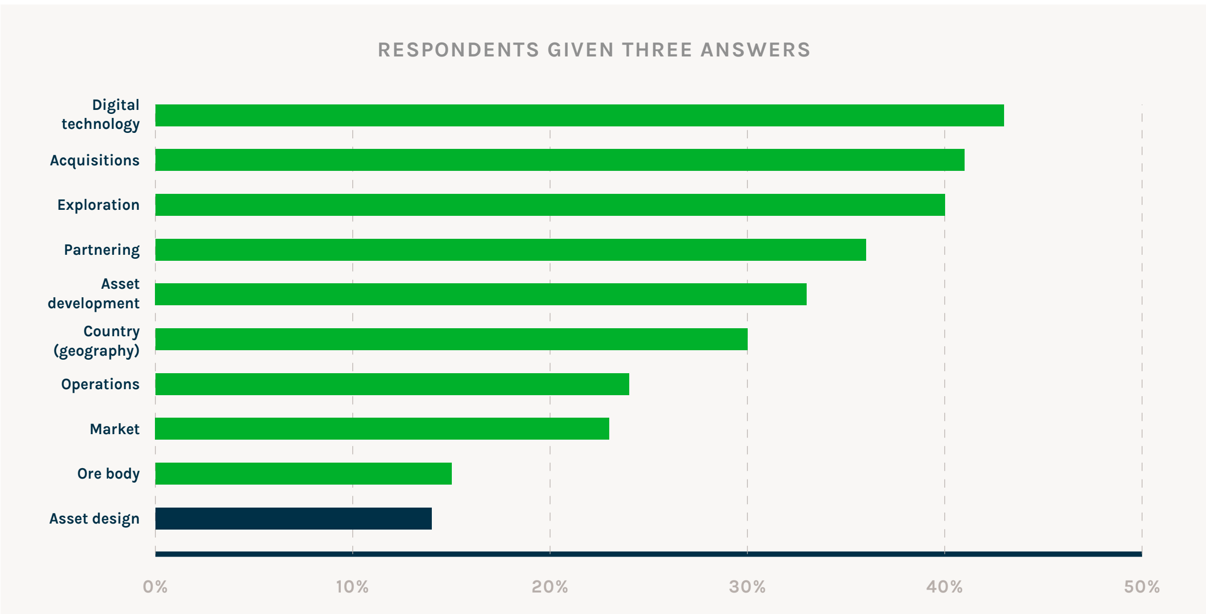
Dealing with physical asset change in mining

The State of Play group have run a global strategy survey of over 700 executives every two years for the past 12 years – there is one question we have always asked, where would you accept risk to increase financial returns? And always, down in the bottom two, is asset design. Across geographies, age groups and through time, mining executives will not accept risk in the design of a new mine. It is a large reason for the design inertia that has led to mining looking much the same today as it did half a century ago.

In mining, the risk of exploration, market prices and operating mines themselves is high, leading to a low-risk appetite for doing things substantially differently. The risk appetite has already been consumed by the large capital outlays for projects for both miners and investors. The resultant conservative attitude to innovation is counterproductive when trying to mitigate the inherent environmental and operational risks of mining using existing models and methods.

The challenge we have is that electrification, and indeed fundamental energy transformation, sit right in the physical transformation zone. As such, it is directly connected with company leadership and external drivers – that is, while executives and boards might not want to take risk here, they will eventually have to, given what is lining up in the external world. As it is against the incumbent DNA, the leadership requirement is significant.

As a mining business, where would you accept risk in order to increase financial return?



Source: State of Play survey 2023

19 Geoscience Australia

It is, however, a mental block that we as an industry will have to face and overcome if we are to decarbonise our assets with the urgency required. Electric mines demand new designs. Renewable energy combined with electric equipment, but operated as we have always done, will be truly suboptimal. New designs are necessary, and many leading thinkers in the industry are already working through the implications. The Consortium's mine design working group identified and worked through dozens of these questions, and in so doing, identified many more. It will be the central work of studies teams for the next decade(s).

Designing, building and operating electric mines is becoming a core competence for leading mining companies. We are currently at the beginning of the roll-out of first generation electric mines – those built using diesel mine designs and operated with electric equipment. These will soon lead to second generation electric mines in which the mine design itself is optimised for electric equipment built on the experience operating first generation electric mines. Miners have long been advocates and skilled practitioners of continuous improvement practices – we are already seeing the effect of this in Perenti operated mines as they optimise the operation of the Sandvik 65t prototype haul truck at AngloGold Ashanti's Sunrise Dam mine in Western Australia.

Enormous benefits are available – but in Australia at least, electric mine designs remain largely theoretical. We are still waiting for the company with the bold strategic vision to build our first fully electric mine. And once we start, there will be no going back.

Technology adoption is a learnt skill – and we haven't practiced in a while

Australia's mining industry has operated in a similar way for several decades, particularly in the underground mining sector. Because of fundamental technology stability, the industry has focused innovation on continuous improvement to reduce operating costs through relentless operational, process and logistics optimisation. A major exception to this is the iron ore operations in the Pilbara who have led the industry in investing heavily in haulage automation and remote operations.

The result of this fundamental technology stability is that organisations are not "match fit" when it comes to major technology adoption programmes, which decarbonisation clearly is. Companies therefore need to rebuild these capabilities at the same time as they are studying and implementing their roadmaps and attempting to do so on the accelerated timeframes demanded by the pace of global warming and their boards' carbon reduction targets. This is no easy task. It leads to the oft-stated catchcry of EMC participants to the industry, whether on webinars or during conference presentations, to "just get started".

Steady state technology adoption processes in heavy capital industries are naturally static – big shifts come along only once a generation. As an industry, we need to recognise the moment to invest in our organisations to support a large transformation. To date, we have been slow to recognise that this is a moment of significant change and the imperative to gear up for it at the right level.

Concluding thoughts

Decarbonisation of the mining industry is currently going through a tough period. The market in some commodities is weak and many companies are pulling back from large decarbonisation investments in their mining operations. However, there are many bright spots. We are likely to see a large pipeline of clean energy projects approved and built to power mines, whether through power purchase agreements and/or behind the meter, and also standalone systems to support remote mine sites. By some measures, this could equate to a capital pipeline of around $17b through 2030 if miners are to reach their 30% carbon reduction targets in that timeframe.

> "The risk of under-investing is dramatically greater than the risk of over-investing."
>
> - Sundar Pichai, CEO of Google

Ultimately though, the question of pace and commitment is a leadership question. Long-term net zero targets can be insidious in their ability to allow executives to slow-walk the transition. As can be portfolio level targets that forgo asset level targets – the risk of not moving, or moving too slowly, is real. The time to adopt electric load and haul equipment is minimum 3 to 5 years – if companies are not getting started now on building capability and running trials, they have little chance of transitioning their fleets by 2030.

Regulations are shifting quickly and are only going in one direction. Diesel prices are as volatile as ever, something that is likely to increase as the market continues to lurch from oversupply to undersupply. Strategically, the seemingly prudent choice to be a fast follower, brings with it the substantial risk of locking in old technology, with higher embedded risks, for decades. Conversely, the leaders in electrification have the opportunity to create heathier, safer workplaces, enhance their reputations and improve financial returns.

Chapter 2: Innovation in collaboration

"Creating the space for cross-company creativity – a radical initiative in a competitive industry."

Capturing lightning in a bottle – The many external factors that led to the Consortium

State of Play is a research group that began as an initiative to better understand strategy and innovation in the resources industries. In 2019, together with the Future Battery Industries Cooperative Research Centre (FBI-CRC), METS Ignited and Project 412, the State of Play team began a research project on mine electrification. The research drew in participants from over 50 companies to discuss the drivers, value case and implementation of electric mines.

Coming out of this, as Covid raged through 2020, was a common suggestion from the miners involved.

– thanks, we clearly see the essential role that electrification will play in our decarbonisation plans, but we can't do it alone. Can you help us to work together?

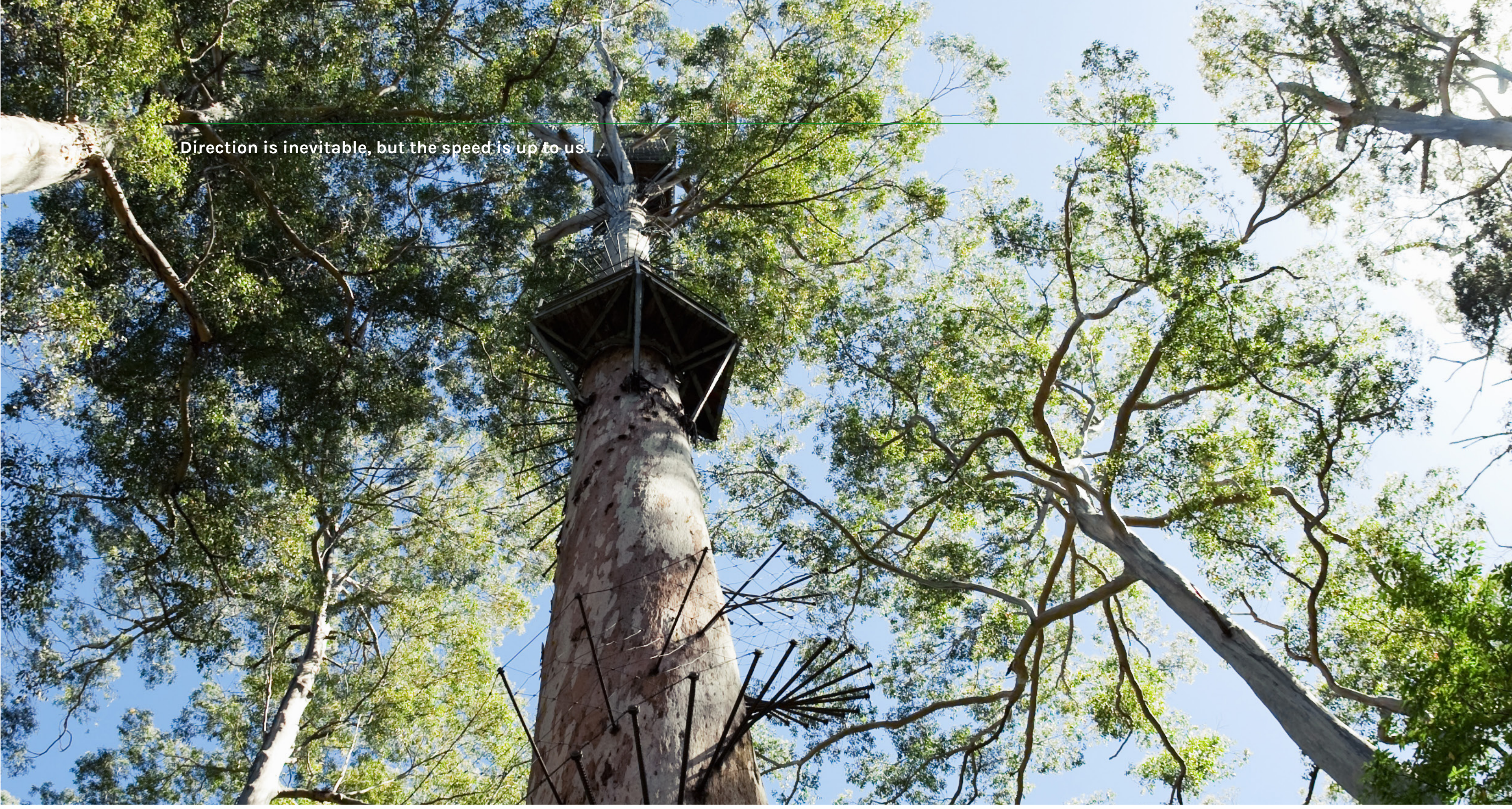
Through the second half of 2020, we assembled the initial coalition of companies, six miners and five suppliers, to establish the Electric Mine Consortium.

In many ways, this was like capturing lightning in a bottle. Many factors aligned to allow miners, who historically have been resistant to working across company lines, to work together closely to accelerate the electrification of their businesses.

In 2020, countries were submitting their nationally determined contributions (NDCs) to reach net zero carbon emissions by 2050, thus attempting to limit global warming to 1.5C. As a result, so did many mining companies in 2020 – notable miners who did so include BHP, Rio Tinto, Anglo American and Glencore. Of miners in the Consortium, OZ Minerals, Gold Fields, Evolution Mining and IGO all announced net zero targets in 2020. Boards were getting serious about decarbonisation, and therefore, so were their businesses – the question was, how?

The year 2020 was also pivotal for electric vehicles and battery technology, marked by significant advances that set the stage, and the tone, for widespread adoption. Professionals in the mining industry were paying attention. In 2020, the Tesla Model Y was launched, and overall electric vehicle sales grew around 40% from 2019.[20] The costs of battery packs continued to decline with the average cost of a battery pack falling to around US$137/kWh (an ~85% drop since 2010), bringing the industry closer to the US$100/kWh threshold needed for electric vehicles to achieve cost parity with internal combustion engine vehicles.[21]

20 International Energy Agency
21 BloombergNEF



Electrification benefits and challenges, as identified in 2020

	Benefits	Challenges
Economics	• Renewable energy price • Maintenance cost • Scale reversion • Mine design	• Initial capital outlay • Equipment cost • Unclear tech choices
System Integration	• Data capture • Automation enabler • Energy usage optimisation	• Complexity • Infrastructure connectivity • Interoperability
Health & Safety	• DPM exposure • Less operators at risk • Heat, noise, vibration	• Flammability • Recycling
People	• Talent attraction • Leaner org. structure • New disciplines • Improved gender balance	• Maintenance skillset • Data & analytic skillset • Conservative culture • Change management
Social License	• Permitting + approvals • Product provenance • Emission reductions • Industry leadership	• Lack of metrics • Government policy
Supply Chain	• Price volatility exposure • Supply security • OEM servitisation models	• OEM innovation incentives • Manufacturing diversification • Technology availability

At the same time, Covid had thrown work life into a new world, as white-collar professionals worldwide became accustomed to working from home. By April of 2020, Zoom's daily meeting participants had jumped from 10 million in December 2019, to 300 million.[22] The mining industry was far from unaffected. The ICMM estimated that mine site visits were almost entirely stopped, and overall personnel on site was reduced by 30 – 50% due to social distancing and other health protocols.[23]

This meant that suddenly mining industry corporate workers had a lot more time than was typical. And without the incredible shift to virtual work, the Consortium as it became would simply not have been possible. Without virtual, we would have been limited to a few meetings a year at huge in-kind travel costs – and would have substantially decreased the innovation and networking benefits. People believed that economy-wide electrification was imminent, and that the mining industry would quickly follow. They believed that their companies and governments were serious about decarbonisation and that they personally had to find a way to achieve it. And they suddenly had the time to study and invest in fundamental industry change.

This was a period of disruptive social, economic and technological change – and the mining industry was not immune.

Making the most of the moment – Pulling together the coalition

The companies who drove the establishment of the Consortium were diverse but shared several commonalities. They were not majors. They were predominantly underground miners. They were not bulk miners, but instead focused on gold, battery minerals or base metals. They had decisive corporate net zero goals, or in the individual case of Perenti, their clients did.

The internal team of the Consortium were not open innovation practitioners, but strategy consultants and researchers. This meant that we came into the discussion as to how the Consortium should be designed and operated with an open mind and a clear understanding of individual corporate strategies, drivers and priorities. Ultimately it was an industry-driven model that we helped facilitate and co-ordinate, and outside the membership of METS Ignited, was established and funded without public sector involvement.

An email from July 2020, captures the nature of this effort well:[24]

"We had about 20 different conversations with participants in the State of Play: Mine electrification workshops, asking for feedback and suggestions on how momentum can be harnessed to accelerate the full electrification of mine sites. The feedback and insights were consistent:

1. *There is a pressing need for some miners (particularly battery mineral suppliers) to accelerate electrification to achieve zero carbon for market as well as social reasons*
2. *There are gaps than need to be addressed collectively, particularly if Australia is to be at the forefront of this trend*
3. *There are a lot of industry initiatives out there, and many do not drive the applied development/ testing action required*
4. *There is strong interest in a focused Consortium that can mobilise action, get things done, and accelerate the transformation process*

These discussions have led to the proposal discussion paper attached, and we would like to get a group of interested entities together for a 2-hour virtual design session to establish the potential objectives and structure and furnish enough information to see if there is sufficient commitment for the Consortium to proceed."

For several months, our team discussed the model, potential participants and commercial terms with key individuals within each business. By July 2020, we had drafted a proposal and shared it with each organisation. It was envisaged that the Consortium would commence with Phase 1, which would be about a six-month process and focus on: establishing the scope and objectives for the Consortium; determining the focussing themes; identifying the critical few projects to advance those themes; designing the project mechanisms for success (inc. funding); and establishing the project management structure. After the initial six-months, each company would individually decide whether to continue.

22 The Verge
23 International Council on Mining and Metals (ICMM)
24 Direct excerpts from emails in July, 2020

Consortium proposal following State of Play Electrification report

H1, 2020 Step 1: State of Play drilldown	H2, 2020 Step 2: Electrification to zero consortium
Key activities 1. Industry survey (ongoing) – Build on deep State of Play dataset – 10+ questions focused purely on electrification 2. Industry workshop – 40+ industry participants across two weeks – 2x industry presentation webinars – 3x working sessions on benefits, challenges and next steps **Key research outputs** 1. Comprehensive dataset derived from survey participants 2. Understanding of electrification drivers and barriers 3. Identification of key electrification technologies 4. Draft industry thematics for collaboration to accelerate electrification 5. Mobilisation of further co-operative research 6. State of Play written report	**Phases** 1. Scoping and movement (~6 months) – Establish the scope and objectives – Determine the focusing themes – Identify the critical few projects to advance those themes – Design the project mechanisms for success (incl. funding) – Establish the project management structure 2. Project development – To be defined with initial participants

The precise objectives and scope of the Consortium were to be determined by its members, but in assembling the initial group of members it was necessary to establish a starting point for the overarching goals. The suggestion was:

- Accelerating the full electrification of mining operations to achieve
  - Zero carbon emissions
  - Zero harmful particulate exposure
  - Step change in the development and operational economics of mines
- While enabling Australian METS businesses to increase their global competitiveness

The general rationale for forming the Consortium was that a group of mining companies, selected technology providers, and industry representatives capable of influencing deployment of development capital could accelerate the achievement of these goals both individually and collectively.

Each company had aligned overarching goals and overlapping challenges to the extent that they could see value in collaborating to achieve these stated goals.

Ultimately, the case for forming the Consortium is that as a collective, the group would be more able to:

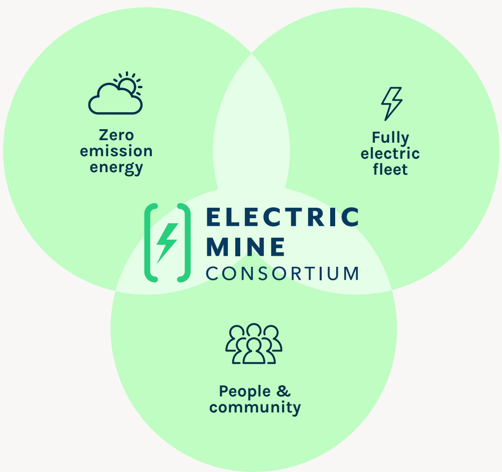
- Direct developmental work to the critical areas of concern slowing progress
- Influence providers of development capital to support the most effective projects
- Provide spread of the asset testing opportunities to resolve technology issues
- Influence suppliers to accelerate innovate in provision of appropriate products

The proposed role of the Consortium was to identify the critical few development projects that could have the ability to significantly accelerate mine electrification – and that, if funded appropriately, executed effectively, and communicated widely could mobilise support, resources, funding and management for their execution.

We did not aim for complete industry coverage across participants, but rather aimed for sufficiency in progressing resolution of the key applied development challenges. In this respect, the group needed to be just big enough to mobilise influence and capital, but not so big as to impede progress.

Momentary lapse in competition - Designing the Electric Mine Consortium

The Consortium was designed around the direct participation of two types of organisation – mining companies (members) and technology, supplier, and services companies (partners). Within these two categories, our intent was to prioritise the role and perspective of mining companies. It was their challenges which needed to be collectively addressed, and to which the focus of the Consortium and its partners needed to be applied. We didn't want the Consortium to have the same dynamic as an industry conference where there are many more suppliers present than mining representatives.



The Electric Mine Consortium is served by three core operating concepts which illustrate our vision:

1. A zero-carbon emission mine powered by 100% renewables
2. A fully electrified, data-driven fleet, unlocking greater productivity
3. A people and community approved mine, that is safe and healthy

The electric mine is safer for the workforce, has less impact on the natural environment and is more productive for its operators. This is underpinned by new servicing and contract models, as new metrics for performance, driven by data, emerge and dominate.

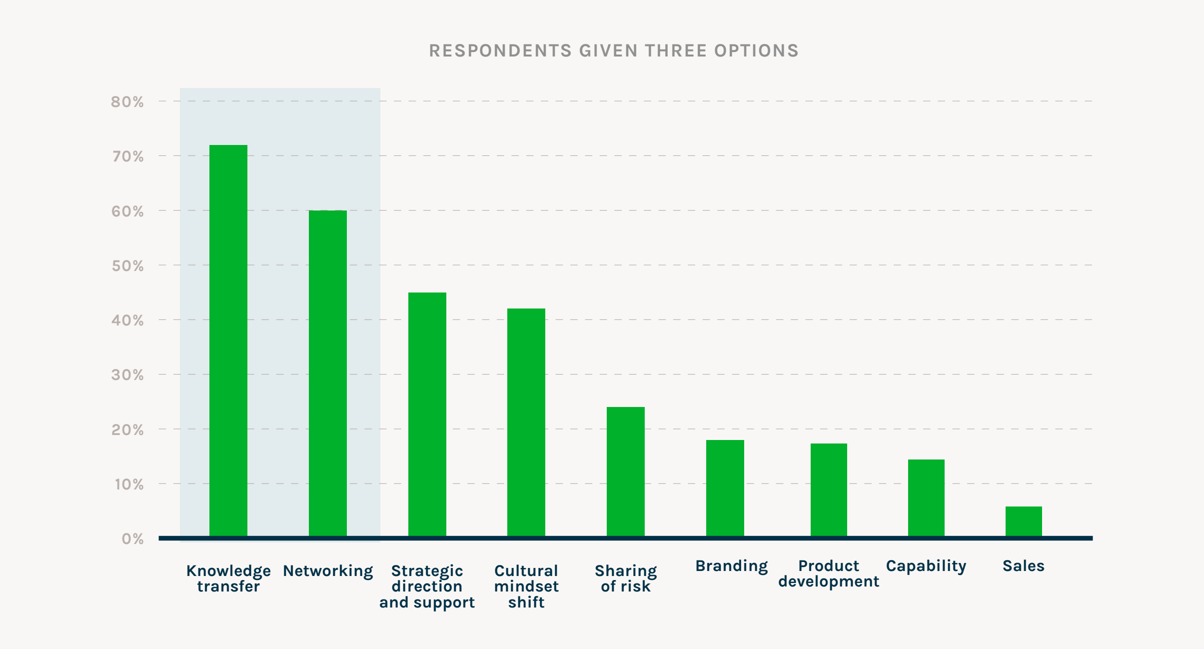
The initial group of members were mining companies with similar objectives, in particular those that had a pressing need to deliver zero carbon minerals as a differentiator in the market (especially the minerals used in electrification), and where the economics of their growth plans will be enhanced through acceleration of this technology. Mining companies (initially limited to around 8) were effectively handed full control, as a group, over the framing and selection of projects.

The miners themselves effectively self-selected. There were four broad reasons why each joined:

1. Gold companies felt pressure from the "green gold" movement, while several others were related to the battery minerals sectors which created an incentive to product products low in embodied carbon.
2. Underground electrification had the clearer case to electrify given the added element of diesel particulates impacting long term worker health. It also uses far smaller equipment than open pits, which was initially better suited to battery electric technology.
3. The companies themselves were not so large that they thought they could do it all themselves, there are simply too many equipment types to trial economically. This led to the push to individually align on trial plans and share insights collectively.
4. Over time, juniors joined the Consortium and had an outsized impact due to their sheer ambition and aggressiveness in taking risks to achieve their strategic goals related to decarbonisation – in this way they were very different to the typical large and mid-tier miner.

The initial group of partners were predominantly technology companies who are progressive and intent on leading the delivery of new products that can accelerate the adoption of the fully electric mine. Given what was considered as a likely source of project funding, the Australian government, preference was for companies with the capacity to advance Australian economic development. An equivalent number of potential partner service companies, government bodies and research groups were provided with full access to the information generated by the Consortium and unconstrained attendance at working sessions.

Early feedback on EMC benefits



Source: EMC survey 2022

1. **Balance Scale and Agility:** Be sufficiently large to instigate industry-wide transformation yet remain agile enough to seize emerging opportunities.
2. **Industry-Savvy Facilitation:** Operate under the guidance of individuals who combine in-depth industry knowledge with a strategic outlook.
3. **Enable the leaders:** Structure programs to enable the leading and ambitious companies to continue to lead, thereby creating the most valuable knowledge set for dissemination.
4. **Value in Growth:** Welcome new members who enhance the consortium's diversity of capability and approach, and who will accelerate EMC objectives through ambition and contribution.

From the beginning, we were clear that we did not want many, if any, consultants joining the Consortium. This was to preserve the co-development intent and work environment without the risk of inadvertently facilitating overt sales processes. This was another factor in trying to avoid the conference type atmosphere many corporates often try to avoid.

Outside of this, partners joined the Consortium for a mix of three simple reasons:

1. Branding
2. Product development
3. Business development

Depending on the business, the order of these priorities could shift. For example, smaller, newer companies like ZERO Automotive and Safescape were primarily focused on product development whereas larger companies like Sandvik and Epiroc were possibly more focused on branding and business development.

The Consortium was designed to achieve its two objectives of speed and impact through embedding a "highly aligned, loosely coupled" operating philosophy. Supporting this was the resourcing of the internal Consortium team which was a concertedly high capability, small team of experienced executives and advisors. This team was very active in its facilitation and steering of projects and ideas and responsive in both design and feedback.

As a facilitation group, we provided the overall direction of the Consortium and were the single point for co-ordination and process management with responsibility for things such as commercial and legal administration, strategy and design facilitation across working and enabling groups, maintenance of stakeholder relationships and networks, and leadership of select working groups.

The key principles by which we designed the structure and approach of the Consortium were:

- Equal voice in key decisions (members)
- Collective project selection (members)
- Project-by-project participation and funding (members and partners)
- Full transparency of data generated in projects (members and partners)
- Cash and in-kind input valued transparently and agreed collectively (members and partners)
- Value retained proportional to value provided (members and partners)

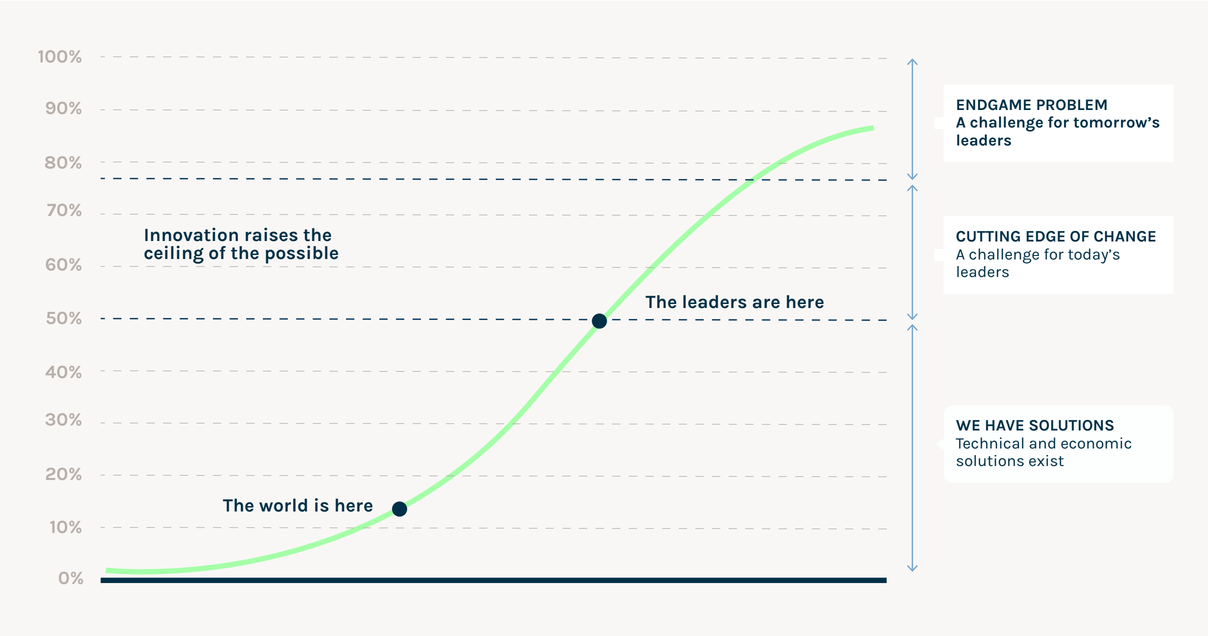
We also envisaged several possible project types:

- Internal pilots
- Collaborative pilots
- Joint ventures
- New companies

All people involved with these initial discussions wrestled with the question: how many company participants is enough? While 10 is insufficient to fund necessary resources, 25 might lead to a dilution of focus. At one point, the EMC team gave consideration to the thought the Consortium should grow to 50 plus organisations, spread through Australia, the Americas and Africa and Europe, but this received clear pushback from miners. There were different schools of thought on this, and even collaboration theory was not definitive.

Ultimately, the driving consideration was to achieve a balance of leaders and observers – too many followers and the burden of work and input on those actively investing is too high to be sustainable. The collaboration must be relevant to the leaders – the followers will always follow. If you're not on the cutting edge, then you're not adding value. The question for anyone designing and operating a group like this is, how to use the weight of the followers that are present to help the leaders go faster for cheaper (and for the leaders to recognise this benefit). This is the magic sauce that keeps the initiative alive.

The ceiling of the possible keeps rising



Source: RMI

This begs the question, if we had stayed with the original five members, would the Consortium have lasted longer and ultimately had greater success? Would this have undermined the dissemination of insight to the broader industry and in aggregate limited the advance of decarbonisation in mining? The delineation between industry leaders and followers is became more distinct as we progressed - in some cases, a clear roadmap to meeting emission targets was quickly articulated, whilst in others there remained a disconnect between corporate objectives and practical realities (if the corporate objectives existed at all).

Legally, the initial six-month trial period began with a relatively clunky, but crucial, multiparty nondisclosure agreement, covering all expected activities, towards the end of 2020. The following year, once the participants had committed to the Consortium going forward, we convened the senior legal counsel from each company in fortnightly sessions to draft, finalise and sign the cornerstone Consortium Agreement.

This agreement allowed seamless joining of the Consortium without requiring a new NDA to be signed by every company every time. It provided clear guidance on the treatment of intellectual property contributed and developed to and within the Consortium. It also allowed for, and guided, the development of an unprecedented data sharing platform by AWS and Nukon. This legal drafting process took over 10 months and was a significant achievement for the group. It also established a Governance Committee with senior and/ or legal representatives from all participants, which oversaw sharing and use of intellectual property, competition policy and commercial decisions.

Recipe defines the flavour – How the Consortium worked in practice

The EMC was designed for the big unresolved questions – and perhaps, didn't evolve quickly enough in its approach or in its business model as the questions narrowed. However, it was very effective whilst commodity markets were strong and the push from corporate targets drove capital projects. Investment and movement are the lifeblood of collaboration – talk alone is not enough. When things were moving, collaboration was healthy. When some members came under financial pressure from a commodity down cycle, collaboration came under real pressure and struggled as a result. During periods where there is a lot of study and investment, there is a lot to share.

The working model for participants remained steady throughout the four years the Consortium was in operation – we had between five and eight working groups (depending on the year) with monthly meetings, a Consortium wide monthly update and a Consortium wide design workshop every month. During 2021 - 2023, there were between 150 – 200 individuals participating in the Consortium across these sessions each month. In 2024, this number dropped below 100 – still healthy, but notably less so than previously.

The EMC work processes

Design workshops	Project management	Work streams
• 2.5 hours per month • All members and partners • Used to accelerate and share insights	• 1 hour per month • Work streams share progress • Aligned with project objectives and plan	• 1 meeting every 6 weeks (minimum) • Set up and facilitated by EMC leadership • One rep from each company preferred • Emphasis on key focus areas and projects
Shaped by prioritising and addressing the biggest barriers to electrification in the industry	Include presentations by vendors and technology leaders (schedule separately as warranted)	Parallel project meetings (where required) to drive progress

Each working group was identified and established to address a distinct challenge to implementing electric mines. These were initially, Energy Storage; Heavy Underground Equipment; Light and Auxiliary Equipment; Surface and Long Haulage, Mine Design; and Electrical Infrastructure. These had evolved until in 2024, the groups were Energy Supply and Storage; Equipment and Data; Mine Design and Infrastructure; Policy and Skills; and Carbon. From 2020 - 2022 these were all led by mining companies, while from 2023 - 2024 these groups were led by Consortium facilitators as a result of the in-kind burden.

As you can see from the evolution in these working groups, scope was a constant topic. Over the past four years, the group considered a large number of challenge areas and how to address them. Processing was an ongoing question, given its centrality to energy load management and energy consumption, as was automation given its technological symbiosis with electrification. Logistics and shipping came in and out of focus at different points. Products, in particular green products, were frequently the subject of cross-industry discussions and strategy development for individual companies via the Consortium, but ultimately none of these were formalised into a Consortium working group for various reasons – most frequently, scope creep and broad relevance to all participants. It is inevitably about resources and the ability to manage them.

The EMC workstreams (2024)

Workstream 1 **Energy supply and storage**	Mine scale, long duration energy storage systems to supplement renewable power supply are not yet economically or operationally proven, and lack of shared infrastructure is impeding alternatives.
Workstream 2 **Design and infrastructure**	Traditional asset design does not consider or realise the full benefits of mine electrification, many fundamental design assumptions are changing with the shift to electric and associated digital technology.
Workstream 3 **Equipment and data**	Limited number of zero-emission vehicles commercially available. In addition, the operating assumptions and costs are poorly understood which is slowing adoption.
Workstream 4 **Energy and processing**	Optimising energy across the value chain to improve productivity and reduce emissions through processing technology and time shifting, can be high impact, yet is poorly understood with limited adoption.
Workstream 5 **Policy and skills**	Policy settings do not actively support technology investment at the pace required to meet emissions targets. Skills shortages are becoming a larger uncertainty for roll-out of electric mines.
Workstream 6 **Carbon**	The inability to efficiently certify and value low-carbon materials, coupled with the rapidly changing policy and regulation landscape for emission reporting, requires greater understanding and progress.

Workstreams and whole of EMC design meetings were an incredible resource, particularly in the early stages as the big questions were being framed and understood – when everyone is aligned. The ideation process of divergent and convergent phases is well tested for good reason. These sessions were real working sessions in the first two years, in which we would split everyone into sub-groups (virtually) and have each work on virtual whiteboards to discuss a specific question. These groups would cross company boundaries and so the networking uplift was very strong. Over time, these sessions became more focused on presentations and experts as the questions narrowed and understanding deepened.

As the understanding deepened, the working group framing broadened. This is because the unresolved questions ceased being about simple engineering and more about establishing the business case and policy context. Sustainability teams became an important stakeholder, as did CEOs and their corporate affairs teams in their efforts to shape policy. We held several CEO forums in which the mining company CEOs discussed the challenges to mine electrification and proposed industry-level initiatives to address them. From these came the Policy Working Group.

Throughout the EMC, initiatives were promulgated and pursued that either did not get sustained traction more broadly or were not feasible technically. It is the firm belief of the facilitator team that these false starts are an essential part of successful transformation, particularly in the early stages. This a reflection of how the EMC operated - when the failure rate of initiatives dropped to a conservative level, the important breakthroughs needed for ambitious transformation also tended to evaporate.

"Fail often so you can succeed sooner."
 – David Kelley, Stanford Professor

Navigating the complexities of building and implementing an ambitious policy platform to influence government outcomes is not straightforward. Our move into this space with the Consortium has given us all an enhanced respect for those groups and associations who do this work for a living. We will go into what we did and what we achieved in the next chapter, but the key here is to understand why we did it. Policy is the highest leverage tool in the package – and in theory, is the right place for a large group of companies to go to improve the business case for electrifying. It is the highest leverage tool because it ultimately sets the incentive framework for companies to pursue long-term change – particularly when the short-term economic case is incremental.

EMC reach

200+ Participants active in the consortium	**75** Hours in "all of EMC" workshops and design sessions	**10** Dynamic panel discussions and networking events	**20** Conference and industry event presentations
	150 Hours of working sessions across the workstreams	**15+** EMC Supplier engagement sessions leading to innovative partnerships	**6** Publicly released reports and articles

Which means...
Access to a multitude of independent, best-in-class, practitioners in the industry to de-risk EMC company investments.

Our insights on this process were hard won – tread carefully and stay away from processes that require unanimity. There is too much diversity in strategic objectives, individual asset economics and executive culture to achieve universal consensus in many situations. We talked about policy in the Consortium from the outset, but it was only when pushed by the CEOs that we formally structured to address it. Federal and state governments were always active in engaging with and through us on policy consultations across a diverse range of topics.

Policy support within a company requires a higher level of direct hierarchical support than does specific technical initiatives. So, it was more complex on two dimensions: consensus across the Consortium and a higher level of responsibility within each company. This requires a large increase in specialised resources compared with a technical extension along the value chain. Ultimately, as a result, we probably lost more skin in a collaborative sense than we had anticipated.

EMC evolution

2020 - 2023	2024...
FROM: Maximum learning, minimum competitive tension	**TO: Maturity, specialisation and competitive tension**
• "there's a point [at the start] where when nobody knows anything" • "when we started, no one had an electrification strategy or plan" • "at the start everything's broad, and it's easy to understand" • "you're all learning the same...the same new things" • "we've been able to start to get up the curve" • "minimal to no competitive tension in anything that we did"	**Maturing understanding with diminishing returns** • "someone provides 10 points of feedback on a case study [but I knew most of that already, or its not relevant to my case]" **Leaders are expecting reciprocity to share** • "so you're spending $300,000 a month in doing this trial activity. Human Nature says I'm not just going to put it out there..." **Diverging, specialised requirements** • "now I've got priorities we're digging down into the detail and there's more channels around that and it becomes divergent, and a collaborative thing doesn't really quite work, and competition kicks in" **Increasing competitive tension** • "I think people are starting to realise what the competitive nature of getting electrification right could be...so they're holding the cards close to their chest"

Delay inevitable competition as long as you can - Learning from our experience at the Electric Mine Consortium

It's one team at the start.

The collaborative maturity cycle matches closely that of smaller teams of individuals - forming, storming, norming, performing and adjourning. As an industry, we are going through a period in which there is a broader recognition of the need to work together. In the large but closed collaborative model pursued by the Consortium, we were the first and set the tone for those that followed, such as the Charge on Innovation Challenge in 2021.[25] Another separate but related initiative is the fantastic annual Electric Mine Conference run by International Mining, which is also helping to grow and consolidate the electric mining network.

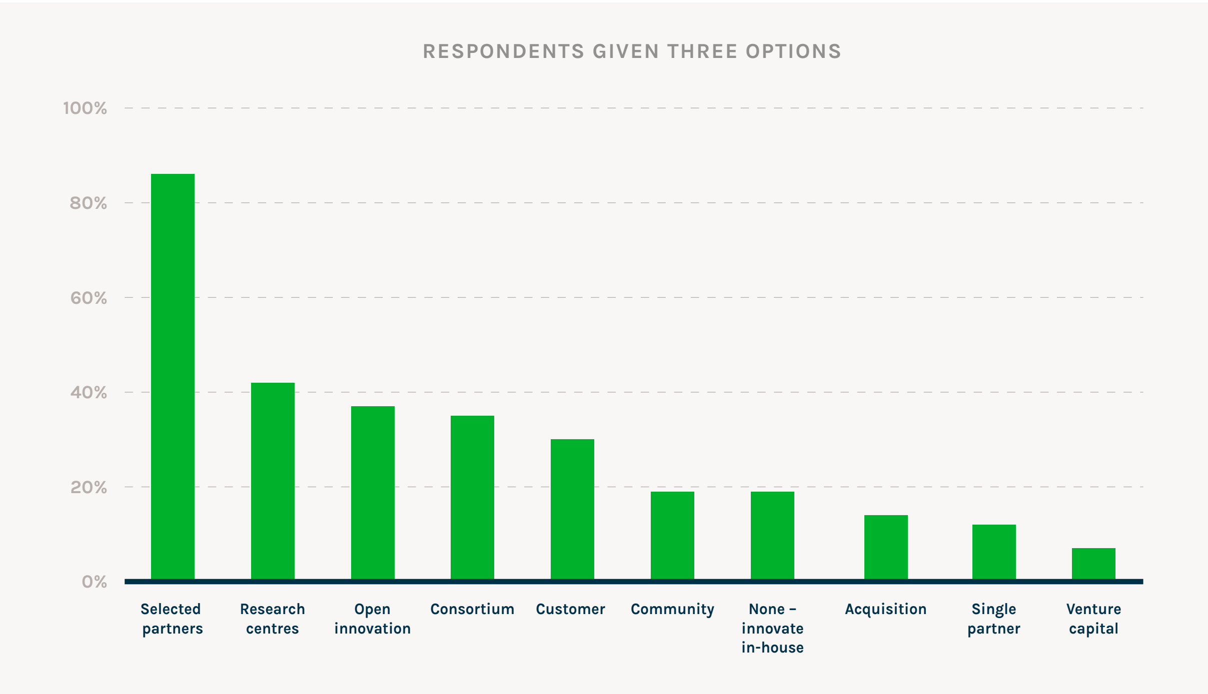
Why this has been so unusual in the past is open for debate, but it is hard to argue that the enormous social, economic and technological shifts of the past 5 years have not played the central role. When times are turbulent, we become a community and are open to broader collaboration and rely on social capital. When we feel secure, we retreat and compete as smaller tribes. So, it is likely that collaboration will continue but the approach will evolve – and we are seeing signs of this already.

1. Smaller groups of collaborators working together in a closed partnership is one trend that has already become commonplace. Close to home, Perenti, IGO and ABB publicly released one of the more impactful industry reports in recent memory, focused on the study for a fully electric Cosmos mine in Western Australia.
2. Miners and manufacturers share many possible areas for deeper coordination and collaboration, many of which we have identified through the Consortium's work. Examples include working to develop better operational integration and readiness, as well as codified product co-development processes with the roll-out of this new platform of technologies. Recent examples of partnerships are those between Sandvik and Barminco, Gold Fields and Epiroc, and Newmont and Caterpillar.
3. We may begin to see geographically focused collaborative groups who are aligned through shared local challenges. A great example of this is the decisive shift towards decarbonisation, and the concomitant investment in skills and infrastructure required, in the Gold Fields of Western Australia.
4. There will be ongoing collaborative benefits from working across country boundaries in a bilateral sense, for example, between Australia and Canada. Canada is ahead in the study and deployment of electric equipment, whereas Australia is leading in its design and development of high renewable microgrids.

25 Austmine

5. Physical trials are another area that we attempted to progress as a collaborative initiative through the Consortium, but which has to date tended to be funded and implemented by a single miner and/or contract miner with the insights shared. Larger scale trials with co-investment across several miners is a great potential model to share the costs and risks of investing in the more expensive early generations of electric equipment.
6. The physical space is a necessary complement to virtual collaboration. The Australian Automation and Robotics Precinct (AARP) is an incredible resource for the Australian industry, long sought after but finally available. Over the past four years there have been ongoing discussion and strategies among the companies to fund or provide physical test facilities outside of core production areas. Newcrest offered unused sections of their Cadia mine, BHP looked at a global model of test mines, and OZ Minerals worked closely with the South Australian government and partners to try to get a test mine started near their operations.

Following the EMC, what partnering and collaborative approaches will you use to accelerate decarbonisation in your business?



Source: EMC survey 2024

All of these future collaborative models are likely to progress, and some will become commonplace. But what have we learnt from the Consortium's work that could be applied in future? Looking back at many sliding doors moments where we collectively made judgement calls is an instructive way to consider this question.

1. The structure of the collaboration will heavily influence what it is able to do. The Consortium was bound by a commercial contract with the management services of the Consortium provided by Slate Advisory, a private business. This structure was adopted because it enabled rapid ramp-up of the Consortium and agile decision making. The Consortium would not have originated without this structure.

At some point the Consortium could potentially have been converted to a member owned form of organisation, much in the same way as Rethink Mining (CIMIC) or Mining3. This rationale for considering a member owned structure is the view that it could more readily facilitate direct investment in projects and commitment through time. The rationale against is the view that it is not necessary for direct investment and that bureaucracy would increase.

2. Despite many attempts, there were no occasions in which the companies co-invested in capital projects (such as long duration energy storage trials, equipment trials, etc.) via the Consortium. We believe there were several factors that contributed to this reticence. The first was the lack of roadmap imperative. For example, a joint proposal for an energy storage trial PFS was promoted heavily, but ultimately near-term targets could be met without this. The second was a combination of the free-rider effect and IP constraints.

   Significant direct investments in trials were by smaller groups outside the Consortium structure directly with OEMs. Ultimately for direct invest to occur separate JV structures for each project would need to be set up. This has been the case even for broad member owned organisations.

3. In the end, what was the right size for a group of companies with the objective to accelerate the electrification of the industry? Getting the size right is a balance but is also a function of demand and operational economics. Too few companies, and the quality of resources required cannot be supported, the sustainability of the model is fragile, and over time thinking can become ossified. If the starting number of 10 had been held constant for 4 years, these issues would have manifested.

   Too many companies and the amount of administration (and organisational cost) expands significantly diluting both transformational intent, alignment of members, and potentially quality of facilitation. The peak number of 25 was at the edge of this boundary. To move beyond well beyond 25 the Consortium would have to become global, and likely restructured, with the lingering question of whether the drive for change could have been maintained.

4. The Consortium scope was global, but in practice was mostly an Australian underground mining effort. Could the EMC have become truly global with equal participants across continents? Would this have increased influence, and potentially accelerated progress, or would this have simply duplicated structures that exists such as ICMM, and diluted focus.

   An even more local, regionally based Consortium may have found better alignment, but our view is that this would have been marginal and at the expense of broader influence and relevance.

5. The Consortium considered the establishment of an advisory board many times. The case for doing this would have been added influence and top cover, potentially protecting the industry through down-turns and encouraging investment in projects.

   Ultimately, we chose not to do this because of the additional layer of organisation, and because this would potentially usurp the direct influence of member companies who were our priority.

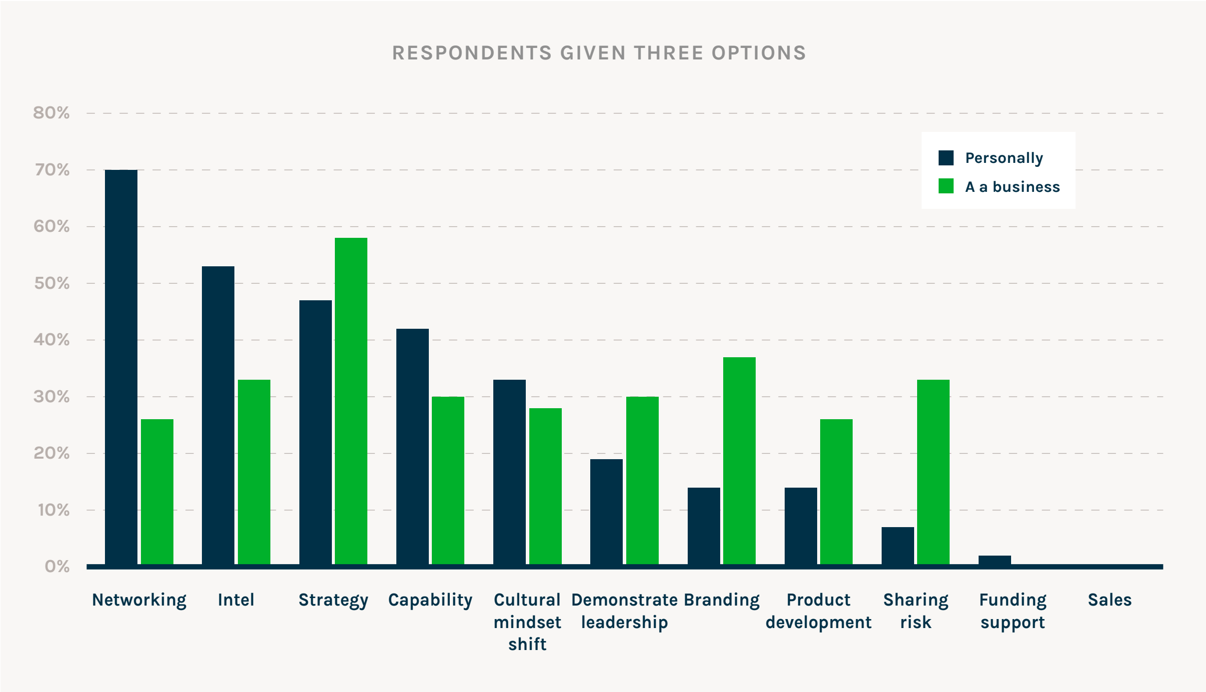
6. What was the right scope – did the evolution of the focus areas help or hinder the collaborative effort in the key areas? There is a strong case that ongoing stability in the key areas would have been a good thing to do – for example, limited to Energy, Equipment, Business case/ Valuation, and Marketing/ Branding.

   There is equally our strong experience in strategy and innovation, wherein once an entity stops searching for new horizons, it starts to ossify and lose touch with the external environment.

Ultimately, attempting to navigate the complexity of the industry in a rapidly shifting environment required a very clear purpose and focus. This was evident in the initial few years and perhaps less so as it went on. We were structured to be agile, move fast, deploy high capability resources, and be entrepreneurial. The focused challenge demanded this, and existing industry bodies catered to the alternatives.

What we achieved, and what was a radical departure from the past, was in building a safe space and community across company borders – and this is likely to be one of the most lasting contributions of the Consortium to the mining industry.

What are the biggest benefits you got out of the EMC?



Source: EMC survey 2024

Chapter 3:
EMC as Bell Labs

"The evolution of EMC ideas – maturity phases and giving people the freedom to be creative."

EMC through the years

What characterised the Consortium was the ability to create a safe place in which individuals from different companies, across miners and suppliers, felt able to put forward big ideas and see them tested, and in many cases progressed, by their peers and traditional competitors. From the start, there was an incredible enthusiasm and the aspiration to drive industry change, combined with an openness that goes against many industry stereotypes.

In the initial months, very few people knew anyone else well, let alone had a working relationship with them. As the years went on, relationships deepened to a level of personal comfort and trust that is hard to replicate, and that has fundamental value in its own right. It is surprising how many of the individuals remained consistent through this time.

Looking back through the years, it is clear to see in retrospect a maturity cycle that we collectively navigated. The group started with the sense that something was going on that companies needed to look at more deeply. It shifted quickly to a diagnostic and opening minds process with the State of Play: Electrification report. From here we aligned on a commitment to the Consortium initiative, formulated a roadmap and work streams. For each company and individual, achieving the desired visceral understanding of the necessity of electrifying came at different points. It is finishing with the handover to delivery teams internally – which is a natural evolution of strategic transformation cycles.

Commercially, this maturity process was simpler but more emphatic. It began with a dynamic openness through each business to establishing a work process and environment that was universally accepted as a good approach, before progressing to being more protective and guarded as competency developed and competitive realities came to the fore. Once people see a clear pathway to value, competition becomes inevitable.

In a relatively short amount of time, participants in the Consortium conceived of and attempted an enormous amount of creative, innovative and ambitious projects. The analogy to Bell Labs is a nice one – in a lot of ways, many of these ideas were before their time and won't be properly realised until mines themselves are largely electric. In the same way as Bell Labs is often found to be the starting point for many transformative ideas, it would be no surprise if in the world of mine electrification, many big shifts in the next 10 years can be traced back to the work of individuals in the Consortium through the years 2020 to 2024.

2020: Awakening

- Origination: Slate Advisory and State of Play's partnership with FBI-CRC, Project 412 and METS Ignited was the starting point. Jacques Eksteen, Paul Lucey and Adrian Beer were instrumental in working through the underlying rationale for electrification and the concept itself.
- Electrification report: Broad industry engagement to research the best way forward to decarbonise mining, finding alignment on the value and roadmap for electrifying all new mines within a five-year timeframe.
- Virtual working sessions: Throughout the covid years, hundreds of people worked together using Zoom, Teams and the virtual whiteboard, Mural, to ideate, collaborate and initiate new concepts and projects.
- Identifying central challenges: From a long list of 12 potential challenges to electrification, the group selected 5 to focus on through several weeks of discussions. These became the working groups and evolved to some extent through the years.
- Establishing working group leads: Each miner was responsible for leading one working group, working through who would lead what was a delicate exercise of aligning strategic relevance and workload equity. This took several weeks and dozens of phone calls.
- METS Ignited: As the sole government participant through the entire life of the Consortium, METS Ignited played an important role in facilitating the dialogue between companies and governments, as well as helping support local industry involvement.
- International Mining and the Electric Mine conference: Very early in the piece we established a great ongoing partnership with the team at International Mining, initially to avoid confusion between similar focus, but over time sharing much insight in both directions.
- Retrofit industry support: Provided heavily discounted, in some cases free, participation to new local Australian retrofitting businesses ZERO Automotive, Safescape and VivoPower who were trying to develop technology, scale businesses and sell equipment in a very tough environment.
- Marketing: Brought all marketing teams from participating companies together in a monthly session to align on messaging and support each company getting the most from their investments – leading to dozens of conference presentations and media interviews.

- Early leaders: Gold Fields and OZ Minerals were very ambitious in the early months, investing heavily in big trials and software development, respectively. These trailblazing companies, and the leaders within them, really set the tone for everyone else.
- State government regulator: Several representatives from companies prepared for, and attended, sessions with the state mining regulator to discuss the treatment of electric equipment underground and possible regulatory pathways going forward.

2021: Ambition

- CEO joint statement: The CEOs of the six mining companies drafted and co-signed a public statement endorsing the Consortium's objectives of accelerating the shift to zero particulate and zero carbon mines.
- Fleet transition plans: The light and auxiliary equipment working group established a 3-year investment and fleet transition roadmap across the Consortium in which there would be 90 vehicles across 3 sites within 3 years.
- Gold Fields universal charger: As leaders of the infrastructure and charging group, Gold Fields developed a concept for a modular, mobile universal charger for all equipment types in the absence of any charging technology in the market.
- OZ Minerals crowd simulation: Without any existing providers being able to deliver electric mine simulations, OZ Minerals ran a global crowd challenge to identify and develop an electric mine simulation platform which was ultimately won by SET and SimGenics.
- Blackstone Minerals life-cycle analysis (LCA): Developing a world-first zero carbon nickel mine in Vietnam, Blackstone Minerals led and shared a full life-cycle analysis process with Minviro, setting the benchmark for low-carbon mine designs.
- Long duration energy storage EOI: Seeing LDES as the central challenge to achieving high renewables remote mines, EMC miners led a global expression of interest to identify the best LDES technologies and providers. This led to BASF sodium-sulphur battery and VSUN vanadium flow-battery pilots at IGO, and an Energy Vault gravity storage concept proposal at Gold Fields.
- Legal agreement: 10-month process to negotiate a binding commercial arrangement between current and future participants in the EMC, driven by the individual senior legal counsel of each major mining and supplier company.
- Gold Fields Artisan Z50 trial: The first major trial in Australia of a fully electric underground haul truck was conducted by Gold Fields at great expense, and the learnings and operational data of which was shared with all miners in the Consortium. The driver for Gold Fields investment was primarily the reduction of DPM underground.
- Virtual trials: Due to the multimillion-dollar cost of running trials, the Consortium participants established the "virtual trials" concept, by which all data from trials would be shared such that any trial would have the same value to members regardless of where it was conducted.
- Processing and energy shifting: Discussions about a processing stream continued, driven by substantial advances by OZ Minerals with variable speed comminution and Bellevue Gold's use of a 1.3 mtpa mill to utilise solar, even though mine operations required only 1.1 mtpa.
- Virtual Battery Park: In partnership with Consortium miners, the FBI-CRC and the University of Western Australia, established an initiative to create a full virtual twin of the proposed storage trials to capture and share trial results, allow future battery suppliers to join and contribute, demonstrate and present technology in an accessible manner, while also encouraging further support and funding.
- Skills working group: Led by Gold Fields, a skills working group was established with a charter, governance and strategy to identify and overcome the expected skills gaps for electric mines.

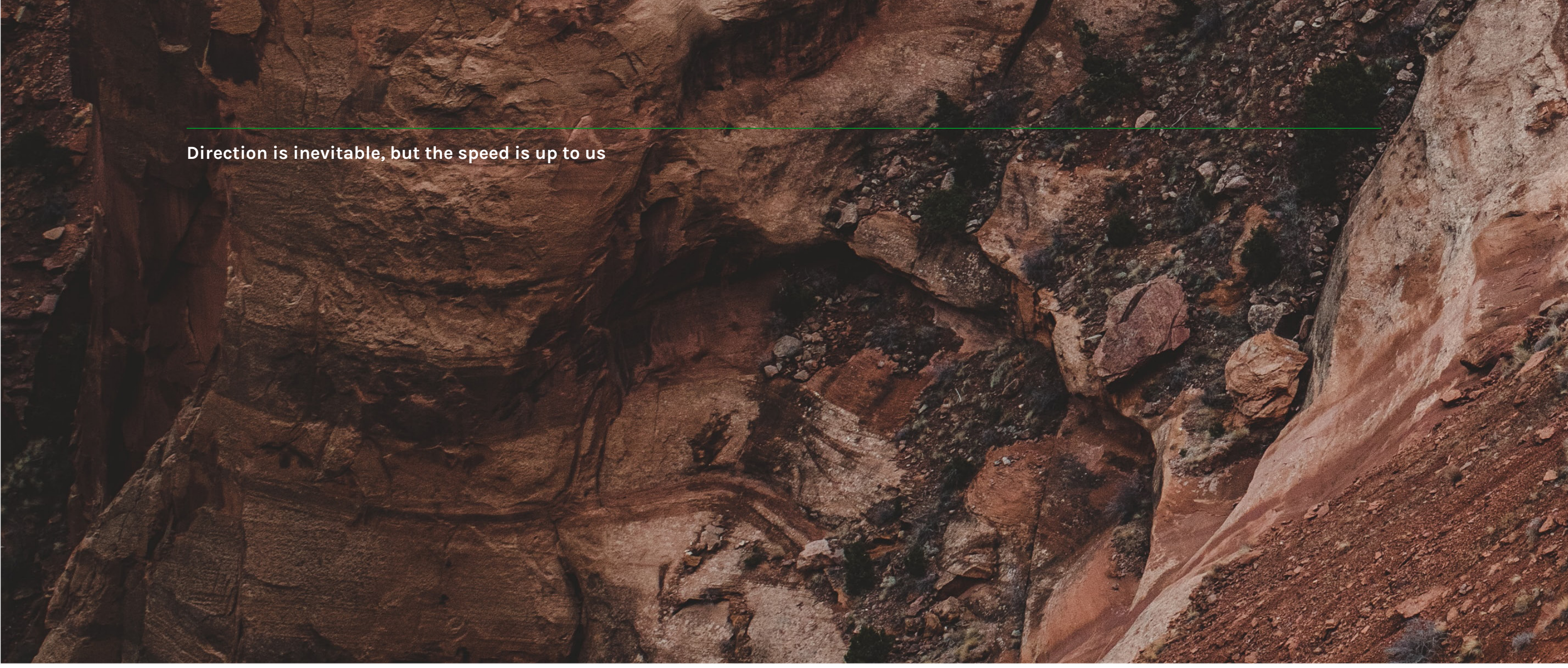
2022: Growth

- Gold Fields Gravity Storage trial: Progression of LDES EOI to implementation study of Energy Vault gravity storage pilot at Gold Field's Agnew site, for large scale roll-out of 80 – 100 MWh battery at St. Ives site to allow it to achieve 94% RE. Ongoing funding discussions with ARENA and MRIWA, together with industry knowledge share via Consortium, universities and CRCs.
- IGO Vanadium Flow Battery trial: IGO selected the VSUN Energy LDES battery to trial following the Consortium's LDES EOI and supported by $3.7m of funding from the federal government, applied the battery trial to the Nova site's bore pump.
- IGO Sodium-Sulphur battery trial: IGO also selected the BASF as Australia's first sodium-sulphur LDES battery and progressed to detailed study through 2022 and was commissioned in mid-February 2023 in a successful trial of the technology.
- AWS data platform: Unique partnership between AWS, Nukon and the EMC to co-develop a big data platform to support the "virtual trial" objective of the Consortium's participants.
- Rokion data share: Evolution Mining facilitated the data share of deep, real-time data sets from the Canadian electric vehicle manufacturer, Rokion, with EMC participants via the AWS and Nukon platform.
- Long haul EOI: Ran a global expression of interest to understand the zero carbon long haul technologies and suppliers to provide decarbonised logistics to several remote mine sites within the Consortium. Proponents included behind the meter renewable project concepts, infrastructure and charging elements.
- Janus electric highway: OZ Minerals studied at length the concept of building a hydrogen highway between their South Australian mines and the Port Augusta port, before deciding battery electric trucks were a better option. Established an Australian-first trial in mining with the local retrofitting start-up, Janus.
- Videos: Worked with most of the EMC participants, and their key individuals, to develop public videos describing their work with the EMC and highlighting to the industry the achievements of their teams and businesses in these technical areas.
- Carbon working group: Established by IGO, Iluka and Evolution Mining to understand how miners could progress beyond static, and MS Excel-based, carbon data management.
- Carbon survey: Carbon working group conducted a survey of EMC participants to identify best practice carbon data management, only to find all were using MS Excel, which led to a collective EOI process to find better pathways forward as an industry.
- SET and SimGenics electric mine simulation: Following the electric mine simulation crowd challenge, OZ Minerals selected the companies SET and SimGenics to collaborate to develop a fit-for-purpose electric mine simulation platform. The outcomes of the work were presented to the EMC participants.
- CEO forum #1: Brought most of the Consortium's mining CEOs together in a working session to identify the industry-level challenges to electrifying mining and to identify initiatives with the potential to address these challenges. The outcomes from this session were to focus on policy and skills.
- Cross-industry skills forums: Led by METS Ignited, the Consortium convened several open cross-industry skills forums with training organisations, universities, TAFEs, technology providers and corporates from the industry to discuss the looming skills challenge, identify gaps and to develop ways the industry can work together going forward.
- EMC site visits: Members offered many site visits for others to go see, such as Energy Storage – EDL and Agnew site visit, solar, BESS, sodium sulphide battery at IGO; Heavy Haulage Equipment including trucks, loaders and charge infrastructure – courtesy of Gold Fields; Light and ancillary equipment – LV, ITC, DL422iE longhole drill, charge infrastructure across many sites; and several others including AARP, EPCA, light vehicle testing visits, etc.

2023: Influence

- Policy group initiative: In response to request from member CEOs during the CEO forum, we established an EMC Policy Working Group to develop a charter by which the group would act to influence policy, as well as to develop a policy platform that was agreed across all companies. These policies were designed to accelerate the electrification of mine sites across the Consortium.
- Green accreditation: Led by Blackstone Minerals, the Consortium worked together in a cross-industry working group with IGO and other miners in the Consortium, to investigate ways to uncover a price signal for carbon in minerals – i.e. a green premium, particularly for nickel. Participants in this were Circulor, a supply chain transparency business, and Fidelity, a major global investor in the resources sector. This initiative was initiated via the policy working group and ultimately interrupted by the supply shock from Indonesian nickel in early 2024.
- AWS carbon platform: 12 months of discussions between AWS and EMC to co-develop a global Scope 3 carbon data and management platform to support the industry (initially EMC participants) to share resources and data for carbon disclosure and abatement options. Predicated on the premise that mines are a source of Scope 3 emissions for the rest of the global economy, and such a platform would help with provenance and accreditation of raw materials.
- Voluntary DPM code of practice: The policy working group identified targets to reduce the level of DPM underground as one of the most important levers to accelerate the electrification of sites. Safe Work Australia had released a consultation paper in which a health-based DPM level of 0.015 mg/m^3 was proposed as the basis for a new national exposure limit (far below current practice). Sites could only achieve the limit through electrification. Members proposed a voluntary DPM code of practice be drafted and adopted by Consortium members prior to a Safe Work Australia determination.
- Kathleen Valley shared infrastructure initiative: The policy working group identified shared infrastructure as a major policy focus - the largest value case was between the three new mines in the Kathleen Valley. Bellevue Gold, Cosmos and Liontown were all within 5 – 20 km of one another. This initiative expanded to include over 10 miners from inside and outside the Consortium, as well as several observers looking to apply learnings to other regions.
- Gulf Country shared infrastructure initiative: Observers from the Kathleen Valley process included miners operating in Queensland's Gulf Country in the Mt Isa region, MMG, South32 and Evolution Mining. The main driver was the Copper String transmission project and the large number of remote or semi-remote mines all looking to decarbonise quickly – the initiative was interrupted by market conditions at an early stage.
- Ravensthorpe shared infrastructure initiative: Arcadium Lithium were observers of the Kathleen Valley work, and on this basis, worked with the Consortium to develop a concept for sharing a new renewable power facility at their Mt Cattlin mine with the township of Ravensthorpe.
- CEO forum #2: We again brought most of the Consortium's mining CEOs together for a second forum, 12 months after the first. The directive coming out of this was to focus heavily on increasing the supply of battery electric heavy underground load and haul equipment through working with the incumbent OEMs, Epiroc and Sandvik, concertedly at a senior level.
- Offsite trials model: Understanding the difficulty and risk in testing prototype equipment on operating mine sites, the Equipment and Data working group developed an off-site trials concept for roll-out in which technical readiness is undertaken off-site, at much lower cost and risk, and operational readiness is completed in a far shorter time on-site.
- Australian Automation and Robotics Precinct MoU: To support the off-site trials model, the Consortium entered into a partnership agreement with the newly established AARP in Perth, Western Australia. This facility is an incredible resource for the mining and services industry that we were working hard to make a central aspect of the industry's electric fleet transition.
- Long duration energy storage EOI #2: The Energy Supply and Storage working group delivered a second expression of interest to update the landscape, roadmap and associated technical and financial assumptions to feed into high renewable project designs and co-investment. Ten LDES technology suppliers pitched their technologies to the combined EMC membership, including specific technical and commercial responses to a site use case.

- Joint LDES pre-feasibility study: The Energy Supply and Storage working group negotiated a funding model to deliver a joint long duration energy storage pre-feasibility study that would answer varied questions relating to the different use cases. Despite 6 – 12 months of negotiations, the study was not ultimately approved.
- EPCA battery electric 100-tonne haul truck: The Consortium worked with the EPCA team, and its founder Clayton Franklin, to support their development as possible and to help lift the industry's awareness of their incredible technology and business. A fully indigenous-owned business, EPCA designed and built a 100-tonne battery electric haul truck in 6 – 8 months, while the major open pit OEMs are not predicting commercial supply will be available until the 2030s. EPCA already has factory capacity, and the supply chain, to produce 80 battery electric trucks a year.
- EMC and Global Mining Guidelines Group partnership: The Consortium and the GMG entered into a non-commercial partnership with the intent to disseminate the learning from the cutting-edge work within the Consortium into the GMG system which is designed to take such knowledge and produce the detailed standards and guidelines critical to the safe and effective operation of the global mining industry.
- Energy management system EOI: The Mine Design and Infrastructure working group identified energy management systems as a crucial technology to support the operation of mine operation microgrids that are powered by intermittent renewable energy and operated by electric equipment. Over 20 global companies submitted proposals. Ampcontrol was the original catalyst for the working group studying this question, outlining in detail the future scenario of hundreds of pieces of electric equipment requiring real-time sensing and control to manage the intermittent energy and charging requirements of the site.
- PXiSE and Yokogawa, EMS proof of concept: Following the EMS EOI, Yokogawa and PXiSE were selected to develop proposals for EMS concepts at the South32 Cannington and IGO Cosmos mine sites. The proposal discussions and scoping were shared with Consortium participants.
- Joint ARENA funding application: Following the announcement of the ARENA's Powering the Regions Industrial Transformation Stream, most of the Consortium's miners worked together to develop fleet trial and transition concepts for submission to the ARENA fund. By this point, it had become abundantly clear to all in the Consortium that the upfront capital premium of battery electric equipment was too high to allow companies to invest. Therefore, the potential of the ARENA funding was enormous – this work and dialogue with ARENA is ongoing.
- Carbon Compass proof of concept: The Carbon Working Group introduced the Engie venture-backed software business, Carbon Compass, to the Consortium. Their offering was unlike anything in the market with its use of deep AI, neural networks and a focus on energy cost optimisation – leading IGO to quickly step forward to fund a proof of concept at the Nova mine site.
- South32 Caterpillar R2900XE trial and data share: South32 conducted a trial of the R2900XE hybrid loader at its Cannington site and held a very detailed presentation to the Consortium, sharing operational data and their business case outcomes. From this trial share, four other Consortium companies ordered this equipment without requiring a trial, saving a lot of time and money. These companies were MMG, Gold Fields, Barminco and IGO.
- Carbon Expert Q&As: The Carbon Working Group began holding expert Q&A sessions from the beginning of 2023 with the insight that sustainability regulations and reporting rules were changing too fast for any one team to stay abreast of everything. Sessions included LCAs with Minviro, Climate Risk Assessments with Engie, Carbon Offsets with Carbon Neutral, ISSB S2 updates with Decarbonate, supply chain provenance with Blockhead, ACCU markets with ANU's Andrew Macintosh, ASRS regulatory shift with Energetics, and many others.
- Skills platform partnership: Developed a concept and partnership with NIIT to develop a skills and training online platform, building on a previous $20m funding round from the EU, to support the upskilling of existing workforces on sites moving to electric mines. This had a long 6 – 12 month gestation, but ultimately could not settle on a commercial model.
- Electric mine valuation study: An EMC member commissioned a detailed financial valuation of one of its mines with the commercial modelling business, Model Answer, comparing the diesel valuation vs. a fully electric valuation. The model was handed over to the company, providing them with a tool to quickly determine the value of electrification scenarios. All non-confidential insights and outcomes of this process were shared with Consortium participants.



2024: Change

- Collective decarbonisation roadmap: All mining participants in the Consortium prepared detailed presentations of their decarbonisation roadmaps, including their underlying assumptions and calculations. The discussions, analysis and sharing were focused on the asset level which provided an immense degree of insight across different locations, grid supply, commodity-mix and mining method. Summary outcomes of this process are shared in the decarbonisation roadmap chapter of this report.
- Shared trials: As much of the commodity market suffered a downturn through late 2023 into 2024, many companies were unable to make the capital available for large scale trials of electric equipment. As a result, many companies in the Consortium began developing a deliberate shared trials model in which equipment would be purchased collectively (potentially with support of ARENA funding) and then moved across various sites of a multi-year period.
- Sandvik supply initiative: Australian miners prefer a 65t underground haul truck, where North American and European underground miners prefer the 50-tonne class. As such, Sandvik and Epiroc prioritised the 50-tonne size when developing battery electric haul trucks. The Consortium's miners worked together to engage with Sandvik to identify ways, and potential commercial models, by which the 65-tonne class of haul trucks could be produced and brought to Australia more quickly. The key to this being reducing the realised upfront capital cost premium. This impasse remains difficult to overcome as Sandvik maintains the trucks are ready for order while miners maintain the trucks are still prototypes that need further trialling.
- Kwinana Industry Council and EMC forum: The two groups held a forum on the basis that collaborating on common initiatives can allow both groups to accelerate the objective of decarbonisation and competitive advantage for their members.
- IGO, Perenti and ABB Cosmos All-Electric Mine study: Building on data and insights from the past four years, the IGO leadership team determined their goal of developing the Cosmos mine as an all-electric mine. They established a partnership with Perenti and ABB to study the question, resulting in an industry first study in Australia that the group shared in the first half of 2024 with the industry as a seminal electrification White Paper. Unfortunately, the nickel price crashed before the project reached FID.
- Industry conferences, events and presentations: The EMC and its participants shared insights, content and learnings at dozens of conferences and industry events through the years – these included several presentations each year at major annual conferences such as Energy and Mines, the Electric Mines Conference, the Underground Operators conferences, and IMARC, along with many others. The EMC team also wrote papers for conferences such as the AusIMM Underground Operators and the World Mining Congress.

"Getting around the Electric Mine conference, it was clear that as a group we knew more about electrification than the rest" - EMC member (May 2024)

- Bellevue Gold electric mine valuation model: Building on the earlier valuation model, Bellevue Gold commissioned Model Answer to work through the Consortium to establish the diesel vs. electric case for the Bellevue Gold mine in the Kathleen Valley. All non-competitive outcomes of this study were shared with the Consortium once cleansed of commercial information.
- CSIRO battery calculator: The Energy Supply and Storage Working Group partnered with CSIRO to develop an industry battery calculator to support towns and sites designing high renewable penetration projects to build on the research undertaken by CSIRO on LDES and energy economics for national reports such as GenCost. This work remains underway.
- Perenti 65t haul truck trial with Sandvik: Perenti trialled the world's first 65t battery electric haul truck in Australia at AngloGold Ashanti's Sunrise Dam and has since extended the trial to be 12 months long. All indications are that the battery electric truck is TCO equivalent with the diesel trucks and productivity is limited by running mixed fleets. Performance will improve drastically with the Sandvik Gen 4 battery which will increase range and power by 35%.
- Mine simulation white paper: Together with BHP, the Consortium drafted an Electric Mine Simulation white paper based on the simulation studies completed to date. This report is yet to be released.
- Ampcontrol megawatt charger: Ampcontrol has developed a megawatt charger for use on mine sites based in part on learnings and product development discussions held through several years as active participants in the Consortium. This is an incredible local development for Australia's manufacturing industry.
- Canadian-Australian collaboration: Given the head start that the Canadian mining industry has over Australia with respect to equipment electrification, the Consortium reached out to New Gold and Agnico Eagle and their New Afton and Macasa mines respectively, to discuss their learnings. The focus of this collaboration has been battery fires, performance, change management and operating insights.

2025 and looking forward: Transformation!

"In economics, things take longer to happen than you think they will, and then happen faster than you thought they could"
– Rudiger Dornbusch, economist

Chapter 4: The business case: Valuing electric mines

"Many factors impact the evaluation of electric mine designs – but in the end it comes down to a couple of things."

The business case for electrification – an overview

The business case for electrification is compelling. Electrification delivers a healthier, quieter, more comfortable work environment, supports the attraction and retention of people, facilitates ongoing access to capital markets at competitive rates and delivers against committed emissions reduction targets.

However, the financial return is a hurdle for many in the industry, due to the required capital investment and uncertainties around future operational performance. A typical underground mine in Australia seeking to transition from diesel fuelled haulage to battery electric haulage and applying today's input assumptions to a financial model will come up with a marginal to negative net present value case.

Our analysis of a case study mine shows that credible changes in the input assumptions create a strong positive financial return for electrification, with the net present cost (NPC) reduced to just 56% of the diesel powered equivalent.

An example of a key input is the undeniable trend of battery improvement – the next generation of batteries will be cheaper and perform better than today's. Another example is the inevitability of carbon emissions pricing, either directly or indirectly via market mechanisms. Our analysis combines credible changes into future scenarios, in which the financial opportunities from electrification overwhelm the downside risks. We are already at the point where any executive team contemplating signing off on an investment in diesel-powered load and haul equipment should pause and consider why electrified options are not superior.

A healthier, quieter, more comfortable work environment

Diesel particulate matter (DPM) in underground mines – overdue for change?

The underground mining industry has historically accepted that employees will be exposed to diesel particulate matter arising from the combustion of diesel fuel. DPM is a known carcinogen, and there is uncertainty as to what level of long-term workplace exposure is harmful to health. EMC member companies actively manage the risk via ventilation controls and monitoring of DPM exposures, and mobile equipment suppliers have made incremental improvements in vehicle DPM emissions. Electrification presents the opportunity to eliminate the risk to employee's health from DPM exposure. Unfortunately, exposure to DPM remains the accepted status quo in the underground mining industry.

Health and safety legislation in the Australian mining industry is framed around the SFAIRP principle, placing obligations on mine operators to eliminate or control risks "so far as is reasonably practicable". There are subtle variations in wording across mining legislation in Australian states (e.g. in Queensland the equivalent is ALARA: "as low as reasonably achievable"), but the broad risk management intent is consistent, and similar wording is common in global mining safety legislation. Operators are typically required to take into account the availability of suitable methods to eliminate or minimise hazards or risks, and the cost of eliminating or minimising risks.

Given the technology exists to eliminate diesel particulate matter from the underground environment, and that costs are comparable (see analysis in sections below), it is only a matter of time before the SFAIRP argument for electrification becomes compelling. Indeed, companies taking no action may soon be obliged to argue the case for why they are not removing DPM emissions from the underground environment.

Less noise, less dust, less heat

The feedback from underground miners that have trialled and operated battery electric vehicles is very positive – the BEVs are quieter, generate less dust, and generate less heat than their diesel-powered equivalents. Much of the feedback is qualitative, coming directly from the employees working in and alongside the BEV equipment. Recently, gold miner New Gold have quantified the improvements via testing conducted at their New Afton site in Canada. In a paper published by the Canadian Institute of Mining[26], they were able to measure a 3°C temperature reduction from operating BEVs vs diesel equivalents in a ramp environment. Respirable dust samples taken whilst operating BEVs were at negligible background levels whereas the equivalent sample taken during diesel equipment operations were at 22% of exposure limits.

Employee noise exposures are typically controlled via the use of PPE, the lowest level of risk control. BEVs present an opportunity to eliminate a source of noise. The mining industry has long faced high rates of noise-induced hearing loss. Estimates in 1976 found that 70 – 90% of miners would develop hearing loss by age 60, with a 1996 update showing 90% would experience impairment by age 50. Analysis of audiogram records from 1981 – 2010 reveals a persistently high prevalence of hearing loss in mining. A recent study confirms that mining has the second-highest prevalence of hearing loss among industries, at 24%, only behind the railroad industry.[27]

Heat generation is also a key constraint for many deep mines, and the combustion of diesel fuel with its inherent heat losses is a major contributor. Once again, the improved thermal efficiency of electric motors presents an opportunity for a step change reduction in heat loads.

The combination of eliminated DPM, less noise, less heat and less dust create a step change improvement in underground working conditions that materially improve employee working conditions. The early movers stand to create a competitive advantage in attracting and retaining employees, and workplace expectations will change with late movers left behind.

Less ventilation required

DPM and heat are primary constraints on the calculations for ventilation airflow required for a safe and healthy underground environment. Removal and/or reduction of these constraints creates the opportunity for reduced ventilation airflows. Early experience from Canada, shared with members of the EMC, is that reductions of 20% are immediately accessible. The most direct benefit is the reduced operating costs for the ventilation fans, where even small changes in flow can generate major electricity consumption savings. The impacts of the savings are reflected in the analysis below.

However, in green fields and major expansion scenarios, there can be even greater savings via reduced sizing of primary and secondary fans, and mine design changes such as a reduction in ventilation shaft infrastructure.

The environment – meeting the industry's commitments

The mining industry's contribution to global carbon emissions, and commitments to reduce those emissions, have been explored in previous sections of this report. A clear picture has emerged of companies needing to accelerate progress to meet their interim 2030 targets and deliver against their roadmaps to net zero emissions. Having committed to emissions reduction targets as part of their business strategy, the business case for electrification from an environmental perspective is straightforward – it is doing what is required to deliver on the company's commitments.

The direct financial impacts of meeting – or not meeting – emissions reduction targets are considered in later sections of this report. However, companies that do not meet their commitments are also exposed to other risks, for example:

- Reputational risk as a slow mover – with adverse media coverage and impacts on the ability to attract and retain employees.
- Risks of being less attractive to investors, including potential to be excluded from institutional investor screening, with a long-term impact on share price.
- Ultimately, a risk to the environment if a large industry sector is moving slower than required to limit global temperature rises.

26 E. Acuña-Duhart, J. Le, M. Levesque & P. Le (25 Apr 2024): New Afton Mine diesel and battery electric load-haul-dump vehicle field test: Heat and dust contribution study, CIM Journal

27 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5848488/

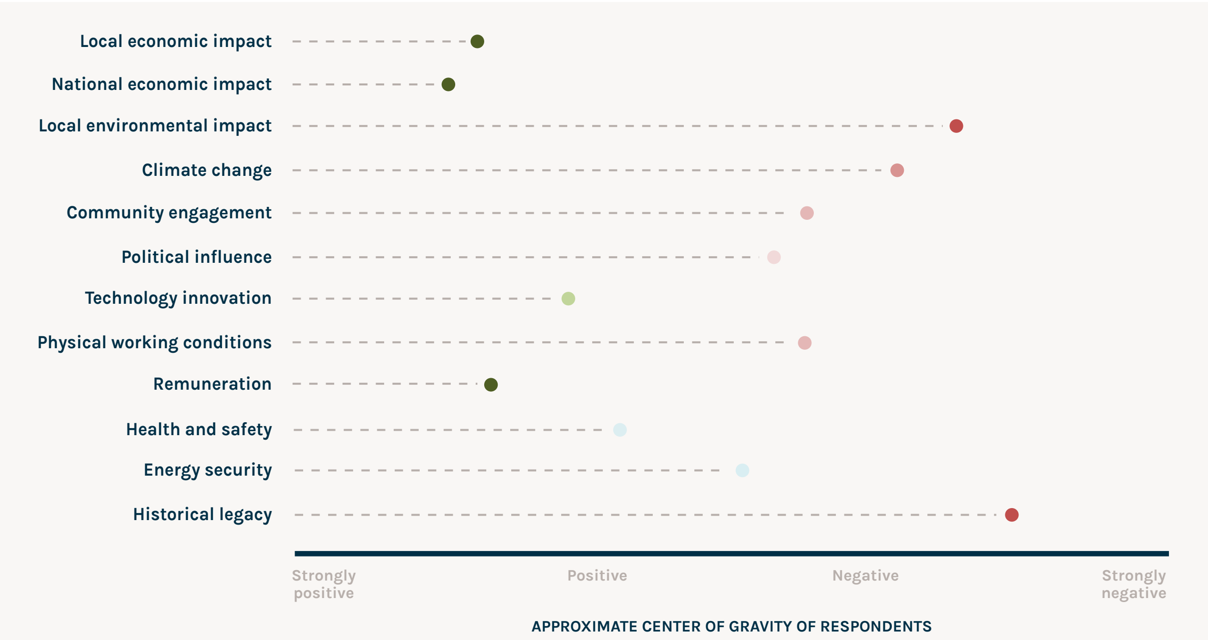
Attracting and retaining people

The 2023 State of Play survey asked respondents how mining is viewed by society in several areas. The response showed that mining is viewed strongly negatively in relation to environmental impact and climate change. The reality is that mining companies have committed themselves to stretching emissions reduction targets, and through initiatives like the EMC are actively investigating how best to proceed. However, this reality is not cutting through with the public who perceive the industry as a slow mover.

A flow on impact from the societal view of the industry is a challenge to attract and retain people. For a mining company, a constraint on attracting and retaining talented people has real bottom-line impacts including increased costs due to turnover, an inability to meet production goals due to roles being vacant, and constraints on the ability to improve and innovate. The bottom-line impacts are quantified in the case study presented later in this section.

Leading companies in the mining industry can overcome these challenges and set themselves apart from their peer groups by leading in electrification. The implementation of electrification demonstrates a commitment to emissions reduction, and the creation of a better working environment.

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



Source: State of Play survey 2023

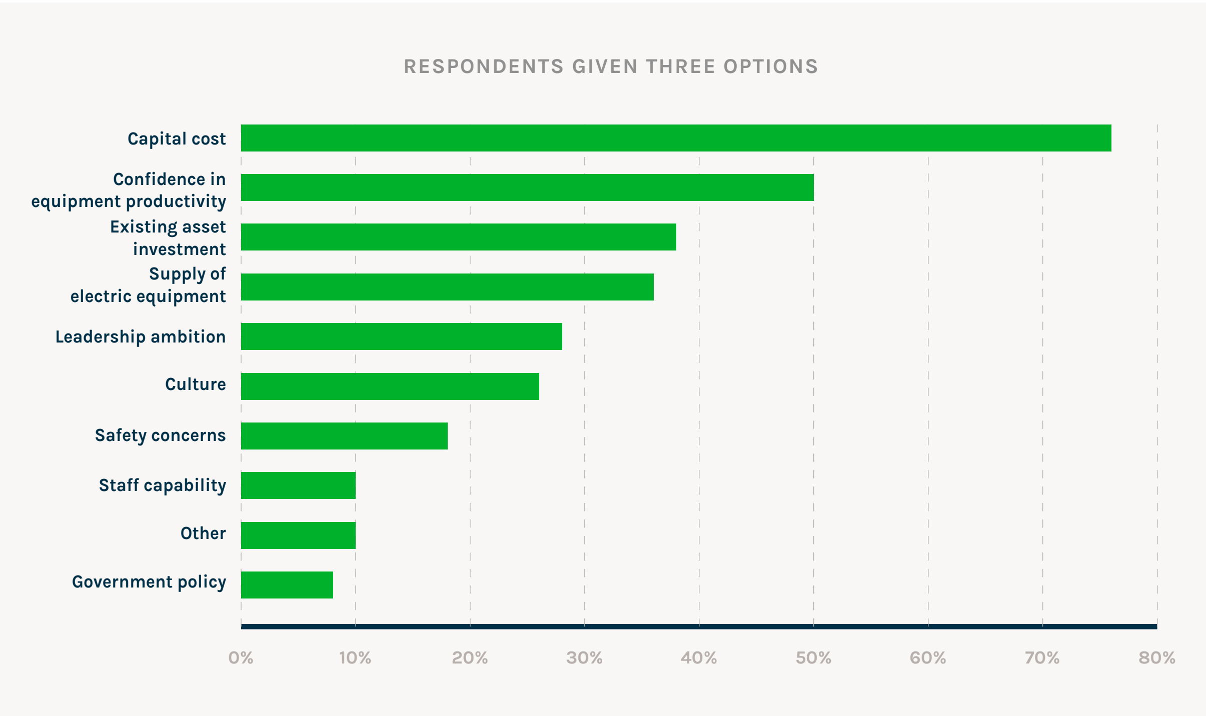
Access to capital at competitive rates

The EMC's discussions with investors in the mining industry indicate that companies that are not committing to, and delivering on, emissions reduction will be gradually filtered out for investment consideration. For the remaining potential funders, emissions reduction performance is only one of many risks considered when pricing debt. However, the trend is inevitable and over time the pool of capital available to mining companies who are not delivering on emissions reduction will shrink. The natural impact of this trend is for a differential in cost of capital to open between the fast and slow movers.

The financial case for electrification – lowering the hurdle

Whilst the social and environmental case for change is compelling, companies must be able to answer the question "well ok, but how much will it cost?". A traditional approach to project valuation creates a hurdle to electrification – in fact, EMC surveys have shown that cost constraints are the biggest hurdle of all.

What are the most important barriers to electric equipment adoption in the mining industry?



Source: State of Play change management survey 2024

Put simply, electrification requires the investment of capital – the scale of which is relatively certain – for operating cost benefits that are less certain. The future uncertainties present both opportunities and risks, but the industry tendency is to be drawn towards the downside risks and to delay the decision to invest. EMC surveys consistently show that the risks of electrification that most concern EMC members are the operational performance of the new technology (will it deliver the tonnes?) and the supply of the equipment itself (is it available and when can I get it?)

There is also a tendency to rely on static valuations, applying a set of input assumptions that are known today or are reasonably foreseeable. In reality the environment is changing rapidly, both in terms of technology improvement and external levers for change like carbon pricing. Given mine capital investments typically have timeframes of at least 10 years, analysis of investment in emissions reduction lends itself to a more dynamic scenario-based approach.

The analysis below starts from a typical base case - a static financial case for electrification of an underground mine applying inputs we know today – resulting in a marginal financial outcome. We then articulate three credible future scenarios and flex key value levers, resulting in a financial outcome for electrification that becomes overwhelmingly positive.

The EMC financial model

Over the life of the EMC, members have consistently provided feedback that analysing and presenting the financial case for electrification is one of the key enablers to progress. To support members, the EMC developed a financial model of an electric mine to enable quick, high-level analysis of electrification as an option. The EMC worked with Western Australian company Model Answer to develop the model and applied the model to two real-life case study mining projects.

For each case study, the starting point was a mine project at study/early execution phase, with the study based on diesel load and haul. The companies wanted to analyse how the financial value of the mine would change with a shift from diesel to battery electric vehicle (BEV) load and haul. The model also generated insights into the leverage of model inputs and provided a direction for further analysis and improvement.

A Net Present Cost (NPC) approach was used to compare options. To simplify the analysis, only the differences in costs between the diesel and BEV cases were considered (e.g. processing costs were excluded as they were unchanged between the two options).

On completion, the confidential information of the EMC member companies was removed, to allow the overall insights to be shared across the EMC.

Levers that can be flexed in the model include:

- Mine plan and schedule – volumes, schedule and mine life
- Operational performance of load and haul equipment (cycle time, reliability etc)
- Load and haul costs (capital, operating and maintenance costs)
- Labour costs
- Electrical infrastructure costs
- Energy costs both diesel and electricity
- External factors e.g. carbon price and green price premium
- Energy supply renewables % (flowing into emissions calculations)

A Case Study of an Australian underground hard rock mine

The case study presented here is based on a real mine project "The EMC Mine" with the following characteristics:

- Underground gold mine in Australia.
- 12-year life, ore production averaging 1.8 Mtpa producing approximately 200 koz gold pa.
- Truck haulage to surface via a decline.
- Batteries are supplied separately to the vehicles in the form of Batteries as a Service (BaaS)
- Renewable energy supply in place – combination of solar and wind to generate 70% renewable energy (typical achievable at remote mine site).
- Charging stations added underground and progressively moved to suit BEV fleet.

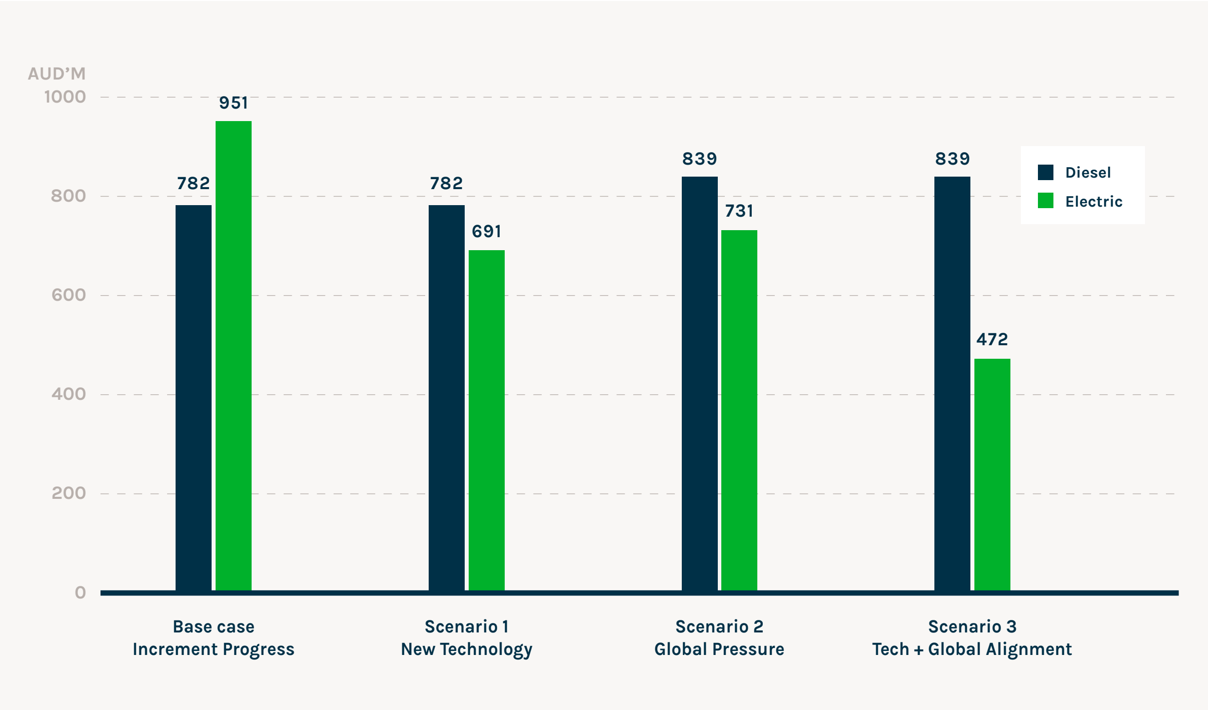
The Base Case – incremental progress

The Base Case presented here is a typical starting point for a mining company analysing a diesel vs BEV financial case. It takes the known technology and external environment today and uses those inputs to generate an NPC delta. The key inputs are show in the assumptions table. BEV cost and performance are as supplied by an OEM manufacturer in 2024. Diesel supply is tax free (with the benefit of the diesel fuel rebate in Australia) and there is no price on carbon emissions – typical for an Australian mine sitting outside the Australian Safeguard Mechanism. A saving in ventilation power is assumed to be achievable.

The outcome is a 20% increase in NPC in the transition from diesel to BEV. Emissions are reduced by 60% with the benefit of high % renewable electricity. The base case is in many aspects a worst case for BEV implementation, however a 20% increase in NPC is arguably an acceptable financial cost for the non-financial benefits described above.

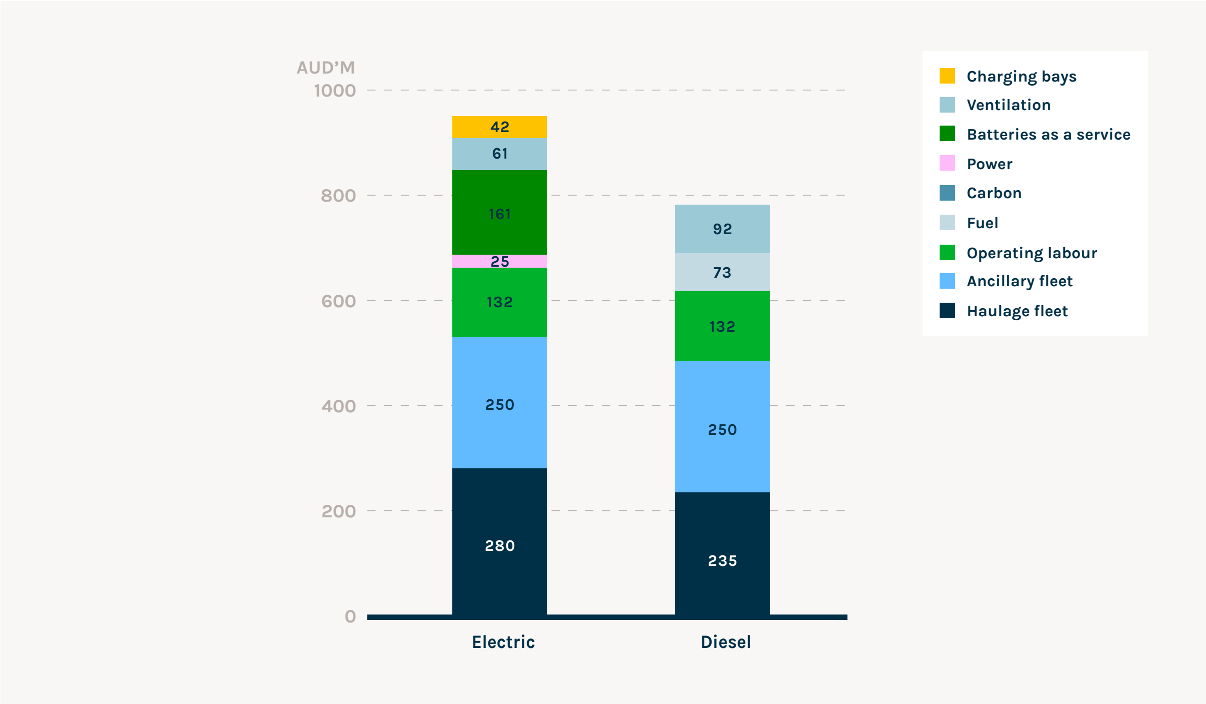
The key driver of the outcome is the capital cost of the BEV equipment. Quotes for supply into Australia are in the order of 50% higher than the equivalent diesel machine, and that is for a BEV with no battery. Batteries need to be either purchased by the miner, or more commonly leased as "batteries as a service" (BaaS). The reduced operating cost of BEVs, resulting from more efficient energy use and lower lifecycle maintenance costs, are not enough to offset the increased capital. In addition, capital is required to set up the BEV charging infrastructure.

Net present cost (NPC) of base case and scenarios



Source: EMC financial model and analysis

Net present cost of base case diesel and electric options

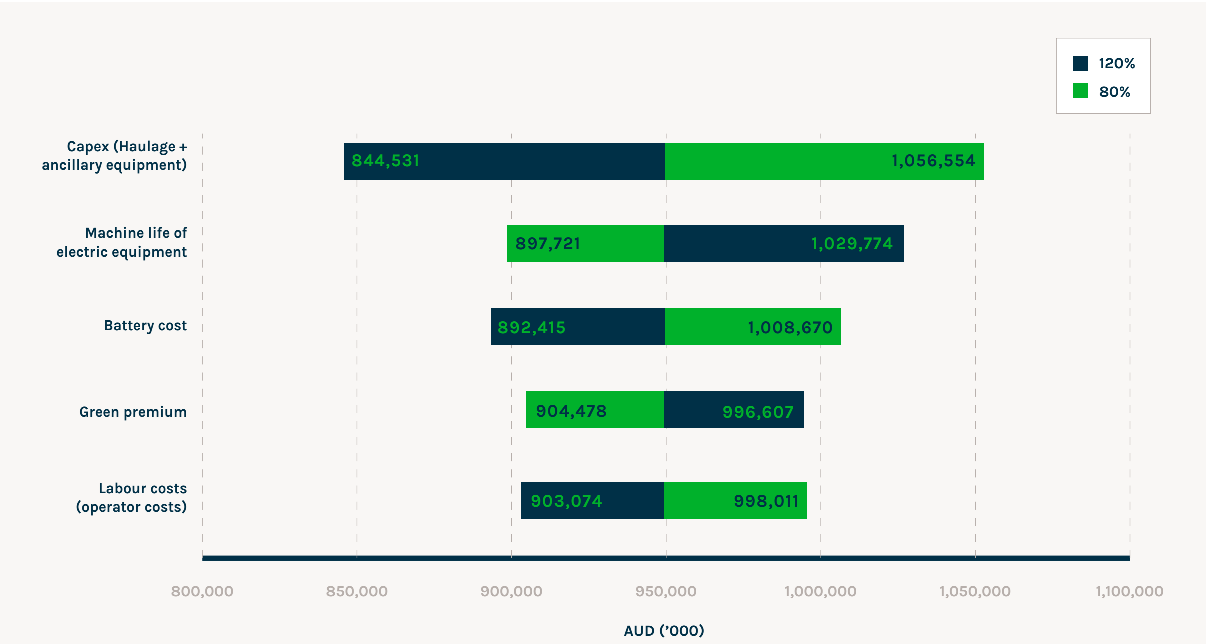


Source: EMC financial model and analysis

Base case sensitivities

The usefulness of the model becomes apparent as the key inputs to the base case are flexed to test for sensitivity. The sensitivity chart shows the change in the NPC of the electric base case (AU$951m) in response to a ±20% flex in input. The chart is useful to assess which are the most significant value levers for a specific case study, and support project teams to prioritise further work and investigations.

Net present cost of electric base case – sensitivity to ±20% change in inputs



Source: EMC financial model and analysis

The overwhelming message is the impact of the capital cost of the electric haulage and ancillary equipment, the largest input value lever. A reduction of just 30% in the capital cost of the equipment is enough to equalise the electric and diesel cases. As discussed in Scenario 1 below, such a decrease is both realistic and expected.

Flexing the machine life is conceptually similar to the change in capital cost, as the equipment replacement cycle and associated capital spend are pushed back in time. Life extension will be most impactful if a whole equipment replacement cycle can be avoided over the mine life (e.g. in a 12-year mine life, there could be three fleets of equipment purchased rather than four). Changes in equipment life are explored further in Scenario 1 below and recognise the potential for extended life of battery electric equipment due to the simpler drivetrains and reduced number of moving parts.

Battery costs and labour costs have similar leverage, but as explored in the scenarios, a continuing battery cost saving can be expected whilst labour cost savings from reduced turnover will be of a smaller magnitude.

There was no green premium included in the base case scenario, but a hypothetical premium of 5% has been included in the sensitivity analysis to visualise the leverage. The flex of green premium from 4% (-20%) to 6% (+20%) has a significant impact on the business case.

Future scenarios – how might valuations and incentives shift

The base case above presents a snapshot in time, but it is clear that the assumptions and inputs are likely to quickly depart from the base case values. For example, in the base case it is assumed that there will no improvements in battery technology over the next 12 years, when improvements are inevitable. Similarly, an underground mine in Western Australia might not pay a carbon price on emissions today, but is it reasonable to assume there will be no price over the next 12 years?

A scenario analysis approach is helpful to articulate the shifts in assumptions and their impact on the financial business case. Alongside the base case, we have considered three broad scenarios, described below.

- Future Scenario 1 – New technology, new economics:
  Scenario 1 describes a future where battery electric vehicle technology improves rapidly, achieving equivalence of capital costs with legacy diesel equipment, and battery technology continues along its rapid performance improvement curve.
- Future Scenario 2 – Global carbon pressures accelerate incentives to change:
  Scenario 2 describes a future where societal and government expectations combine to create incentives to reduce emissions, both via carbon pricing, and green product premia.
- Future Scenario 3 – Technology and external pressures align: Scenario 3 describes a combination of scenarios 1 and 2, where technology improvements and carbon incentives align and combine.

Each of the scenarios has been articulated in terms of seven variables.

Electrification business case scenarios

Carbon incentives

Scenario 2: Global carbon pressures accelerate incentives to change	
Equipment	Electric equipment remains expensive, countries with subsidies move ahead
Suppliers	Miners push suppliers to ramp investment, disruptors emerge
Energy	Remote mine renewables stay at 80%, with offsets applied to rest
Regulation	Carbon price widespread including within Australia
Products	Green premium emerges as carbon cost pass through where regs apply
Finance	Non-electric mine asset prices de-rated given regulatory exposure
People	Non-electric mines struggle to attract talent given DPM awareness

Scenario 3: Technology and external pressures align	
Equipment	Electric equipment costs reduce rapidly through major industry investment
Suppliers	Suppliers aggressively ramp production given carbon + demand
Energy	Remote mines approach 100% renewables given storage breakthroughs
Regulation	Full global trading rules on carbon, including China
Products	Sustained green premium built into metals pricing based on quality
Finance	WACC differential between diesel and electric mines is material
People	Mines without aggressive decarb. plans struggle to attract top talent

Parity ← → Electric advantage

Base case	
Equipment	Capital costs for electric equipment remain greater than diesel
Suppliers	Equipment suppliers respond gradually to electric demand, but not ahead
Energy	The benchmark in remote ining energy supply is 80% renewables
Regulation	Cross border carbon mechanisms have limited impact
Products	Premium for clean metals do not exist for majority of market
Finance	Marginal green asset value differential
People	DPM rules are not tightened further, employees accept status quo

Scenario 1: New technology, new economics	
Equipment	Battery and charging step change in performance
Suppliers	Miners drive step change demand in equipment and bottlenecks ensue
Energy	Remote mines approach 95% renewables given electrification opportunity
Regulation	DPM targets tightened given economic availability of electric
Products	Temporal green premium emerges, but then dies away with catch up
Finance	Non-electric mine asset prices de-rated given legacy diesel technology risks
People	Mines without ambitious technology plans struggle to attract talent

Minimal carbon impost

Scenario modelling

For each scenario, the key inputs to the model have been varied as shown in the table. The selection of assumptions should be debated at length by any company undertaking emissions reduction investment. The assumptions selected for this analysis are a step ahead of the current base case in Australia but have a basis in reality either through experience elsewhere in the world or based on technology improvements observed in other equivalent industries.

Each scenario is presented as a comparison to the base case of a diesel-powered mine.

Table: Scenario key assumptions

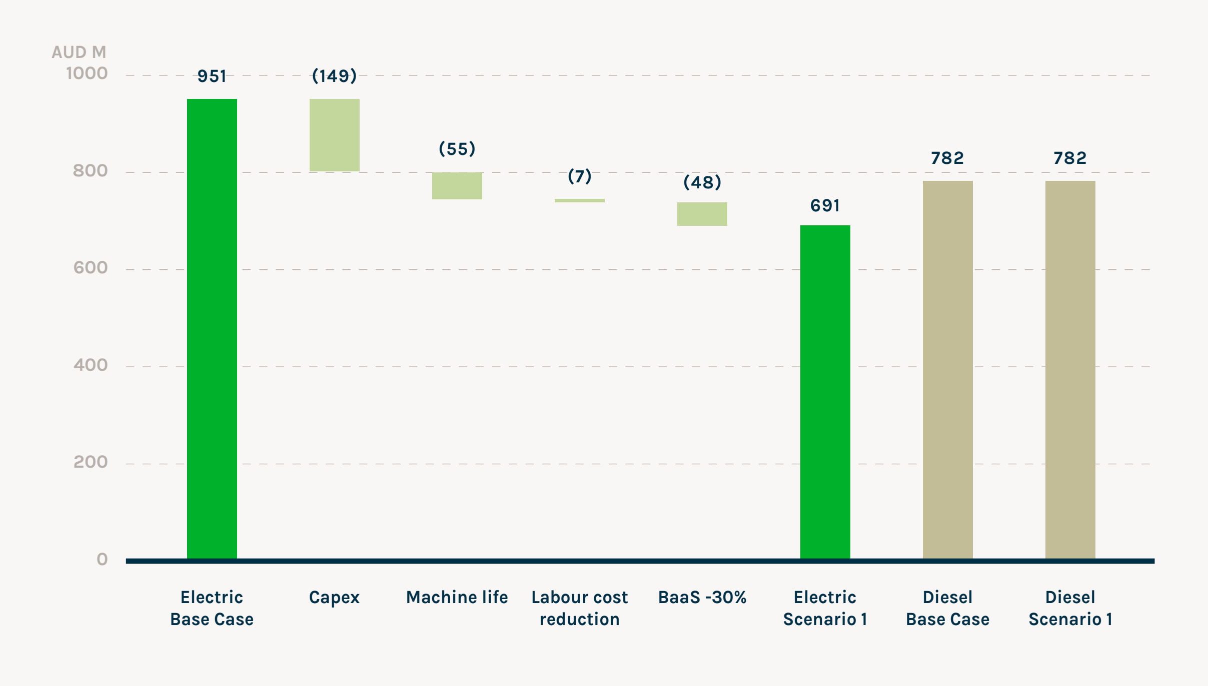
	Base case	Scenario 1 New technology, new economics	Scenario 2 Global carbon pressure	Scenario 3 Technology and external pressures align
Fleet capex	OEM quotes Sep 2024 BEV up to 50% higher	BEV matches diesel equivalent	OEM quotes Sep 2024 BEV up to 50% higher	BEV matches diesel equivalent
Fleet lifecycle	15,000 hrs	20,000 hrs	15,000 hrs	20,000 hrs
Battery performance	Sep 2024 performance	30% improvement	Sep 2024 performance	30% improvement
Employee costs	Typical Australian labour rates	5% labour cost reduction	5% labour cost reduction	5% labour cost reduction
Energy costs	Diesel $AU1.20/L	Diesel $AU1.20/L	Diesel $AU1.70/L (Aus rebate removed)	Diesel $AU1.70/L (Aus rebate removed)
Product premium	Gold price US$2,000/oz	US$2,000/oz	+5% premium	+5% premium
Carbon costs	No carbon cost	No carbon cost	Carbon A$100/ tCO2-e	Carbon A$100/ tCO2-e

Future Scenario 1 – new technology, new economics

In Scenario 1, the rapid advance of BEV technology results in lower battery operating costs and the potential for increased productivity through less frequent battery charging. Increased demand for BEVs prompts a rapid supply response with cost of equipment production falling rapidly and matching legacy diesel costs. Workplace conditions are improved, carbon emissions are reduced, and employee turnover is reduced.

The outcome is that the electrified BEV case is more financially attractive at 88% of the NPC of the diesel case (remember, the base case NPC was 120% of diesel).

Net present cost waterfall (base case to Scenario 1)

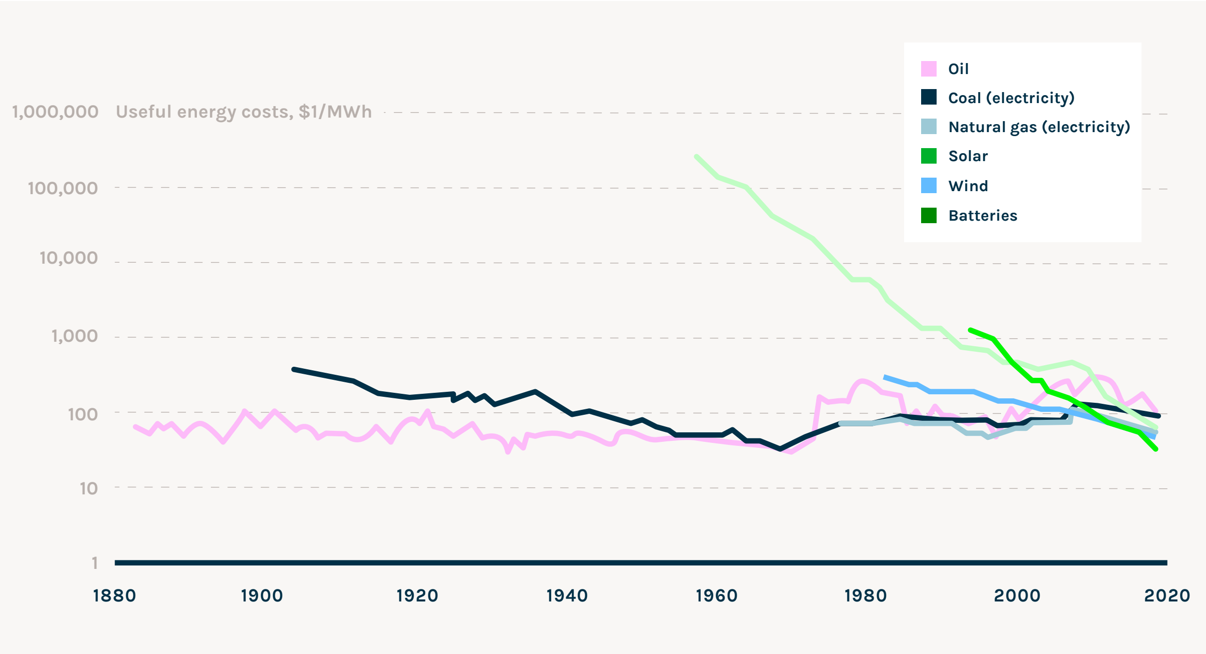


Source: EMC financial model and analysis

The assumed battery performance in Scenario 1 is a 30% improvement compared to 2024. The improvements are expected to be realised through a combination of increased time between charges and a higher cycle count before battery capacity becomes unacceptable. To simplify the analysis, a 30% reduction in batteries- as-a-service operating cost has been applied.

Vehicle battery technologies are still in the rapid improvement phase of technology improvement. An example is OEM manufacturer Sandvik, who will soon be supplying a Gen 4 battery with new BEVs, claiming a 30% improvement on the current Gen 3 battery. Battery improvement is an undeniable trend, and holding the battery assumptions static in a financial analysis is to deny the undeniable. A 30% improvement is arguably conservative as improvements will continue for each fleet replacement cycle.

Technology with scale economies beat commodities on costs



Source: RMI (Reproduced from RMI)

In Scenario 1, it is assumed that the capital cost of BEVs will achieve equivalence with diesel equipment. The key to achieving this outcome is scale up of production, as BEVs are new technology and being manufactured at relatively small scale. Passenger cars provide an example of how costs will rapidly fall as demand and production rise. The EMC's conversations with OEM suppliers suggest that capital equivalence will be achievable within 3 years. This one change alone transforms the financial case for electrification and makes the financial case break even.

It should be noted that another way of delivering the equivalent capital cost outcome for mining companies is via government subsidies, grants and tax incentives.

In Scenario 1, the machine replacement lifecycle for BEVs is extended from 15,000 hrs (roughly 3 years of operating) to 20,000 hrs (roughly 4 years). At this stage there is caution about this potential outcome, as it is too early in the use of the new technology to make a firm prediction. However, the lower number of moving parts (up to 80% less) in BEV equipment should equate to less wear, and a longer time before maintenance costs and delays reach a threshold at which replacement is warranted.

In terms of labour costs, it is assumed that the application of the new BEV technology, and the workplace benefits that it brings, will deliver a competitive advantage in attracting and retaining people. A combination of reduced turnover with lower associated recruitment and training costs, coupled with the ability to attract the best people, are together assumed to equate to a 5% reduction in labour costs.

In conclusion, realistic incremental improvements in technology result in a step change in the financial outcomes, to one where the BEVs are more than 10% favourable.

Scenario 2 – Global carbon pressures accelerate incentives to change

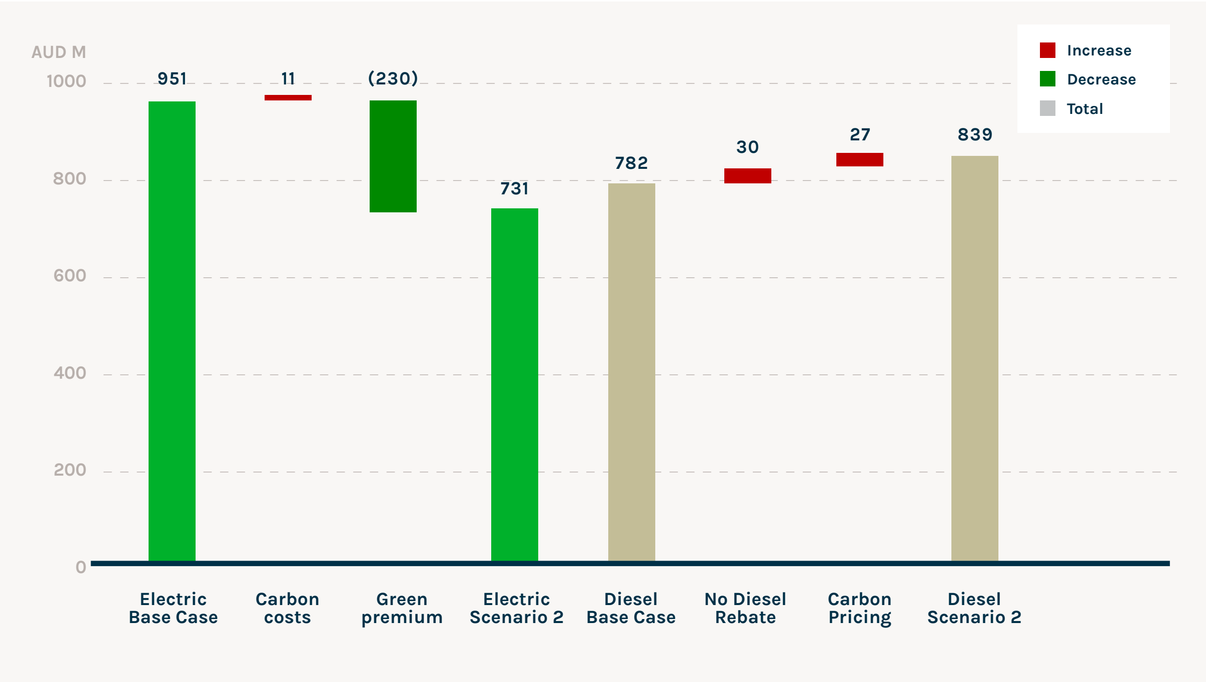
In Scenario 2, electrification technology is assumed to remain static at 2024 levels, whilst external incentives to electrify are accelerated by increasing global pressures. The triggers for such an acceleration are already visible, for example the introduction of Carbon Border Adjustment Mechanisms (CBAMs) and proactive Government-led funding and incentives for emissions reduction (e.g. US Inflation Reduction Act). The trend globally is for the cost of carbon emissions to be recognised and to introduce policy-driven incentives to reduce emissions.

In the context of the EMC Mine and financial Scenario 2, carbon prices are applied, and diesel tax rebates are removed. Miners are required to eliminate DPM health risks via regulation. Commodity buyers are strongly incentivised to source materials with a low carbon footprint, with a price premium opening for demonstrated low emissions.

The pace and degree of these changes are perhaps more debatable than those in Scenario 1, but the direction is clear.

The combined assumptions in Scenario 2 again result in the BEV option being most favourable, with an NPC at 87% of the diesel case.

Net present cost waterfall (base case to Scenario 2)



Source: EMC financial model and analysis

Scenario 2 applies a carbon price of $A100/tCO2-e – note that the impact of the carbon price is primarily observed in the diesel comparison case. The electric case is also impacted to a lesser degree due to the use of diesel fuel for back-up power. EMC member companies typically test their capital projects with a carbon price in the range $50/tCO2-e to $100/tCO2-e, regardless of whether the cost of carbon represents an actual cash cost in the short term. As a reference point, the price for an Australian Carbon Credit Unit (ACCU) in mid-August 2024 is $35/tCO2-e. As illustrated in the waterfall chart, the impact of carbon pricing is relatively modest.

If carbon price were the only lever to be pulled, the cost of carbon would need to be AU$332/t CO2-e for the NPC gap between the diesel and electric cases to be closed (US$225 at August 2024 exchange rates). Such a price is a long way from current levels but is within the range of prices modelling has shown is required to incentivise global net zero emissions by 2050 (IEA).[28]

In Australia, off-highway users of diesel are exempt from the AU$0.496/litre tax applied to on-highway consumers. This tax-favoured position was established for clear historical reasons but is likely to come under increasing policy pressure given the desire to move away from hydrocarbon fuels. For the Scenario 2 analysis, it is assumed that the diesel fuel rebate is removed, and miners are exposed to the fully taxed fuel price consistent with on-road consumers – increasing the price paid from a 2024 market price of $1.20/litre to $1.70/litre.

28 International Energy Agency (IEA). 2021. "Net Zero by 2050—A Roadmap for the Global Energy Sector." Paris.

Diesel prices are challenging to forecast, given the unpredictable impacts of global conflicts in addition to complex demand and supply dynamics. International forecasts include both falling price scenarios (driven by collapsing demand but plentiful supply) whilst others show increasing prices (driven by lack of investment in sustaining supply). Mining companies and mining investors are alert to the risk of diesel price shocks and their potential impact on financial returns. For the EMC mine analysis, the underlying diesel price is assumed to remain static at the August 2024 price.

Scenario 2 assumes that governments move quickly to require the elimination of DPM in underground mines, representing a strong incentive to transition.

The achievability of a green premium for mine products with a low carbon footprint is an area of intense debate within the industry. For Scenario 2, a green premium of 5% is assumed, which if achievable would far outweigh the other external levers in our analysis. There are early signs that some consumers of mined products, through their own supply-chain analysis, are favouring low carbon products. For example, Bellevue Gold has a refining contract with ABC Refinery, enabling the gold from the mine to be refined separately and marketed as a green product. In the aluminium sector, suppliers have been able to differentiate low carbon "green" alumina. For its part, the industry is working to create standards and processes to demonstrate carbon emission performance.

The waterfall chart indicates that it is the green premium that has the most impact on financial value. The other inputs (carbon price, fuel price) have an impact but alone are not enough to level out the BEV vs diesel financials.

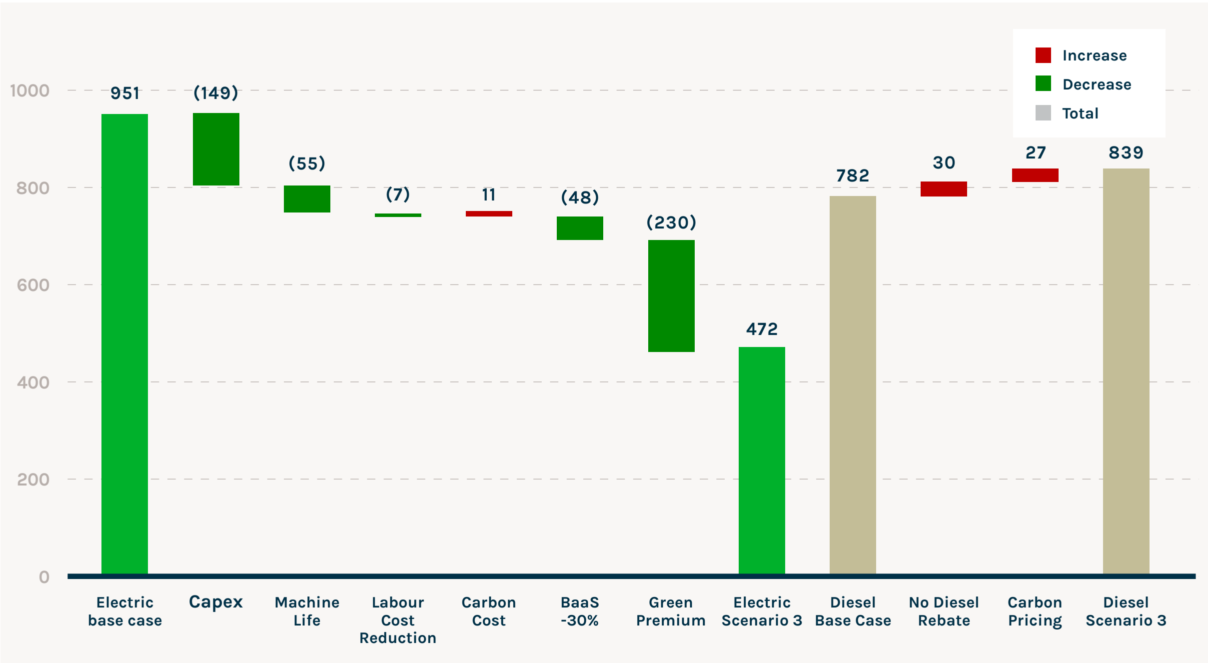
In conclusion, external global trends are undeniable and will impact the case for electrification. Taken together they make an investment in electrification financially attractive, and it would be unreasonable to exclude them from a financial analysis.

Scenario 3 – Technology and external pressures align

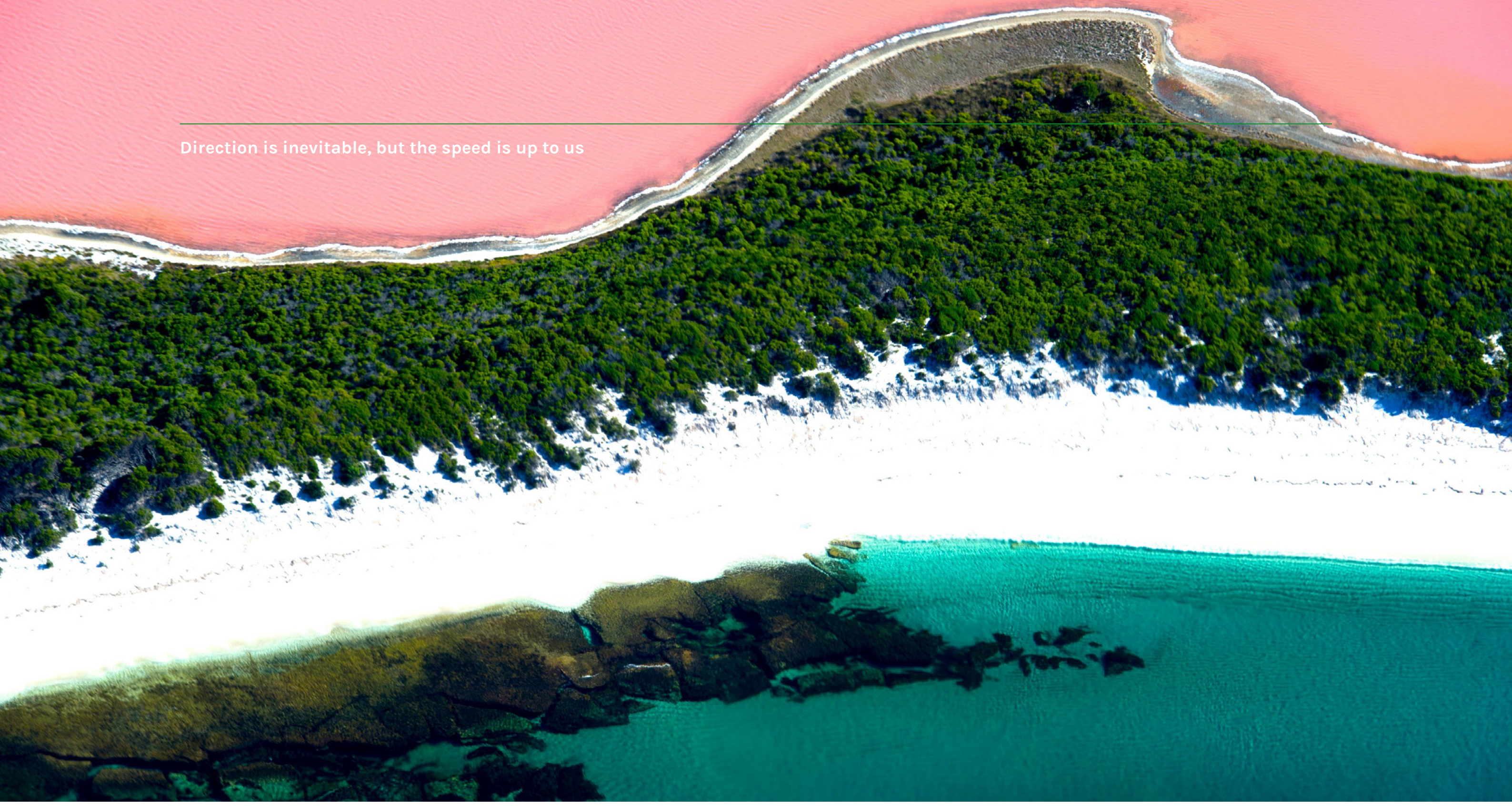
Scenario 3 combines the assumptions from Scenario 1 (technology step change) with Scenario 2 (global incentives) to create a boundary case where all variables trend towards electrification. The scenario can be thought of as the full upside opportunity available to companies willing to invest in electrification.

The Scenario 3 financial case has an NPC for the electrified BEVs of just 56% of the diesel case. The costs of load and haul have been almost halved!

Net present cost waterfall (base case to Scenario 3)



Source: EMC financial model and analysis



The upside opportunity when all inputs are considered is very substantial. Each company will look at the input assumptions and take a different view as to their likelihood. However, it is clear from the waterfall chart that even a modest shift in each of the input assumptions creates a material upside opportunity. Even if only half of the scenario turns out to be true, value has been created by electrifying.

When the analysis is presented this way, the questions prompted for executive decision makers are different. The debate becomes framed about pursuing the upside opportunity rather than focussing on the downside risks of the technology in the short term (and it must be recognised that technology changes will always carry risk).

Cost of capital

A further external factor to consider is whether a cost of capital differential will appear between low carbon and high carbon producers. Fundamentally, the expectation is that high carbon producers who are not delivering emissions reductions will have fewer available sources of capital and will be seen by the market as higher risk.

The implication is that an investment in mine electrification, requiring significant capital, could be funded at a lower debt level than for an investment in a diesel mine. The financial impacts of such a change have not been factored into the case study analysis but are important considerations for mining companies in selecting a discount rate to apply.

Every mine is different

Case studies are helpful to articulate in real financial terms what a transition to electrification looks like. Everyone wants to see the numbers. However, it must be recognised that every mine is different, and as a consequence the business case for every mine will be different. The inputs to a financial analysis of electrification should include an understanding of the ore deposit, mining method and future operating model as an electric mine.

That said, the EMC can be confident that the case study presented above is representative of other underground mines, as the outcomes are consistent with similar mining case studies. Specifically, the EMC has modelled an underground copper mine project in the USA as a diesel vs electric mine, and EMC member IGO in partnership with Perenti and ABB have published a paper[29] into their analysis of the Cosmos project as an electrified operation. A summary of the outcomes is shown in the table. Each project has a base case for electrification (with today's equipment pricing, technology and external environment) with a higher NPC than diesel. Each of the cases can be expected to flex against input assumptions in a similar fashion to the EMC scenarios (i.e. there is significant upside opportunity).

29 IGO, Perenti and ABB: Making electrified underground mining a reality. Lessons from the Cosmos Electrification Study

Model	Context	NPC Elec vs Diesel Fleet	Insights for Electrification
EMC 1 US underground mine	1.3 Mtpa, owner operated, shallow decline haulage, grid connected, 10-year life	104%	• High Capex, low Opex • Short mine life hindered payback • Low % renewables from grid impacted outcome
EMC 2 Australian underground mine (as presented here)	1.8 Mtpa, contract mining, decline haulage, off grid, 12-year life	122%	• High haulage cost for electrified option • Less electricity consumed in electric case due to ventilation savings
IGO Cosmos white paper, Australian underground	1.1 Mtpa, shaft haulage, contract mining, off grid, existing power plant pre renewables	106%	• High haulage cost for electrified option • Less electricity consumed in electric case

Broad mining themes observed from electrification financial analysis

Beyond the case study outcomes detailed above, the EMC has built a body of knowledge around the implementation of mine electrification, and the factors that will lead to a more favourable financial case.

For an underground mine, installation of shaft haulage allows the most energy intensive part of the cycle to be electrified, and haulage cycles to a shaft tend to be shorter with opportunities for downhill loaded hauls. However, the tendency in the Australian mining industry is to access shallower ore bodies quickly and cheaply via declines rather than invest in shaft access, locking the operator into truck haulage. Traditional trade-offs between shaft and decline haulage are challenged by emissions reduction targets. Long uphill truck hauls up a decline powered by diesel are a particularly inefficient use of energy, and when the full costs are considered, investment in shafts may come into play at shallower depths than existing rules of thumb.

Mining methods are also important, as they will dictate the battery charging cycle and operating model options available. Mines with shorter haulage cycles have more charging flexibility, and mines with downhill loaded hauls can take full advantage of regenerative braking.

Total electricity consumption is lower in the electrified EMC and IGO case studies, a consequence of ventilation power savings offsetting battery charging loads. However, electricity loads are peakier in the electrified scenario, and peak loads require more active management.

The available electricity source is also important to financial outcomes, both in terms of renewables fraction and unit cost.

Differences for a surface mine

The EMC analysis has focused primarily on underground mine electrification as the priority area of interest for the members. The financial case for surface mine electrification has some key differences to the underground case.

In terms of haulage technology, surface mining trucks are bigger, and the large truck BEV products, whilst developing rapidly, are less mature than underground options. The larger trucks require a more significant capital spend on charging infrastructure due to the high peak loads for rapid charging. Some mine operators are challenging the "bigger is better" mindset and evaluating how smaller electrified trucks with the benefit of automation compare to ultra-class trucks.

There are alternative electric technologies to BEVs that are being actively considered, for which the financial case is improving. Examples are traditional trolley assist using pantographs, dynamic charging technologies like BluVein[30], and a move away from truck haulage to conveyor haulage such as with in-pit crushing and conveying (IPCC). Alternative fuels are also being considered as a pathway to achieve interim emissions reduction targets, for example Vale in Brazil have an active research program into biofuel utilising sugar cane waste.[31]

The non-financial benefits of eliminating DPM emissions, reducing heat generation and reducing noise are less material in the surface mine environment. However, in heavy equipment workshops in particular all of those benefits will be welcomed by employees.

Mine life

Electrification options will tend to require higher up-front capital expenditure than diesel equivalents to establish the required infrastructure. Payback is achieved via lower operating costs, but the ability to achieve an acceptable return is challenged when the committed mine life is short. It is a common model for a mining company to complete just enough drilling and mine design in a feasibility study to lock in an adequate mine life to fund start up. However, the study is often completed in the confident knowledge that further ore reserves and resources will be available to extend the mine life once established.

A short mine life at the study stage may limit a miner's ability to demonstrate an acceptable financial return on electrification. Consequently, technology options from the transformative (e.g. sinking a shaft) to the incremental (e.g. replacing diesel fleet with BEV) may be prematurely ruled out.

The EMC ran a hypothetical case study, based on a mine project in the US, to test how the financial returns from electrification were impacted when the mine was scaled up in life (from 8 to 20 years) and production level (increased by 4 times). At the smaller scale the NPC of electrification exceeded the diesel equivalent at 104% i.e. the investment looked marginally negative. However, at a larger scale the outcomes were reversed, and the electric option had the lower NPC at 92% of the diesel.

The obligation to deliver on emissions reduction targets will require mining company development and study teams to think differently about the life-of-mine plans for their assets. In particular, whether the cost and effort required to extend knowledge of the ore body will open up value-adding long-term options.

30 www.bluvein.com
31 Vale presentation, Electric Mine Conference, Perth 2024

Financial value of social and environmental benefits

Whilst the qualitative benefits of a healthier working environment and a reduction in carbon emissions are straightforward to describe, attempting to quantity these benefits can be challenging. Typically mining businesses are reluctant to assign a dollar amount to social and environmental benefits, as they are not as immediately measurable as a dollar of capital expenditure or a dollar per tonne of carbon emitted. However, companies will acknowledge that the benefits do indeed have real financial value.

In a recent study, Australian miner IGO together with partner Adaptus took the bold step of quantifying the social benefits of a mine electrification option for their Cosmos project in Western Australia. The quantification of the benefits included health, safety and environmental factors, and combined to deliver a positive financial case for the project. Unfortunately, other factors resulted in IGO placing the Cosmos project into care and maintenance during 2024.

The automated digital mine

For many mining companies, electrification represents one part of a broader technology strategy. Other common elements are an overall digitisation approach, and the introduction of mining equipment automation. Many companies are also challenging the "bigger is better" mindset that has dominated load and haul product development in the past 20 years. The new generation of electrified mining equipment complements broader digitisation and automation strategies due to more readily available data and less complex machine operation and interfaces.

The placement of electrification within a broader technology strategy further enhances the business case as an enabler and building block of the next generation of digital mines. Put differently, miners are challenging themselves as to why they should invest resources into automating and digitising legacy diesel equipment when new electrified equipment is available today.

Valuation processes – missing the opportunities?

Through the life of the EMC, members have analysed and put forward multiple emissions reduction projects for approval. Members have consistently provided feedback that the financial case is a challenging hurdle to get over. This hurdle is common to technology projects, and miners are encouraged to ensure they are thinking through and analysing the full range of opportunities and risks from electrification. There are two common tendencies that constrain analysis for electrification implementation.

Firstly, there is the tendency to analyse projects on an individual, bottom-up basis. For example, an investment in a battery light vehicle fleet with associated charging infrastructure may show a negative or marginal financial return when viewed in isolation. However, when seen and analysed as part of a broader portfolio of emissions reduction projects, the input assumptions and benefits are viewed in a different context and can change the financial case.

A practical example is EMC member Gold Fields who have led the way in installation of remote mine renewable energy generation. Gold Fields have built a deep knowledge of site renewables via analysis of technology options, small scale trials and third-party PPA's. The knowledge and experience gained enabled Gold Fields to announce in March 2024 an AU$296m investment in renewables at the St Ives mine, Gold Fields' largest investment in renewables to date.[32]

A second common tendency is to take a narrow, static approach to the key input assumptions to financial models, and for those assumptions to receive limited exposure and debate. The analysis of the EMC Mine case study above demonstrates how at first glance a transition to electrification can look marginal or negative, when in fact a strong opportunity exists if undeniable trends are applied to key inputs.

Concluding remarks

The lessons from the EMC work in valuing the business case for electrification can be summarised in a few points:

- Understand and articulate the full business case for the change including health, safety, social and environmental impacts.
- The capital cost of electric haulage equipment is currently the biggest financial lever – work with OEMs to get prices down and advocate for support from Governments to lessen the impact and accelerate change.
- BEV technology is improving quickly, and the external environment is shifting to support electrification– debate what this means for business case inputs and ensure the opportunities are articulated.

32 Gold Fields media announcement www.goldfields.com/news-article.php?articleID=13975

Chapter 5: Pathways to decarbonisation

"The pathway to mining decarbonisation is long, but the first steps are clear, and the time to take them is now."

Decarbonisation roadmaps

The last few years have seen the emergence of mining decarbonisation roadmaps: specific plans to address emissions and meet targets, often included as part of companies' annual and sustainability reports. As stakeholder expectations and regulatory pressures surrounding climate risks grow (e.g., the Australian Sustainability Reporting Standards), so too does the importance of publishing a compelling decarbonisation roadmap. We recently studied public mining roadmaps (focussed on an Australian context) as part of an EMC workshop series and report.[33]

Generally, public, company-wide decarbonisation roadmaps in mining tend to follow a three-phase pathway, determined by the relative costs of carbon abatement and technology readiness levels:

- Phase 1 – 2024-2030: Energy supply (i.e., optimising usage and renewable supply)
- Phase 2 – 2030 - 2040: Equipment (i.e., displacing diesel in mines)
- Phase 3 – 2040 - 2050: Hard-to abate (i.e., requiring emerging, nature-based, or technological carbon sequestration solutions)

A good roadmap is transparent, targeted, well-resourced, and detailed enough to be credible – while maintaining license to be flexible in the face of a rapidly changing technological and regulatory landscape.[34] It should be fiscally responsible and context-driven within the business's overarching strategy – and capture any potential competitive advantage from decarbonising.

When establishing their roadmap, miners should carefully analyse a range of potential pathways against the company's established "business as usual" baseline case, while prioritising emissions avoidance ahead of reduction or mitigation. Given the variety of emissions measuring and reporting standards, it's often been difficult for miners to even establish their clear baseline case – slowing down the development of and investment into priority roadmaps. As the industry develops and more precise tools (e.g., emissions models or satellite tracking) come into play, establishing a baseline should get easier.

"Miners should begin transitioning to an all-electric system with installing renewables"

- State of Play: Electrification report (2020)

33 https://www.electricmine.com/projects/electric-mine-consortiums-decarbonisation-roadmap/
34 CEFC MRIWA Roadmap To Decarbonisation - Clean Energy Finance Corporation

Roadmap process

Critical but time-intensive planning

1) Understand current state

Factors include commodity, production level, emissions level, mining method, mine stage (including remaining life), location, existing infrastructure expiry date, grid connection, company portfolio, business model, operational model, stakeholder sentiments, capability and appetite for change, etc.

2) Set ambition for future state

Make the vision visceral. Link decarbonisation and electrification goals to overall business strategy in the short, medium and long term. Secure leadership alignment and organisational commitment.

Each iteration costs $ and disrupts production. If unsuccessful, go back to the drawing board – where new options may now be available.

3) Explore possibly pathways to future state

Understand options surrounding emissions reductions for energy usage, diesel fleet and additional hard-to-abate categories. Be broad and innovative in your thinking, venturing beyond typical industry silos to gather the best ideas before testing how well they integrate into your system.

4) Select and study best pathway(s)

Use simulations, studies, case studies and subject matter experts to determine the most appropriate path forward before making a final investment decision. If you're exploring multiple categories, begin with the cheapest high-impact actions, or those that require completion by a certain date.

5) Select and implement best pathways

Invest in a pathway, from pilots through to full implementation. Track important metrics throughout the process to determine whether the pathway met its success criteria before continuing on.

6) Continue until desired state is reached

Emissions reductions targets

Most miners have committed to reduce their Scope 1 (direct emissions) + Scope 2 (indirect from purchased power) emissions to net zero by 2050, in alignment with the Paris Agreement's goals to restrict global warming to <2° C.[35] While a promising start, the use of long-term net zero targets technically allow for many years of unmitigated emissions and an overreliance on carbon offsets, demotivating the industry and delaying action on decarbonisation roadmaps.

Australia has committed to a 43% reduction in greenhouse gas emissions and 82% renewable energy penetration by 2030. The majority of miners have either not set interim targets or have set them below the national targets. Meanwhile, the average renewable penetration in Australian mining is below 10%. Similarly, indirect Scope 3 emissions from the external value chain have largely been absent from most public mining targets.[36][37]

Still, ambitious emissions targets and detailed decarbonisation roadmaps have been released by some Australian industry leaders, including EMC members Bellevue Gold (targeting net zero Scope 1 and 2 by 2026), IGO (targeting net zero Scope 1 and 2 by 2035), and Gold Fields (targeting 10% Scope 3 reduction by 2030). Beyond the EMC, Fortescue is leading the majors by targeting real zero Scope 1 and 2 by 2030. Such targets demonstrate that across the industry, miners have tangible plans to rapidly decarbonise.

Roadmap to a net zero mine by 2035

Designed by the Electric Mine Consortium for a template medium-sized brownfields underground metals mine in Western Australia.

Overview

	Short term (1-3 years)	Medium term (3-5 years)	Long term (5-10 years)
Business decisions Correctly understanding electrification's value and risk	Companies have a deep, established understanding of their emissions and the value from decarbonisation under a range of future scenarios	Decison making process is expanded to cover automation options and Scope 3 emissions reduction	Remaining emissions are abated or offset using high quality carbon offsets with co-benefits
Renewable energy Divesting from a fossil fuel power supply	60-85% renewable power energy supply project(s) are planned	Renewable power supply is in place; energy storage, management and optimisation processes are developed	Energy optimisation processes are implemented; decarb. progress based on future tech is developed
Electric equipment Transitioning vehicles and pieces of equipment	Transition plans for electric equipment are developed; change management processes are defined and deployed; operational readiness models are developed; funding sources and equipment trials are planned and delivered	Majority of equipment is in process of transitioning to electric (trials or adoption)	Alternative fuels or technologies are continually explored as a potential niche abatement

35 https://minerals.org.au/policies/energy-and-climate-change/mining-towards-net-zero/#:~:text=Overview,through%20significant%20investment%20in%20technology

36 www.climatechangeauthority.gov.au

37 https://arena.gov.au/assets/2017/11/renewable-energy-in-the-australian-mining-sector.pdf

	Short term (1-3 years)	**Medium term** (3-5 years)	**Long term** (5-10 years)
Asset planning & development Retrofitting, optimising and future-proofing the mine site	Energy management architecture is in place; operations are changed to derive full benefit from electrification; simulations are deployed; mine design improvements are understood; electrical infrastructure is in place	Mine planning processes are adapted to incorporate future electrification; Energy Management System (EMS) is evolved	Next phase of mine expansion takes full advantage of electrification opportunities
Organisational capabilities Ensuring the necessary staff, skills and structures are available	Robust culture is established which supports decarbonisation initiatives, with top-down ambition and clear lines of communication and project ownership	Organisation is data-centric and automated, with evolved staff roles and support hybrid human/tech teams	An ongoing faster pace of innovation, technology adoption and skill transfer is enabled

Details

	Short term (1-3 years)	**Medium term** (3-5 years)	**Long term** (5-10 years)
Business decisions Correctly understanding electrification's value and risk	• Use scenario-based valuation models to understand decarb. business case • Understand current and future regulatory and market environment • Drill out mine to understand mine life and improve business case • Collaborate widely to understand new standards and processes • Leverage clean reputation to access financing, partnerships and talent	• Explore equipment automation as a means of improving efficiency/ electrification business case • Understand Scope 3 emissions profile • Mature valuations models based on real-world technology experience	• Work with supply chain partners to mitigate Scope 3 emissions • Offset remaining emissions using high-quality carbon credits
Renewable energy Divesting from a fossil fuel power supply	• Review existing power supply contracts • Study renewable energy options • Install 60-85% renewable energy generation, via PPA or direct investment • Study energy storage, management and optimisation options	• Analyse and select energy storage options to increase renewable penetration • Work with on-grid retailers to lock in renewables • Implement energy optimisation in processing	• Install long duration storage technology • Study future technology solutions to further optimise renewable energy usage

	Short term (1-3 years)	Medium term (3-5 years)	Long term (5-10 years)
Electric equipment Transitioning vehicles and pieces of equipment	• Signal demand to OEMs, securing equipment supply and design input • Plan equipment trials/ purchases based on availability and lifespan • Apply for equipment grants • Trial available equipment, sharing data/learnings where possible • Design and implement operational readiness plans for all site functions	• Adopt electric mobile equipment and associated charging infrastructure across site • Decommission diesel equipment or retrofit to electric where it makes sense • Optimise operating model for electric equipment	• Implement study findings and use new tech to completely remove diesel from operations
Asset planning & development Retrofitting, optimising and future-proofing the mine site	• Design future fleet, including charging infrastructure and battery swap plans • Build charging infrastructure or battery swap-out stations • Work with regulators to share knowledge and design optimal operational plans • Study and simulate options to reduce processing energy and LDES demand, eg. time/ load shifting	• Continue to refine safety systems • Study sustainble options for end-of-life infrastructure • Enable EMS to evolve with new tech • Install energy efficient mineral processing technologies	• Apply electric-integrated mine designs to mine expansions
Organisational capabilities Ensuring the necessary staff, skills and structures are available	• Set and communicate decarbonisation targets, plan and lessons learned • Set decarb. governance, reporting and accountability procedures • Set decarb. targets and offer climate-based incentives to staff • Develop staff talent and skills/knowledge piline • Develop robust change management capabilities	• Continue to develop skillset of team and build pipeline of new talent • Build capability to analyse new data sources and optimise operations	• Have teams of skilled workers, autonomous electric equipment and AI-driven optimisation processes • Identify and adopt new technologies quickly without disrupting the larger system

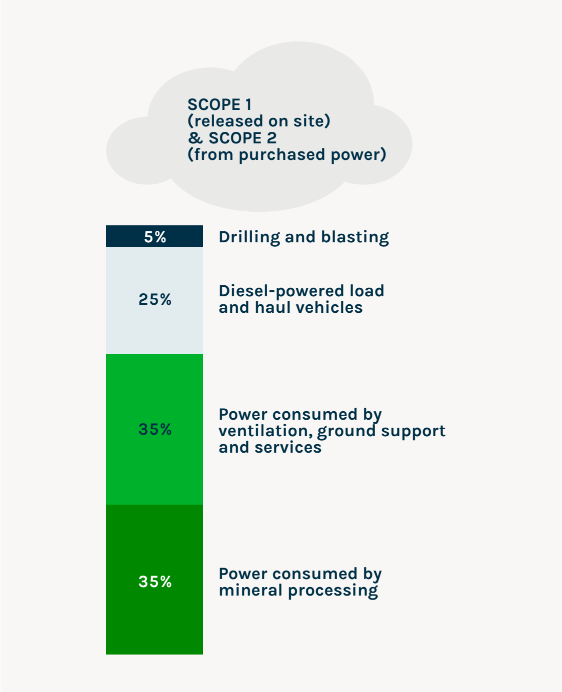
Source: EMC Decarbonisation Roadmap Paper

Not only is the rapid acceleration of emissions reduction possible, in our view, it is the sensible strategy for most businesses (perhaps the exception being mines with very short lifespans). The last decade has seen the swift maturity of both decarbonisation technologies and stakeholder expectations. While the near-term business case may appear marginal – for example, in shorter life mines or very large smelters - miners shouldn't let the current moment lull them into a false sense of security about the need for impending transformation.

Australia's 2035 climate targets are due to be released in February 2025 and may very well be the harbinger of change. As illustrated in the previous chapter's scenario exploration, updates to Australia's DPM regulations, climate risk disclosures, the Safeguard Mechanism, diesel prices (including rebates), and social license may all tip the scales in favour of low-emissions miners – and those with established, well-thought-out decarbonisation roadmaps will be first in line to reap the rewards.

> "The goal is to be able to help members of the EMC to deliver a clear glide-path to net zero... in our opinion there's no reason why we couldn't achieve that before the end of the decade."
> — EMC member

Typical underground mine emissions breakdown



Source: EMC analysis based on member site emissions

Energy supply

Powering the transition

The majority of mining's carbon emissions typically comes from power consumption, either from diesel generators or other power produced on-site (Scope 1) or from coal- or gas-fired power purchased from the grid (Scope 2). To tackle this, mines need to both reduce the amount of power consumed and change their remaining power sources to renewable. Without transitioning their power usage, it'll be nearly impossible for mines to meet any 2030 emissions reduction targets – and they may also miss out on operating cost benefits.

Power usage reduction

Assuming production levels remain consistent, power usage may be reduced through process optimisation. Each asset may take its own innovative approach here; some examples taken from EMC participants' roadmaps include blasting instead of crushing, the insulation of operational areas to reduce heat loss, utilisation of waste heat (mainly in cold climates), and ventilation on demand. OZ Minerals planned an approximate 20% reduction in power usage through the use of Vertical Roller Mill technology at West Musgrave, which allowed processing to be flexibly ramped up and down to meet renewable power generation.[38]

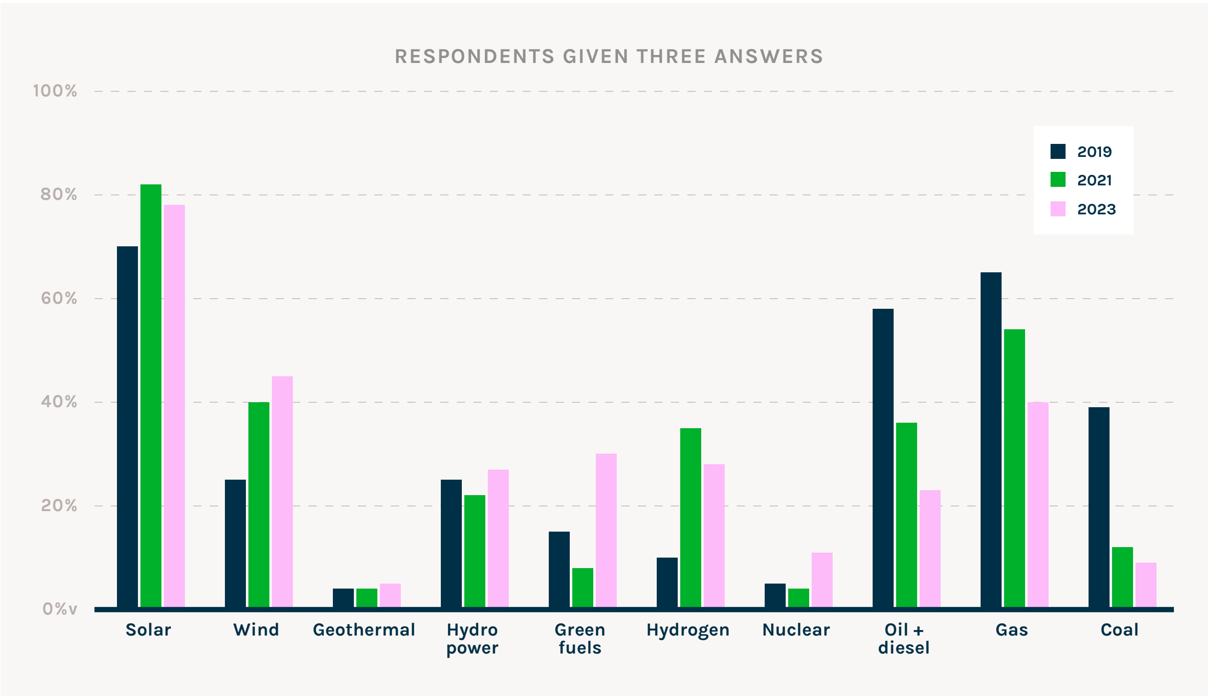
At any underground mine, the electricity consumed to drive the primary and secondary ventilation fans is always a major component of the site energy consumption. The conversion of underground mobile equipment from diesel to electric further reduces ventilation demand and power usage – in fact, the Cosmos electrification study by IGO, Perenti, and ABB found that the reduction in ventilation power completely offset the power used by electric equipment.[39]

The transition to electrified operations together with renewable electricity generation presents new opportunities to optimise electricity use. Future mine electrical networks will become more complex, with greater variability in both demand and supply profiles. For example, a mine may be able to lower operating costs overall by varying production to match periods of low-cost electricity generation. However, such trade-offs are complex and lend themselves to system-wide software and hardware tools such as Energy Management Systems (EMS). EMC members have been exploring the EMS tools available in the market to support the optimisation of site energy management, ranging from bespoke niche systems to network-wide integration software.

Sourcing

While some regions may face systemic barriers to renewable energy penetration, Australia enjoys the highest level of solar radiation in the world, making it well-placed to take advantage of its natural resources and achieve energy self-sufficiency.[40]

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



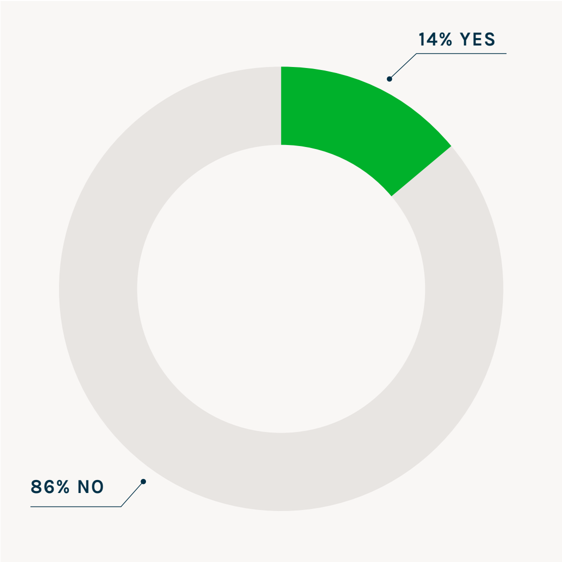
Source: State of Play surveys

38 https://im-mining.com/2022/09/23/oz-minerals-west-musgrave-copper-nickel-plan-receives-board-approval/
39 IGO, Perenti & ABB white paper
40 https://arena.gov.au/assets/2017/11/renewable-energy-in-the-australian-mining-sector.pdf

The payback period for renewable energy infrastructure such as behind-the-meter solar is typically short, and even mines with short lifespans can benefit by installing temporary solar (such as NSW-based provider 5B's prefabricated and relocatable Maverick units). Several companies like Rio Tinto and Arcadium Lithium have also explored building in handover of these assets to local communities as part of the up-front business case.

While grid-connected mines may have it easier (Australia's average national renewable penetration in 2023 was 39%, which is due to double in the next 5 years), it has never been easier for off-grid operations to install their own renewables.[41] Such projects also reduce the site's exposure to volatile costs of gas and diesel – in fact, it is now cheaper for greenfields mines to deploy renewables than to use gas. With over 100 off-grid remote mines in the country, there is now a significant opportunity for both individual companies and national emissions reductions and energy security. The question is, will enough sites take it up in time to meet the national targets?

Will the industry meet Australian government targets for national 82% renewables penetration by 2030?



Source: EMC survey 2024

Major capital investment is required to meet targets in Australia

Today	2030
• +700 ASX listed mining companies • +350 operating mines in Australia • ~10 to 15 year average mine life • ~30% average carbon reduction targets by 2030	• +50 new mines • +$20b capital spend on new mines • $200m to build a 60% renewable energy fraction project • $23b to get remote mines to a 60% renewable energy fraction[43]

41 https://assets.cleanenergycouncil.org.au/documents/resources/reports/clean-energy-australia/Clean-Energy-Australia-2024.pdf?utm_source=account-engagement&utm_medium=email&utm_campaign=cea-24&utm_content =link

42 + 50 new mines (if average mine lives are 10 years, then assuming 350 operating mines, there would be 35 new mines each year for 5 years for 175 mines). Reduced this substantially to account for longer mine lives in practice. 50 new mines assumes average 35 year mine life. +$20b capital spend on new mines: assume $500m for a new mine x 50 new mines = $25b (used +$20b to be safe). $200m capital for 60% REF project: Gold Fields St Ives was $296 for 70%, so this is reduced by a third to be conservative and to account for 60% REF vs. 70% REF. $23b for remote mines @ 60% REF: Remote mines are about one third of all Australian mines (source: Global Data, which also says around 1250 of 3000 global mines are off grid). This equals about 115 mines in Australia x $200m = $23b.

Even in remote areas, the mining industry has started to seriously invest in renewables. For example, in their new greenfields project, Bellevue Gold is looking to achieve up to 80% renewable penetration at its 88MW hybrid solar, wind, thermal, and battery storage power station, in partnership with Zenith Energy.[43] At another new greenfields project, Zenith Energy is also developing a 95MW hybrid power station at Liontown Resources, setting the scene for an integrated renewable energy hub in the Kathleen Valley.[44]

Similarly, Gold Fields' recently announced AU$296M renewables project will add 77MW of wind and solar project to its operations, covering around 73% of the required power for their St. Ives mine. The scale of these projects shows the industry's rapid acceleration from the Australian first mover in 2016, Sandfire's 16.6 MW DeGrussa solar and battery hub, reportedly the largest integrated off-grid solar and battery storage facility in the world.[45] The industry ambition continues on-grid too; BHP recently announced a new power purchase agreement targeting 100% renewable energy by 2030 at their BMA assets in Queensland.[46]

These industry-leading projects have been celebrated widely, but each required heavy investment and complex commercial negotiations, as well as internal advocacy, dedication to the goal and diligent planning and execution. Existing power supply agreements had to be dealt with, ambitious new power supply agreements had to be generated (Bellevue Gold consulted over a dozen different suppliers before landing on their final PPA), and stakeholders including local communities and Indigenous groups needed to be genuinely integrated into the process from an early stage.

Energy source	Benefits and disadvantages	kg CO2-e/MWh electricity[47]
Hydro	✔ Low operating costs, reliable continuous generation ✖ Environmental impact, site-specific feasibility, high capital costs	1 - 30
Nuclear	✔ Reliable continuous power ✖ High capital cost, waste management, currently prohibited in Australia	5 - 15
Wind	✔ Low operating costs, scalable, can generate at night ✖ Intermittent generation, potential impact on wildlife	10 - 20
Geothermal	✔ Low operating costs, reliable continuous generation ✖ Exploration and drilling costs, site-specific feasibility	10 - 40
Hydrogen	✔ Versatile, transportable, storable ✖ High costs, not currently economically viable	10 - 300
Solar	✔ Low operating costs, scalable ✖ Intermittent generation, high installation costs	20 - 50
Bioenergy	✔ Reduced waste, offers continuous power generation ✖ Limited by biomass availability, requires continuous supply chain management	40 - 100
Natural gas	✔ Reliable, dispatchable, can generate heat and power ✖ Price volatility, emits pollutants	450 - 550
Diesel	✔ High energy density, easily transportable ✖ Price volatility, emits pollutants	600-900
Coal	✔ Reliable continuous power, widely used in Aus ✖ Emits pollutants	900 - 1200

43 https://zenithenergy.com.au/bellevue-gold-and-zenith-energy-partner-to-establish-innovative-hybrid-power-station-for-bellevue-gold-project/

44 https://reneweconomy.com.au/australian-lithium-mine-to-be-powered-by-biggest-off-grid-solar-wind-and-battery-plant/

45 https://www.sandfire.com.au/sustainability/esg-framework/climate-change/renewable-energy/

46 https://www.bhp.com/news/media-centre/releases/2024/08/bma-set-to-operate-with-100-per-cent-of-electricity-needs-under-renewable-power-arrangements

47 EMC analysis based on https://www.eia.gov/tools/faqs/faq.php?id=74&t=11, https://iea.blob.core.windows.net/assets/69b838f4-12ad-4f51-9155-9da6435b5d53/IEA_UpstreamLifeCycleEmissionFactors_Documentation.pdf, https://www.dcceew.gov.au/climate-change/publications/national-greenhouse-accounts-factors-2023, https://www.iea.org/data-and-statistics/charts/average-co2-intensity-of-power-generation-from-coal-power-plants-2000-2020.

Though renewable energy generation offers cheap, clean energy, the variability of supply through daylight cycles or weather patterns poses a challenge to those used to a reliable, steady, on-demand power supply. There are a number of different approaches mines may take to stabilise their systems and maximise their renewable energy usage. These include:

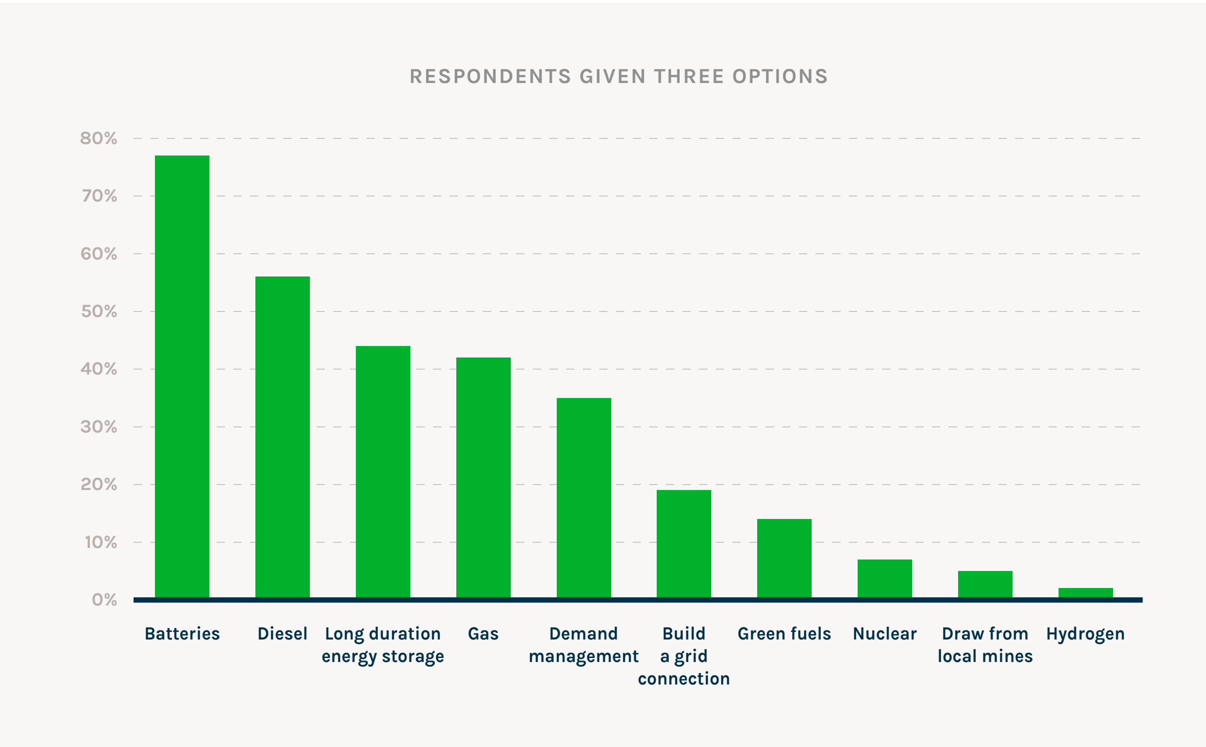
- **Short duration energy storage (<4 hours)**, primarily in the form of lithium batteries. These provide grid stability over seconds to hours but have a limited lifespan and a high capital cost (however, next-generation battery tech may offer some solutions).
- **Long Duration Energy Storage (LDES)**, which may take the form of:
  - Flow batteries (e.g., vanadium redox, zinc bromide, iron), which have long lifespans and modularity but are expensive and may use toxic materials.
  - Sodium-sulphur batteries, which are efficient for large-scale storage but have environmental risks and high operational costs due to temperature requirements.
  - Pumped hydro, which is mature and operationally cheap but capitally intensive and limited by location, water resources, and environmental approvals.
  - Gravity, which is highly efficient and significantly cheaper than battery storage technology (and independent of the cost of battery materials) but has some geographical constraints.
  - Compressed air, which is a mature technology with low costs but is dependent on geographical suitability and requires significant upfront investment.
  - Iron air, which is an order of magnitude cheaper than lithium-ion batteries and is extremely safe, but largely unproven for commercial mining applications.
  - Hydrogen, which doesn't experience degradation and has an expandable storage capacity limited only by the size of the facility but is hindered by large scale hydrogen production costs.
  - Thermal energy storage, which is cost effective but not competitive with other large-scale applications
  - Molten metal, which is durable does not require critical minerals, but is heavy and requires constant heating.

The EMC undertook two major storage market-testing expressions of interest (EOIs), the first in March 2021 and the second in September 2022, where multiple mining asset use cases were detailed and solutions sought from providers. In EOI 2, submissions were received from 17 LDES providers covering 25 assets, with a broad mix of technologies offered including electrochemical, compressed and liquified gases, gravity, hydrogen and thermal.

Throughout this process two things became clear. Firstly, beyond conventional lithium battery storage, the options for electrical storage were wide open. Secondly, for assets that could use stored heat directly, thermal storage was highly efficient. By the end of 2022, the EMC members reached a level of understanding regarding LDES that they could not have otherwise achieved alone, which substantially influenced their roadmaps.

- **Spilled energy,** which involves utilising the excess energy generated during periods of strong solar and wind generation for value-adding purposes e.g. selling into a grid or finding a new use for the energy.
- **Process innovation**, such as time-shifting energy intensive processes (e.g., crushing) to occur during periods of high renewable generation, or increasing storage in leach tanks.
- **Hybrid stations**, which combine multiple renewable sources as well as energy storage to stabilise the power supply and may also supplement with low-emissions fuels such as natural gas, particularly during transition phases. These stations offer enhanced reliability, but at a high level of complexity, capital cost, and management requirements.
- **Renewable energy precincts**, which operate like a micro-grid to share renewable power supply and minimise the overall power usage related emissions of a region. These reduce individual company costs, as well as overall costs through economies of scale and potential. They also provide potential community benefits such as power supply or job creation. They do require clear governance and cooperation with multiple stakeholders, including local communities and traditional owners, who must be engaged early and authentically in the process.

For remote mine sites using renewable power, how will the electric systems primarily be supplemented when this source alone is insufficient?



Equipment

The problem

Even with 100% renewable energy, a significant amount of direct mining emissions persists from diesel-powered mining equipment (and off-road diesel haulage equipment contributes to the Scope 3 budget outside the fence). Not only is this diesel equipment carbon-intensive, but it also creates serious workplace hazards in the form of DPM, fatigue-inducing vibrations and noise, and excess heat. Moreover, it necessitates high levels of ventilation, which increases a mine's power consumption and upfront capital expenditure.

Equipment class	Australian examples	Typical breakdown of equipment emissions for a mid-sized mineral mine[48]	
		Underground	Open pit
Light vehicles	Utes, buses	~10%	~10%
Ancillary vehicles	Jumbo, longhole drill, cable bolter, charge-up rig, spraymec, agitator, grader, integrated tool (IT) carrier, water truck, stores truck, forklifts	~25%	~20%
Underground load and haul	Loaders, trucks (40-tonne to 65-tonne)	~65%	n/a
Surface load and haul	Loaders, trucks (100-tonne – 300-tonne)	n/a	~70%

Between the planning, studies, funding, infrastructure upgrades, existing fleet replacement schedules, supply lead times, trials, and training, it could easily take 10 years for a mine to transition its diesel fleet. This lead time may be further exacerbated by supply chain challenges and skills shortages once an industry-wide transition gets going.

While a few companies (including most EMC members) are leading the way on planning and trials, most of the Australian industry is taking a fast-follower approach, putting them at real risk of missing their mid- to long-term emissions reductions targets. Our change management survey found the biggest reasons for this are the capital cost (selected as a top-three barrier to electric equipment adoption by 76% of respondents) and the confidence in the equipment performance (selected by 50%).

On these issues the industry is at somewhat of a standoff. Many suppliers are unwilling to lower their prices, given the high R&D costs and lower services fees they'll recoup on new equipment types – but many miners do not have the free capital to justify the higher costs. Even if they did, miners are waiting to see equipment proven in operations before they place orders, and suppliers are not willing to accelerate supply until they see a demand signal.

48 EMC analysis based on https://bellevuegold.com.au/wp-content/uploads/2023/12/J006813-BELLEVUE-SUSTAINABILITY-REPORT-DIGITAL.pdf (Bellevue Gold sustainability report 2023)

The pathways

Several options exist for transitioning away from diesel machines – and many of them offer a lower operational cost or improved efficiency compared to their predecessors. However, many of the new technology options have had limited testing, particularly in Australian underground mining conditions (which use larger 65-tonne-class haul trucks to move material up long declines).

Diesel abatement technology options include:

- **Battery electric equipment,** which is now commercially available in Australia for almost all underground equipment classes, excluding the 20-tonne loader. The most recent entrant to the market is Sandvik's 65-tonne truck, with Barminco undertaking the world's first 65 tonne underground prototype trial at AngloGold Ashanti's Sunrise Dam. The larger electric equipment used in open-pit mining is also ramping up development, with the CAT 793, Komatsu 930, and EPCA "Green Machine" set for on-site trials in 2024.

  Batteries may be available to purchase outright, or through a lease arrangement with OEMs (BaaS); not all suppliers offer both options, and the anticipated rate of improvements in battery technology need to be balanced against the cost offset of an outright purchase. BEVs may then be "refuelled" through direct plug-in or battery swapping systems, which require the installation of powered charging bays at strategic locations within mines, and careful fleet management to minimise disruptions caused by depleted batteries.

  BEVs offer the advantage of regenerative charging while braking (which is useful when going downhill), and reduced maintenance (due to fewer moving parts). They are quieter, smoother, and less heat-intensive than their diesel counterparts, and produce no DPM. They are, however, more expensive to buy, and their operational performance (particularly related to battery range and life) is yet to be conclusively proven on mine sites.
- **Hybrid electric equipment,** which typically use a diesel generator coupled with electric wheel motors and an onboard battery to store energy during braking. Hybrids deliver incremental fuel efficiency savings but continue to emit DPM. They simplify the infrastructure and fleet management requirements associated with battery-only charging systems; however, the dual-technology engines require more maintenance than true BEVs.

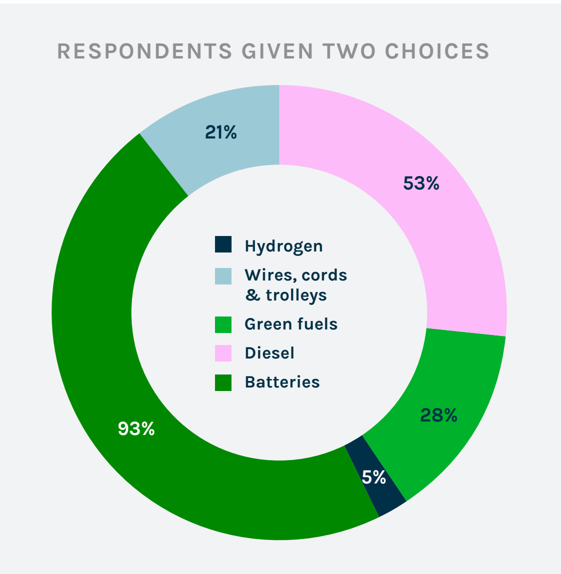
  Hybrids are becoming an increasingly popular transition solution to partially reduce emissions until 100% electric vehicles have proven operational performance, particularly in the Australian load and haul market. The Cat R2900XE is a great example of a hybrid loader which delivers both emission and productivity benefits, and underground hybrid trucks have also been developed in Australia. However, mining companies will not be able to achieve emissions reduction targets using diesel-powered hybrid equipment.
- **Trolley-assist electric equipment,** which is used for heavy haulage applications. An overhead trolley-assisted ascent both powers and dynamically-recharges the battery of the electric vehicle, eliminating the need for battery-swapping or static charging, and the construction of dedicated charging bays. It also increases tram speed and allows the retrofit of existing vehicles. However, it comes with limited flexibility in vehicle movement and large infrastructure costs, making it most suited to specific mining applications where there are consistent long uphill hauls on semi-permanent ramps.

  Trolley-assist equipment has been used in some surface mining applications for a number of decades, but is still rare in underground settings, making it difficult for the market to understand its true performance potential. New innovations in trolley assist such as BluVein seek to address the infrastructure and flexibility constraints of traditional trolley assist through lighter more flexible tethering.
- **Conveyor equipment,** which represents a low operating cost, fully electrified method for transporting mined materials. Conveying is already used commonly in underground coal mines, and the use of conveyors in underground tunnels and declines is being commonly considered in studies as a low emissions transport method. Conveyors are constrained by high capital upfront costs, space limitations in underground tunnels, and limited flexibility to turn corners.

  In surface mines, in pit crushing and conveying (IPCC) solutions have been available for many years, though successful implementation requires a mindset shift in terms of mine design, layout, and operating philosophy.

- **Alternative fuels,** including hydrogen or biofuels such as biodiesel, and natural gas. The emissions and DPM reduction depend on the fuel used. Alternative fuel options are currently expensive and in limited supply in Australia, but some pilot projects are exploring their viability should they become economically scalable in the future. For a time, the industry was focussing on hydrogen as the alternative fuel of choice, but many (including Fortescue, who once championed hydrogen) are now pivoting away from this option. Outside of Australia, Vale are exploring a number of alternative fuel options, including biodiesel and ethanol, to reduce their carbon emissions.
- **Incremental modifications to existing equipment,** that offer moderate emissions reductions may be stacked to meet targets at a lower capital cost and risk than a full fleet transition. These options have the advantage of being versatile, relatively straightforward to implement, and able to be applied to an existing fleet rather than waiting for a fleet replacement schedule. Many reduce DPM and NOx emissions as well as CO2. Examples include fuel additives to improve diesel combustion efficiency (though not popular with and often uninsured by fuel suppliers), diesel particulate filters (though some controversy surrounds their effectiveness), selective catalytic reduction systems, exhaust gas recirculation, hydrogen direct injection, and supercapacitor engine-start modules.

What will be the dominant energy source for heavy mobile equipment underground in the next 5-10 years?



Source: EMC survey 2024

Once a preferred fleet solution is identified, there are a number of technical factors to consider. For example, which part of the site and fleet will be transitioned first? When (and where) will companies begin trialling, and what are the success criteria for these trials? How will restrictions on commercial availability affect the equipment rollout? And how will mines deploy infrastructure upgrades, staff training, and management systems for the new equipment?

Ultimately, for an operating mine, the schedule of the diesel fleet transition may depend largely on the remaining useful life of the existing fleet, which for financial and environmental reasons most mining companies will run as long as practicable. Depending on the equipment, fleet replacement windows may only occur every 3 to 10 years, so missing the first opportunity to transition to electric may dramatically impact a company's ability to meet mid-term decarbonisation targets – and to benefit from potential production improvements.

Hard-to-abate

Even with full investment in energy and equipment-based solutions, current technology levels are unlikely to allow mine sites to reach true zero emissions levels. While the exact level of emissions remaining depends on the commodity and chosen decarbonisation pathway, at minimum, the remaining Scope 1 and 2 emissions include components from drilling and blasting (e.g., carbon released from ANFO), diesel or gas firming of energy and equipment, and processing-related (e.g., anodes in aluminium smelting, reductants in mineral sands, etc.). These remaining emissions are generally classed as "hard-to-abate emissions" and must be dealt with in one of the following ways in order to achieve net zero:

- Carbon credits: which best practice dictates should be verified, local to the mine site, removal-based (rather than avoidance-based) and have co-benefits for the community beyond just carbon removal. There is some risk that certain credits may become devalued before they can be redeemed, as governments become more stringent.
- Nature-based solutions:which employ tactics such as tree-planting or soil/environmental rehabilitation to sequester greenhouse gases. These solutions may be similar to those used by carbon-credit schemes but are deployed more directly by the mining companies (e.g., planting trees on their own land). Nature-based solutions must also consider the overall impact on the native biodiversity, communities and waterways – for example, avoiding the planting of invasive species or monocultures.

- Technology-based solutions: which use new technologies to further abate emissions or sequester greenhouse gases (e.g., hydrogen calcination, carbon capture and storage). These technologies hold promise, and ultimately are likely to play some part in addressing hard to abate emissions.

Science based net zero targets require companies to abate all possible emissions before neutralizing the remainder through these techniques.

Putting the system together

Each mine is a unique, complex, integrated system, and it is difficult to fully predict how changes brought about by new technology will affect the other components of a site. Over time, we expect to see the industry standard evolve from diesel mines to partially diesel/electric mines, to electric mines based on diesel mine design, to electric mine designs optimised for electric technology. Each of these steps will build on the learnings from the preceding step and include different system design assumptions and decisions.

The specific decarbonisation pathway chosen will have large implications for a mine's structural and operating design, and vice versa – mine design choices will embed carbon emissions for future production. A fixed asset design (e.g., existing decline) limits the number of viable decarbonisation pathways a mine may pursue, so it's generally easier (and cheaper) to design a low emissions greenfields mine than to transition a brownfields site. Similarly, it's more efficient to design a mine system based on a thorough prior knowledge of both the underlying ore body and the interrelated components that will occur within the mine (e.g., power infrastructure and supply/demand profiles, safety systems, communication systems).

Still, strategic design tweaks can make a significant difference to the emissions intensity and productivity of existing mines, and in face are likely to be necessary even for today's greenfields mines, as emissions reduction technologies are evolving rapidly. Site roadmaps should therefore be reviewed regularly enough to incorporate these new offerings in a timely manner, and the design of the mining system should aim to preserve optionality where possible in order to take advantage of any future developments.

Chapter 6: Electrification transformation handbook

"Mine electrification learnings from hundreds of experts over hundreds of hours through the EMC."

Our consolidated learnings

Over the course of the EMC, we have learned countless lessons (both generic and specific) about how to best electrify mines. In this chapter, we share a non-exhaustive list of these practical lessons, spanning the topics of vision, studies, energy, equipment, system design, and human factors. Our suggestions here are based on our unique whole-of-system perspective, which encompasses details from strategic and commercial planning all the way through to day-to-day implementation across the entire operation. We hope they may act as a handbook to guide the industry when working on mine electrification projects.

The requirements of transformational change

Vision

- Generate discomfort with the business-as-usual status
- Understand the visceral, inherent value of changing
- Secure unwavering CEO intent, leadership and support for the change
- Know your peoples' appetite for change

Planning

- Understand the technical feasibility
- Define strategic goals and project scope - where to lead versus where to follow
- Spend time in uncertain early planning stages - open minds and explore all options
- Identify stakeholders, team and strategic partners
- Set KPIs and assign accountability structure
- Create tipping-point objectives

Cultural Implementation

- Cultivate supportive social environment
- Communicate vision consistently
- Engage top-down to create champions
- Engage bottom up to smooth frictions
- Celebrate wins for resilience

Technical Implementation

- Anticipate + remove roadblocks
- Upskill employees
- Resource the work
- Use cross-discipline taskforces
- Integrate into business as usual

Embedding change long-term

- Insulate against leadership change
- Guard against reversion to the status quo
- Make the behavioural change inherent and satisfying rather than compliance based
- Analyse results and record lessons learned

Strategic vision

The transition to an electric mine is much more than a technological shift; it is a major organisational transformation. Successfully navigating such a transformation requires a clear and compelling vision. This overarching vision (which should integrate seamlessly into the company's strategy) will not only guide the technical choices but also the timing and will further help in rallying support across various levels of the organisation. Establishing a convincing vision is therefore the first step towards the electric transformation.

"Leadership intent will be the biggest determinant of rate of change now" – EMC workshop (August 2024)

EMC learnings:

- **First things first: think the strategy through.** When developing good strategy, an organisation should begin with an open-mind about what change is possible – this starts with engaging with thinkers who will test the status quo and considering case analogies. Organisations should invest time into understanding the short and long-term implications of asset system change under a range of plausible external scenarios. Finally, they should examine the impact of the change on a day-to-day basis for a range of key work areas. In this case, leadership without hands-on mining experience should consult trusted operators for guidance.
- **Sow seeds of discomfort with the current state.** In order to move towards an electric future, mines must first move away from diesel. Organisations can prepare their people for this change by highlighting the issues with diesel operations and allowing a forum for complaints, as well as exploring some of the more foreboding analytics related to factors such as class action lawsuits or tightening emissions regulations. Then, when the workforce begins to call for change, organisations can deliver it.
- **Encounter the future.** Once people have seen what's possible, it's hard to unsee it. To build trust in an electric future, organisations should give their visioning, implementation and operations teams the opportunity to experience it first-hand by taking trips to see electric mines in operations overseas, speaking directly to those working in established operations, or test-driving electric mining equipment. For example, anyone who has sat in the EPCA green machine is quickly convinced of the inevitability of electric haulage, and those operators who have seen firsthand electric drive loaders need no convincing of their productivity advantage.
- **Demonstrate top-down investment in the vision.** Without resolute CEO support and sponsorship, transformation efforts will end up spinning wheels. We have already laid out much of the value case needed for innovative executives to buy in to the electric future. By repeatedly demonstrating authentic, undivided support for the vision (and the steps needed to get there), leadership will keep the organisation aligned and able to clear the inevitable hurdles. Leadership must also reserve an adequate pipeline of resources (both capital and human) for the work.
- **Develop the vision into context-driven goals.** From the big vision comes a tight set of specific, measurable goals which lay out the path from the current to future state. These must be compatible with other organisational goals. They allow an organisation to work towards milestones in stages to maintain focus, secure early wins, and avoid overwhelming or disengaging the workforce with distant horizons. Interim emissions targets are a good example of this, though asset-specific goals for each area of the strategic roadmap should also be put in place.
- **Protect the transformation effort from organisational opposition.** Transforming a system at equilibrium (such as a productive diesel-powered mine) will no doubt encounter threats in the form of dissent, competition for capital, leadership changes, market forces, change fatigue, and technological and procedural teething issues. Once a vision is established, limit the transformation team's exposure to these threats by giving them high-level organisational authority and test facilities (e.g., skunkworks) with a significant resource runway, until they have gathered enough momentum to overcome significant barriers.

- **Market the vision broadly.** Getting the early sponsors committed to electrification is one thing, but ultimately it must be sold to the next wave of stakeholders. This includes the rest of the organisation (remember, change affects everyone!), but may also include shareholders, regulators, community groups, commercial and financial partners, customers, or the future workforce (including future leadership). Understanding the broad range of benefits and leveraging early wins can go a long way in this process. By repeatedly communicating the elevator "what's in it for me" pitch, tailored for each individual's interests, organisations can embed broad support for the change and energise their people to make it happen.

"Without clear and realistic organisational strategy, individuals are given conflicting personal goals (e.g. productivity vs electrification) which cannot be reconciled."
- EMC survey respondent

Studies

Studies are a crucial part of the planning process for mine electrification. If done well, studies (and associated planning tools, such as simulations and models) can identify how best to maximise the productivity efficiency of new systems and encourage stakeholder confidence in the investment decisions. Just how to do these well is still a difficult question to answer – modern mine electrification is a new game, and the appropriate methodologies, tools, and expertise are still being established. Companies must first clearly identify the goals and scope of the study, as well as their uncertainty tolerance. Real traps to be avoided are analysis paralysis (over-agonising the studies phase and delaying action) and utopia myopia (proceeding with a seemingly obvious option while being blind to preferable alternatives).

"BEV mines will operate differently to diesel mines – an open mind is required! Build your mine from first principles and be prepared to revise / rework as your study progresses."
– EMC workshop (June 2024)

EMC learnings:

- **Be prepared to think differently from the beginning.** Whether working on a brownfields or greenfields mine, an electric mine study must put aside conventional mining philosophies to design for the completely new systems required. Approaches may include building out a study from a "blank slate", designing for the evolution of technology options that may not currently exist, workshopping ideas with cross-industry experts, taking a whole-of-system perspective, and working backwards from a highly ambitious goal to discover what's possible.

  This reveals a need to develop simulation capability in order to visualise and test a variety of operational concepts, including those that move away traditional truck and shovel methods. In addition to defining the path for electrification, these fresh approaches can lead to the development or justification of complementary initiatives such as autonomous equipment, shared energy infrastructure, or opportunities for asset optimisation based on new levels of data and control.

- **Ask the right questions of the right people.** What answers does the study need to find, and to what level of accuracy? Who will provide them, and how? The specific analysis made will depend on the constraints and opportunities of the particular asset. Electrification studies are a prime opportunity to partner with a range of internal and external subject matter experts to get the best possible results. This may include corporate, operations, and maintenance staff, clients (for mining contractors), OEMs, community groups, regulators, or other complementary companies. It may also be useful to consult the operators from the first generation of electric mines in the 1960s-1980s, or the new electric mines operating in North America and Europe. The study phase is where the change management process begins – involving operations leaders in evaluating a range of options at study phase is helpful to project acceptance as the study moves into implementation.

- **Be smart with data acquisition and analysis.** Unlike diesel, electric equipment does not have a wide body of existing data points to draw from. The collection of reliable data is therefore a primary focus of new equipment studies; this data helps to ensure the studies are based on reasonable input assumptions and provide confidence around equipment performance. It is important to design the most useful operational metrics up-front, so they can be used to guide the study.

  Site technology teams should be engaged early to ensure infrastructure is designed to enable regular data acquisition and transfer from electric equipment – data will be much more available than with diesel equipment. The efficient collection, storage, and analysis of electric equipment data and other data should be well-planned to answer the study's key questions. Studies can then make effective use of these increases in data through advanced analysis tools, including financial models, detailed operational models (e.g. time-usage), and full-scale simulations.

- **Consider the whole picture.** Accounting for the long-term whole of system business case is the best way for studies to capture the full benefits of electrification. Electrification is characterised by high capital outlay and low operational cost, which is more favourable over longer time frames. Also, the inclusion of non-traditional valuation model factors such as social license to operate will further enhance feasibility of the project.

  A systems approach incorporates integrated consideration of the full fleet, energy systems, and workforce, rather than on a truck-by-truck basis. For example, integrated questions include. How much equipment is required to achieve the target production in an electric mine? How do the battery charge and discharge rates inform the charging infrastructure? And what impact does that have on peak load and required power infrastructure? This systems-wide view of the physical assets may unearth greater opportunities from electrification; for example, the Cosmos study (a collaborative effort between IGO, Perenti, and ABB, comprising over 2000 engineering hours) examined the impact of fleet electrification on the underground mining system, and found that the reduction in ventilation power usage more than offset the increased power usage from the electric fleet.

- **...But don't forget the granular details.** For a reliable study result, the devil is in the details. It's important to understand what each of the equipment, workforce, and assets specifically need to do over different timescales (shifts/days/weeks/months/asset life). This allows the study to identify optimisation opportunities (e.g., for charging and energy smoothing) as well as potential problems to overcome before they manifest. Breaking these details down for the distinct phases of the project, from initiation through to operational readiness, commissioning, and deployment, will help to ensure that the unique requirements for each stage are defined and met. It also helps to understand the timelines for commissioning and ramp up, which often takes months for new technologies.

- **Communicate results effectively – both internally and externally.** Studies teams must take care to communicate their findings effectively. This means engaging the right stakeholders, at the right stage, with the right information. Clear internal communications are critical to establishing broad organisational support through the decision-making process. For example, long reports with complex background calculations but lacking a clear and logical story about the results can undermine support from operating executives accountable for implementation. Communicating studies outcomes outside organisation is important to build reputation, attract partners, customers, and staff. This is also important for developing the broader industry landscape for electrification.

Over the life of the EMC, members shared the methodologies and results of various studies, to strengthen our collective knowledge and demonstrate their leading capabilities. Studies that were showcased include OZ Minerals' feasibility study for light EVs at Carrapateena, South32's heavy equipment design at the Hermosa greenfields site, and IGO/Perenti/ABB's study for a full electric underground fleet at Cosmos. Below is a typical sample of the information shared in the studies:

Objectives

- Compare the performance of diesel light vehicle fleet to a fleet of underground electric light vehicles.
- Model the movements of the fleet underground at a Consortium site.
- Study the impact on range anxiety and day-to-day operations.

Process

- Measure and compare battery state at predefined intervals.
- Generate a topographic model of the site and track the new equipment using Mobilaris
- Trace the shift boss weekly journey and end of shift recharge times.

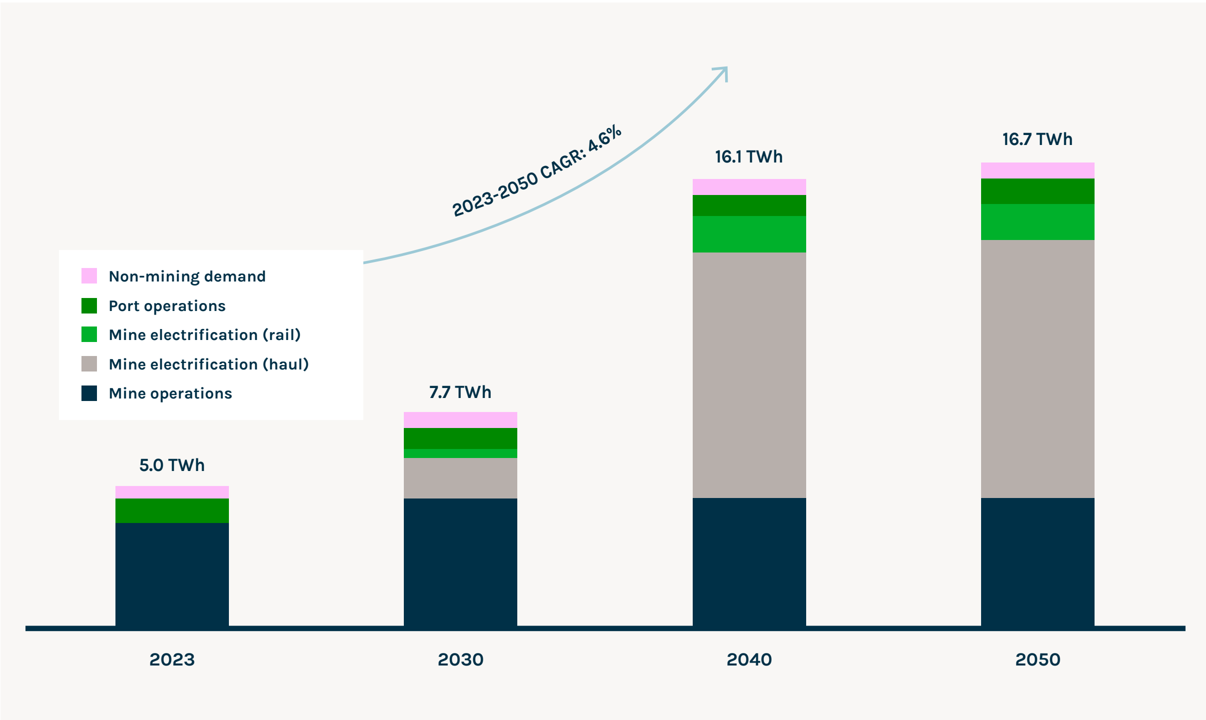
Learnings

- The actual battery state closely matched the modelled battery state.
- The new equipment successfully replicated the weekly journey with end-of-shift recharge times, demonstrating the feasibility of electric vehicles in underground operations.

Energy

Energy is the bedrock of transformational mine projects – without efficient access to clean energy, there's little decarbonisation value in electrifying. Fortunately, the complex challenges surrounding energy generation or procurement, storage, and usage are not unique to the mining industry, so there were plenty of experts to contribute to the EMC's body of knowledge. While the sheer scale of the supply challenge can be daunting, the facts are that there is a growing number of miners who already have plans underway to exceed 80% renewable penetration, and the cost advantage is growing every day. Energy storage to address the remaining 20% remains a technology development challenge.

Mine decarbonisation will drive electricity demand (Pilbara region)



Source: APA, BCG

EMC learnings:

- **Protect optionality during the rapid technology ramp up.** Many mines are transitioning to renewable energy supply at a time when technology is also evolving rapidly (particularly in the LDES space). It is therefore important for miners to balance acting with preserving optionality and avoid locking themselves into unsuitable long-term solutions through sunk investments. For example, a mining company may opt not to connect to a gas pipeline in order to avoid long-term gas offtake obligations. This decision reserves some capital and avoids locking in a financial commitment that would be a future disincentive to expanding renewable generation.
- **Take a local approach to power partnerships.** The need for power is universal – but the most efficient way to share it is locally, be it with other mine sites, processing or industrial hubs, or communities. This takes advantage of economies of scale while minimising loss from electricity transportation. By exploring the regional common generation capacity, storage capabilities, and usage requirements, companies may discover a mutually beneficial energy solution that lowers the infrastructure cost and risk for any one member of the precinct. Local hubs may also motivate future grid connection, build relationships with local communities, and forge ongoing professional partnerships in the region.

The EMC successfully helped establish the concept and ongoing process to develop shared infrastructure for renewable power generation, battery storage, and desalination assets in Western Australia's Northern Gold Fields mining epicentre. This represents a transformative shift in how the mining industry approaches power production and environmental stewardship, beyond just reducing carbon emissions. It aims to create an integrated ecosystem that fosters economic development, community empowerment, and technological innovation.

The vision includes the creation of a microgrid between three large mine sites, targeting construction commencement in the next two to three years. Plans are also in place to develop two substantial renewable energy generation hubs, in the north and south of the Gold Fields to connect more mine sites to Western Australia's south-west power grid (the "SWIS"), providing opportunities to optimise energy emissions and costs. The hubs have the potential to form a private network stretching over 700 km from inland Western Australia (Kalgoorlie) all the way to coastal regional centres like Geraldton.

- **Leverage energy and technology experts.** The ubiquity of energy challenges and the potential size of the developing mine electrification market means there are a number of high-quality service providers available for the industry to call on. Whether it's tangible cable management solutions or advanced energy management system software, consulting widely to find the right solver for the problem will save time and energy in the long run.

  EMC members Ampcontrol and 3ME Technology have a demonstrated track of innovating and supplying products and services to support mine electrification, and Zenith Energy have become a leader in fully integrated remote site renewables supply. We have also started to see the emergence of large electric integration companies such as ABB and Schnieder Electric playing a key role in partnering with multiple miners across several projects.

- **Don't forget about physical infrastructure.** The supporting infrastructure and equipment required to generate, transport, store, and utilise energy has to interact smoothly with the rest of the site and its operations. This infrastructure is often bulky, expensive to purchase and install, difficult to move, and subject to the harsh conditions of mining environments – so setting up the right infrastructure in the right way from the outset is important.

  Understanding the physical constraints of a mine's power assets and how they must function in an integrated mine environment is an important optimisation problem to solve in an age where an abundance of potential assets and configurations exist. Outcomes may be as simple as installing a protected channel to ensure cabling isn't accidentally damaged by mobile equipment, or as involved as developing a separate renewable farm for the energy intensive electric fleet, to remove peak load issues in the main site. Industry-wide development of physical asset standards and methodologies (such as charging infrastructure) may ease the burden of work on any individual company when trying to best design their physical asset plan.

- **Create a standard of power conservation and renewable energy optimisation: Over the life of a mine**, the minimisation of wasted energy can add up to significant savings in both emissions and fuel/provider costs. A mine that is more energy efficient runs at a lower operating cost and requires a smaller renewable installation to supply at a lower capital cost – a rare double cost saving opportunity.

  This opportunity can be seized through energy saving devices such as variable speed drives, motion sensors that switch off lights when there is nobody in an area, and plant control systems that stop running empty processes (e.g. conveyors). Such technologies are all typically built into new sites but have patchy adoption in brownfields. Energy saving can also be built into processes, such as opportunistic charging, prioritising ore sorting to minimise the material being processed, or recycling degraded equipment batteries into lower-capacity stationary energy storage.

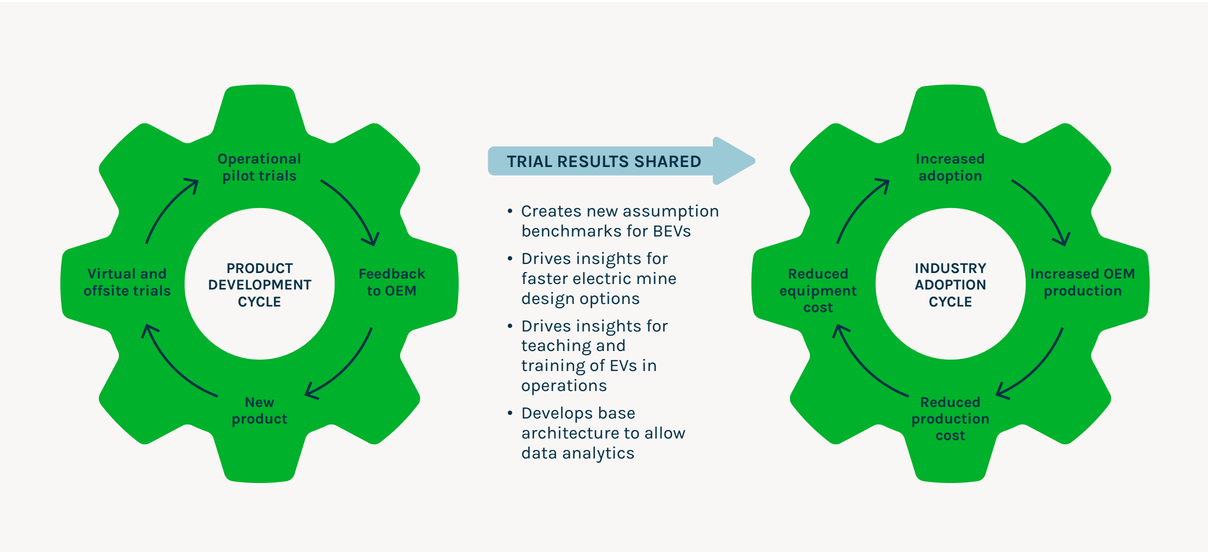
  Organisations can find further opportunities for power saving by cultivating a culture that views energy as a precious resource rather than free and unlimited. Tactics to motivate such a mindset and behaviour change include clearly communicating the energy saving mandate, measuring and reporting team energy usage to gamify the savings, or adding related incentives. In 2021, EMC member IGO added a culture and behaviour change category to their business-wide decarbonisation roadmap, for an estimated CO2-e abatement of 800 tonnes per year.

Equipment

Introducing new equipment to operational mine sites is no small feat – particularly in the case of electric vehicles, which so far lack the broad user experience and knowledge base of internal combustion vehicles. Beyond simply choosing the right gear to purchase, equipment transitions depend on training the workforce for usability and maintenance, the installation of supporting infrastructure (e.g., charging bays), and the supply and reliability of the equipment itself – often established through trial programs. A continual feedback loop is necessary for both integrating site trial learnings into future operating assumptions but also into ongoing product development.

Understanding how to best adopt electric equipment was a central focus of the EMC's work. While supply chain disruptions and high initial capital costs remain problematic, our members have now developed and shared knowledge about the capabilities and technical readiness that will equip them for an effective transition.

Collaboration can drive equipment development and adoption



EMC learnings:

- **Invest now to meet long term targets.** The lead time on electric equipment adoption, or the introduction of any new technology class, can be deceptively long. While 93% of our survey respondents do not expect most existing mines to transition to electric within the next five years, this period represents a crucial window for investment in early learning programs that will steer future decision making.

  It is also often the case that supply bottle necks occur with transformative technology adoption once an industry decides to move en masse. Investing early is one way of mitigating this challenge. By establishing a growing pipeline of investigation, training, studies, and site-specific trials, mining companies can prepare for a smooth scale-up when the time comes for a full fleet transition – and enjoy some of the early benefits of electrification.
- **Choose commercial partners carefully.** The choice of commercial partner may be just as important as the choice of technology strategy when trying to accelerate emissions reductions. For example, there are many suppliers in the light vehicle arena, including some small and Australian-based OEMs – are miners better off partnering with these emerging businesses to access the benefits of bespoke offerings and domestic support?

  Meanwhile, the heavy load-and-haul market tends to be concentrated into a few large companies, which are generally able to provide greater support. These suppliers often focus on producing proprietary equipment (e.g., charging stations), resulting in slower innovation cycles and making it difficult to mix-and-match incompatible equipment from multiple suppliers. However, there are signs of new suppliers emerging in small-to-medium truck haulage, both those crossing over from on-highway transport, and those with close relationships to the battery supply chain (e.g. from China).

  Automation is another important factor to consider - can selected partners enable interoperability across suppliers to provide access to electric-automated vehicles in the future? The choice of who to partner with, and how to manage those partnerships, will inevitably affect the roll out of any equipment roadmap.
- **...Particularly when it comes to batteries and chargers.** Two commercial areas requiring a new approach are the supply of batteries, and the supply and installation of infrastructure. Batteries and chargers are integral components – if they go down, your BEV goes down. The batteries are a new dimension and have effectively become separated from the base vehicle in terms of commercial arrangements. Some suppliers place limitations on their commercial offerings by only offering battery as a service rather than outright purchase, limiting the reuse pathways for stationary energy storage.

  The supplier and miner need to work through a new set of risks that are still not fully understood. upfront capital, expected life, declining performance over that life, ability to adopt step-change improvements and end of life arrangements. There are potential traps in these risks and a long-term partnership approach will be required if disputes are to be minimised. Similarly, there needs to be a rethink on respective party roles in funding, installing, operating, maintaining and upgrading the associated infrastructure.
- **Be prepared to rock the boat with contractor services.** Traditional mining contract models see much of the operational cost risk adopted by the contractor, who often operate on thin margins. This model may need to evolve to suit the capital- and risk-intensive scale up of mine electrification. Depending on the priorities and capabilities of contractors with regards to emissions reductions, miners may even have to look for new providers.

  Decarbonisation-focussed miners may have a difficult time changing from a diesel fleet if their contractor is inexperienced or unwilling to invest in new technology options. On the other hand, contractors such as Barminco (Perenti's underground mining service) have established an expert team of mine electrification engineers and trialled almost every piece of electric equipment required in an underground mine; however, given the higher capital cost and more integrated infrastructure required, they are unlikely to scale up investment in such equipment without seeing the demand from their mining clients. In any situation, early conversations can motivate risk sharing and avoid getting locked into unsuitable commercial arrangements (or locked out of the electric equipment supply chain).

- **Communicate expectations clearly and work together to achieve them.** Now is also the time for transparent conversations between miners, contractors, OEMs, and other service providers supporting the equipment transition. The greater the mutual understanding of asset and equipment constraints, performance expectations, expected costs, emissions and DPM targets, supply timelines, business realities, and contract agreements (including performance guarantee clauses!), the smoother the process for the whole group of commercial partners.

  A healthy ongoing relationship between partners also helps to identify and address any equipment delays or malfunctions as early as possible – and makes OEMs available as a good starting point for insights on site readiness needs, vehicle specifications, and maintenance strategies. It then follows that partnerships should be owned by a mine's operational and functional teams, who will be working with the infrastructure and equipment on a daily basis. Skilled negotiators should also be included in the partnership teams; there has been some tension between OEMs and miners regarding low-emissions equipment, with just frustrations occurring on both sides. At the end of the day, though, all parties will need to work together to overcome the teething issues and deliver on the equipment transition.

- **As much as possible, test equipment away from operations.** Across the EMC, members undertook planning or execution of trials for over 70 pieces of equipment. One lesson quickly became clear – on-site trials are disruptive. All too often they negatively impact production and cause frustration for the mining teams, harming the attitudes towards broader electrification. While some aspects of a trial may require a site-specific set up, we recommend using off-site proxies such as simulations, dedicated testing facilities, or siloed mine sections to work through early tests and build familiarity ahead of full site deployment. A convenient testing ground is the Australian Automation and Robotics Precinct (AARP) 30 minutes north of Perth, which offers a range of lease facilities suitable for mine equipment testing.[49]

- **Prepare for roles and responsibilities to change significantly.** The equipment transition represents a prescient opportunity for miners to reconsider the way they define roles and upskill staff in a range of areas that will deliver benefits far beyond the tenure of the electrification project. Throughout the EMC, a number of implementation leads testified to the need for greater project planning and management capabilities when deploying new electric equipment. Similarly, we heard that dual-ticketing engineers for mechanical and electrical work was an effective tactic for electric mines operating in Canada. Mines are therefore presented with a timely opportunity to upskill teams in areas that may be useful for a variety of projects beyond just electrification.

  In terms of outsourcing, some members found that they could lean more heavily on vendors to communicate with the site on operational readiness, safety and risk assessments, and maintenance. Other members effectively utilised fire departments or industry safety bodies (e.g., EV FireSafe) to allay fears about battery fires.

- **Trials present a strong opportunity for mutually beneficial collaboration.** The EMC's commitment to knowledge sharing extended to equipment trials. Results were distributed in working sessions and via a shared data platform, which has had a demonstrable positive impact on the adoption of low emissions equipment for our members. While the size of our membership saw us face lengthy negotiations for confidentiality agreements and inconsistencies across data collected from different sources, more straightforward sharing of valuable trials results (e.g., in press releases, conference talks, or small groups of collaborators) can and should continue. This sharing enables peer review of the trials and results, boosts the industry's confidence in the new technologies, develops our collective skills and methodologies for executing trials, and generally continues the momentum towards an electric mining future. Innovative risk sharing approaches are also emerging, such as "trials roadshows" where multiple sites trial the same piece of equipment in succession, iteratively learning from each other's experiences and sharing the total cost.

49 https://www.theaarp.com.au/

The EMC's information sharing sessions allowed all members to see the real operational benefits (including a 23% increase in productivity) South32 and others gained during their trial of Cat R2900XE loaders. This inspired the purchase of 7 loaders across the member companies, including several who had not trialled the vehicle themselves. Below we list a few of the other trials shared, and the key learnings that were passed on to EMC members:

- EMC member trial of battery electric explosives charging vehicle.
  - **Outcomes:** Demonstrated no battery or system limitations during normal duty cycles. Charging on 1000 v between faces saved time and reduced manual handling.
  - **Learnings:** The importance of maintaining state of charge (SoC) and the effectiveness of high-voltage charging systems. As a vehicle commonly used in areas with less ventilation, remaining stationary for periods while running, a vehicle with zero heat and DPM provides a significant step forward for operators.
- EMC member trial of electric personnel carriers.
  - **Outcomes:** Both models performed as well as business-as-usual vehicles, with notable tight turning radius and excellent lighting capacity.
  - **Learnings:** The suitability of specific vehicle designs for mining use was evident.
- EMC member trial of battery electric light vehicle.
  - **Outcomes:** Inspired an EMC discussion about ongoing opportunities for industry trials roadshows and demonstration programs, and dedicated test facilities such as AARP near Perth, WA.
  - **Learnings**: There is a need for thorough planning and stakeholder engagement to ensure successful trials. Early involvement of the site team in trial planning is crucial for maintaining momentum and ownership.

- **Be clear on the difference between the old and new equipment.** Though it may be tempting to promote electrification by saying "the equipment is not that different to diesel", it is more valuable to focus on the differences and make sure they are well understood by the workforce. Many of the ways we interact with diesel vehicles are intuitive or based on muscle memory, and reprogramming those behaviours for electric vehicles to minimise incidents requires a dedicated communications and training effort.

  To ensure a smooth integration, everyone should understand what "normal" looks like for the new technology and be confident using it as well as recognising and responding to its different states. We've included two EMC member stories to demonstrate this point:

  - Electric vehicles consume power when going up an incline and generate power through regenerative braking when going down... so how did one vehicle run out of charge when going downhill? It turned out the operator had been riding the mechanical brakes – a reasonable practice when in a diesel vehicle, but a counter-productive approach in an electric vehicle.
  - Though the probability of occurrence is low, battery fires pose a serious risk in mining operations and are the source of fear in the workforce when BEVs are introduced. In a recent light vehicle BEV trial, the vehicle's fire suppression system was falsely triggered by a voltage drop in the vehicle's electrical system. Operators observed the fire suppressant discharging and assumed the vehicle was on fire. Whilst ultimately the explanation was simple, the initial uncertainty as to what happened resulted in a lengthy suspension of the trial.

- **Get some easy wins on the board to build confidence in new tech.** The initial introduction of electrified equipment will, like most other new technologies, elicit a range of responses from people, from excitement through to outright opposition. Establishing some momentum by beginning with low risk, scalable projects will go a long way towards a successful total transition. For example, miners may focus on converting the light/auxiliary fleet first, as it offers the opportunity to develop cultural acceptance and operational readiness without compromising production.

Moreover, capital costs for electric consumer vehicles are also forecast to converge with internal combustion engines (ICE) as the cost of Li-ion batteries fall. This suggests that light BEVs will become economically viable to replace ICE vehicles on mine sites. While the forecast does not refer to auxiliary equipment, the cost of niche, mining specific equipment should follow suit. Similar staging may also be applied across a company's portfolio, transitioning the most compatible site first and using the process to inform future conversions.

Staged trials process

	Stage 1: Off-site technical readiness	**Stage 2:** On-site operational readiness	**Fleet transition:** New business as usual
• Vendor test & commission offsite	• Initial performance data • Calibrate simulations • Common user facility • Skills and training, e.g. operators • Drafting procedures, e.g. HSE • Risk management • Business case for fleet transition • Awareness and branding	• Technical integration • Calibrate mine plans • Upgrade infrastructure • Refine performance assumptions • Finalise business case • Finalise training	• Commercial procurement of fleets • Commissioning and ramp-up • Decommissioning diesel fleet • Reap the benefits

AARP: World-class facilities ready for lease

- The AARP offers next-generation facilities for leading robotics and automation innovators.
- Six large test zones are available for lease ranging from one to 22 hectares. The sites have been purpose buwilt to suit a broad range of industries to develop, test and showcase products and services in real-world environments, without the need to disrupt operations or production.
- An interim on-site office with co-working spaces is currently available for use, while the AARP Headquarters building is under construction.

Mine system design

Traditional asset design does not enable the realisation of the full benefits of mine electrification; for example, the reduced need for ventilation, increased equipment productivity (acceleration, torque, turning, control), the ability to recover energy through regenerative braking, and a more data rich environment. Leveraging these benefits requires a systems approach to mine design from the outset which integrates the incorporation of new equipment, infrastructure, energy supply, storage solutions, ventilation systems, and management systems. These changes are most beneficial for greenfields projects, where the full range of benefits can be deployed, increasing mine lives and potentially unlocking marginal ore bodies. Brownfields sites, while more challenging, can still benefit from electrification through targeted upgrades and procurement strategies.

The limited application of electrification technology means that many design assumptions are based on OEM specifications or limited trials. Without operational verification, there are risks – experience suggest that OEM claimed performance for new technology may not be met; however, the operational use of the equipment may expose new opportunities and operating models that had not been considered. Until electrification is widespread, the industry should invest in innovative and cost-effective simulation models to validate new design principles.

Mine Design Simulation

- **Objectives**: Develop an open-source platform to compare electrified and diesel mining approaches. Identify roadblocks to electrification and establish a mine design standard.
- **Process**: Invitations were sent for submissions, leading to 23 entries and 8 shortlisted candidates. SimGenics, in collaboration with SET, was selected to design the simulation platform and undertake a case study simulation.

EMC learnings:

- **Understand the ore body.** From the outset of the EMC, members pointed out that if they had more ore body knowledge and (presumably) a longer mine life, the case for electrification would be much easier to make. A longer mine life allows more time for payback on major capital investments for electric haulage e.g. shafts at underground mines and trolley assist infrastructure at surface mines. For the underground case, haulage to the shaft can sometimes be via level (or in some cases, downhill) routes, which are more compatible with battery electric equipment than long uphill inclines.

  It is worth noting that in Australia, the trade-off of drilling costs vs JORC reserve reporting vs capital raising models tends to result in mine projects being designed with shorter initial lives than in other countries (e.g. Canada). The opportunities presented by electrification, and the need to meet emissions reduction targets, will change the balance of this trade-off, with more drilling required to properly assess electric mine options.
- **Design to enable big wins.** Designing the mining system is like any other design task – the big value objectives need to be identified early so that the full range of emissions reduction options are included and assessed. Key variables include the orebody itself, the mining method, mine layout, cut off grades, mine capacity and life, how the orebody will be accessed, and overall financial returns.

  There is a new imperative as part of the design process: how can material be moved from the mine to the processing plant as energy efficiently as possible? This requires mapping out how much energy must be delivered and stored, at what times, in which locations, as well as options to use spilled energy. The design process will include adjustments to traditional electrical load calculations, considering loads that are materially increased (e.g. rapid battery charging) and those that are decreased (e.g. ventilation in underground mines).
- **Design to enable small wins**. Electrification enables a host of operational benefits, that while not impacting significantly the overall mine development architecture, are significant in aggregate. For example, a full electric fleet may allow for steeper declines (given their higher torque) and the use of smaller vent bags and drive profiles but requires strategically placed charging bays in order to maximise regenerative charging, match the operating cycle and meet safety requirements.

- **Preserve optionality.** We are at the start of a physical technology transition that will impact how assets are designed and operated for decades to come – in some cases, mines will be designing for things that aren't invented yet. It's therefore important to prioritise scalable, flexible equipment and evolving infrastructure to preserve optionality and mitigate future risk. In large projects, the imperative for embedded optionality increases with the quantum of up-front capital expenditure, the life of the project with respect to the pace of technology progress, the uncertainty of the up-front designs given the environment, and the degree to which different components of the asset are integrated.

  Specific areas where developers should look closely to embed optionality include:

  – Avoiding committing to take-or-pay fossil fuel energy contracts.

  – Design of energy supply infrastructure to allow modular increases to solar and wind capacity, cater for the later installation of long duration energy storage, whilst maintaining local grid stability.

  – Designing processing operations with adequate capacity and in-process storage to take advantage of the daily cycle of low-cost renewable energy supply.

  – Design of major ramps (surface mines) and development drives (underground) and electricity reticulation infrastructure that allows for inclusion of trolley assist on ramps and declines

  – Design of energy reticulation infrastructure that allows for fast charging developments

  – Design of charging infrastructure for ready re-location

  – Design of ventilation systems for underground mines to allow future variability

- **Consider the risks of mixed-technology systems.** With the mix of legacy and greenfields assets, and the evolution of technology, it is inevitable that assets will be operating, for a period, with mixed diesel based and electric technologies. This presents several challenges, including:

  – Optimising the mixed system, which is generally less efficient than a fully electric system. Simulation and specific design of the operating system will be essential for achieving this.

  – Designing infrastructure to support both types of fleet, such as ventilation to suit diesel vehicles, passing bays to account for different tram speeds between equipment types, or workshops to suit either diesel or electric vehicles.

  – Ensuring that the electric technology is not unduly impeded from operating efficiently, thereby leading to potential reversion. This requires appropriate levels of skills, services and communication.

  – Building electric equipment replacement into diesel equipment management plans. This may require the adjustment of diesel equipment replacement cycles, and/ or adjustments to mining contracts.

- **Understand the new operating principles required.** Operating an electric mine is intrinsically different from a diesel mine, and new operating principles will need to be articulated and implemented. At the highest level, new operating principles will be driven by a new form of site-wide integrated energy management to deal with the step change in the number and intensity of electrical connection points as well as the intermittent renewables supply. At the most detailed level, new operating principles will be required for equipment operators to ensure safe production.

  Articulating and implementing Mine Operating Systems remains an ongoing challenge that businesses face, irrespective of electrification and despite the attention and resources that it already receives. The opportunity exists to use electrification as an ideal catalyst to re-examine mine operating systems and improve their application. Like all operational readiness challenges emanating from new design, the earlier operators and implementers are involved in the process, the more effective the outcome will be.

- **Allow for production impact.** Miners are naturally cautious with respect to physical innovations in production assets, because such projects have the potential to impact their revenue that already suffers from price and ore body uncertainty. So, the potential impact on production across trials, greenfields ramp-up, and brownfields conversion needs to be carefully analysed and planned for as part of the electric transition. A pilot trial or conversion will almost always be slower than the subsequent efforts, so it's important not to get discouraged by the initial results. For this reason, setting unrealistic productivity expectations or underestimating allowances for production impacts to "enhance" the case for electrification will only set back the change. Executives are well aware that once performance objectives have been missed once, they are likely to be missed again, driving scepticism and lack of future support for electrification. On the other hand, setting achievable production targets that are progressively increased can build momentum for the transformation.
- **Develop industry standards for commonly used technology infrastructure.** Common standards would ensure interoperability of equipment from different suppliers. If deployed effectively, standards can also reduce costs by removing friction from manufacturing uncertainty and creating a healthy platform for supplier competition. They can also give peace of mind to potential early adopters who are wary of being captured with legacy technology with an inability to switch or upgrade, and potentially reduce the complexity or learning curve for late adopters. The Global Mining Guidelines Group (GMG), the Charge-On Innovation Challenge, CharIN, and ICMM's Cleaner Safer Vehicles are all examples of industry efforts to establish such standards.

Major electric mine design questions

Timeframe	Orebody	Mining	Processing	Product Transport	Infrastructure inc. Energy	Labour
Strategy (years - months)	• Mine layout and method • Timing – when should investments in electrification be made and when will equipment be available? • Optimal material movement: Hoist vs. haul vs. other	• Haul fleet selection and size • Retire diesel fleet early or wait? • Underground drive dimensions and grade • Light vehicle and auxiliary fleet selection' Ventilation and refrigeration installation optimisation	• Sizing of processing capacity to optimise energy use • Processing technology to optimise energy use – timing, flexibility, energy type	• Optimum location of assets for energy use • Low emissions haulage technology and contractors	• Renewable energy sourcing, size optimisation and backup • Infrastructure required to effectively operate	• Workforce skills and headcount for electric mine • Infrastructure to allow future optionality
Planning & Scheduling (years - months)		• Low energy ventilation operation • Electric/ BEV fleet operating model and charging cycle	• Time shifting of operations for optimal energy use		• Operations planning to optimise energy profile	
Execution (minutes - seconds)		• BEV load optimisation and balancing			• Optimal sourcing and application of energy in execution	

Human factors

No matter the scale or direction of a mining project, people are always at its core. People are the ones supporting or opposing the initiatives, interacting with the equipment and systems to perform the work, and (in an ideal world) acting as a first line of defence against malfunction and interruption. Change-resistant culture and the challenges of managing people and through transformation projects were common themes we encountered, particularly in the EMC's final year when the initial excitement of the transition had worn off. While culture is ultimately set by leadership, we identified a range of easily deployable actions to help build a workforce that supports electrification. We also identified a broad sentiment of capability in the existing teams – the majority of respondents to our industry change management survey described their workforce's capability to electrify as "moderate" or "strong" (34% and 46% respectively).

EMC learnings:

- **Be creative about talent.** Establishing the right project team is a crucial step and can be difficult given the skills shortages and competition for talent. This challenge represents a prime opportunity for miners to think differently about how they attract their workers, and who they are trying to attract in the first place. Moving beyond the traditional mining, engineering, and geoscience candidate pools is a good start – for example, mathematics streams are likely able to solve optimisation problems, and computer science streams can program bespoke systems to manage fleet.

  Those who don't fit the classic mining profile may in fact turn out to be the best fit for the job – one workshop presenter told the EMC their best remote equipment operators were young gamers, some of whom had no prior mine experience. Because there is very little industry experience in mine electrification anyway, this is a good time to relax hiring requirements, pick up promising but inexperienced people and train them on the specific operations – there will always be plenty of experienced miners around to keep an eye on them.

  Mine electrification projects may also help attract talent organically, with the promise of a more pleasant work environment, better health outcomes, and a company direction that aligns with much of the next generation's values. Multiple EMC members reported seeing a boost in hires thanks to their growing reputation as a responsible, environmentally conscious operation.

- **Remember that change affects everyone (eventually).** When it comes to rolling out transformation, the best approach is a staged approach to the workforce. Begin by identifying the pilot team – knowledgeable and supportive individuals from all levels of the organisation (i.e., include some operators in the corporate planning sessions!) who will handle early initiatives and eventually act as "change champions" for the wider team.

  A pilot team helps insulate the project against dissenters while it is still building momentum, but eventually the project must be rolled out (in a controlled way) more broadly. In this case, early planning for role impact assessments, feedback/discussion sessions, and support-building exercises are invaluable. Transformational change will affect every person in the organisation in some way, and those changes must be well understood and accounted for by the project team in order to get it across the line.

  The comprehensive communications approach must extend to the project communication and training, too – even with an enthusiastic team who say they are comfortable with new equipment, it's worth taking them through the same onboarding process to make sure everyone is on the same page and along for the ride.

- **Provide tonnes (of communication).** Between the board room and the rock face, there are a lot of opportunities for the story to get twisted. The results of our change management research were clear – companies must establish a clear picture of the benefits for each of the stakeholders affected by change, and communicate this authentically, and often. For example, an EMC workshop identified the work health and safety benefits of electrification as the most effective line of communication for motivating a mining organisation.

  Teaching the change champions these "what's in it for me" elevator pitches and actively promoting any positive news about the project are two strategies that can help keep staff on board and energised through inevitable disruption. Similarly, smothering bad news (or if it gets out, directly acknowledging it to rebuild trust), addressing any emotions in the room (e.g., fears around battery fires), and identifying and working with active opponents of the change can mitigate friction in the workforce.

  A good check-in technique is to see what operational employees think and know about the change – this will let the change leaders know if there has been a crossed wire in communications and identify any opportunities to train additional champions. The night shift supervisor may just be the most valuable asset in changing workplace culture. Organisations can also draft in communicators from outside – for example, fire wardens, OEM technical teams, or mine safety regulators. Some EMC members found these professionals to be more effective at communicating the mine electrification case to their workers than their internal teams.

- **Foster peer learning, upskilling, and support.** One efficient way of training people in new work processes is through ongoing, organic peer-learning environments. Whether the participants are from a single company or span a broader regional, national, or global group, such environments allow people to stay on top of the latest best practices, technologies, or relevant information in an informal and engaging way. They usually don't cost a lot of money or time and have the added benefit of developing a support network of leading experts for companies to consult when needed.

While the EMC generally functioned as a knowledge sharing and peer learning environment, a stand-out case was the EMC Carbon workstream. This group comprised sustainability experts from a number of companies who were grappling with rapidly escalating responsibilities (e.g., new policies, shareholder and corporate expectations in sustainability reports, and emissions measurement challenges). Workstream meetings focussed on a particular challenge or presentation from an outside subject matter expert, and often included a lively discussion or collaborative working session. Based on the value of these sessions, this network is hoping to endure beyond the tenure of the EMC in an informal capacity.

- **Engage outside the fence.** A company's relationship to their broader community is becoming increasingly important. Not only are these communities the sources of the workforce, but they are also the source of other business partners, investors, regulators, voters (who influence policy), public supporters (or protestors), and the traditional owners of the lands being mined. Engaging positively and authentically with these groups is particularly important in the smartphone era, where information or rumour can be digitally transmitted across the globe in an instant and have far reaching effects.

  Electrification projects can bring deliver real benefits to communities, such as health impacts, emissions reductions, and potential renewable energy. Involving communities early to build a broad coalition of support and provide the feeling of agency over what happens in their area is then the best approach for electrification projects.

Chapter 7:
Policy challenges and recommendations

"A successful policy response will cater for the nature of the industry."

Focus on tax - Don't write-off the importance of good policy to mining decarbonisation

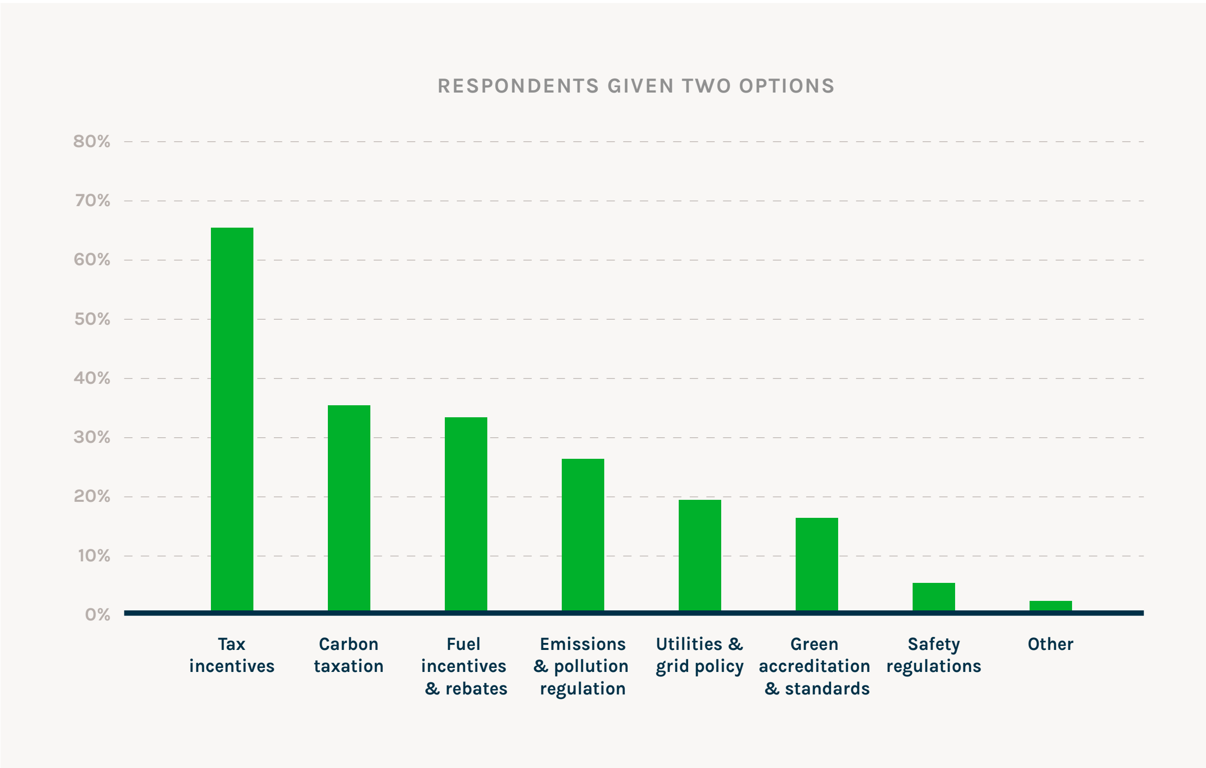
Our analysis in the EMC has shown that the biggest challenge to progress in mine electrification is the initial capital investment required. Our financial analysis documented in Chapter 4 of this report spells out the challenge.

The Australian mining industry would greatly benefit from policies that directly address the large upfront capital challenge of electric equipment. Australia currently lacks capital tax incentives which hinders the adoption of clean technologies in the sector. Implementing incentives such as these would reduce the financial burden of investing in electric mining equipment, promoting the shift to more sustainable practices. This would not only lower greenhouse gas emissions but also improve health and safety outcomes, operational efficiency and reduce long-term costs for the industry.

Such policies would enhance the global competitiveness of the Australian mining industry, attracting investments aimed at modernising operations and meeting international environmental standards. The absence of these incentives in Australia is a missed opportunity to accelerate decarbonisation efforts and achieve corporate, national and global climate goals while also meeting our obligations to underground workforces exposed to diesel particulates whenever they work.

Indeed, there is a risk that the previously world-leading Australian mining industry will become left behind as other jurisdictions push ahead in establishing the assets and skills required for low-carbon mining.

If you could strengthen one policy area at a state or federal level to accelerate mine decarbonisation, what would it be?



Source: EMC survey 2024

Fortunately, there is a great example to illustrate the point from our closest mining economy competitor – Canada. While Australia does not have a single battery electric haul truck in normal operations, Canada's mining industry is ordering anywhere between 15% – 30% of their haul trucks as battery electric.[50] This is helpful to see, but also painful in the sense that our friendly, cold, competitors to the north are comprehensively beating Australia's miners to produce clean metals for a global economy that is increasingly demanding them. So much so, that earlier this year (2024), Canada took over first spot in Bloomberg NEF's annual battery electric supply chain rankings.[51]

Canadian tax incentives – A case study in effective mining decarbonisation policy

Canada's tax incentives for clean technology investments offer significant financial benefits for mining companies, via the 30% Investment Tax Credit (introduced in 2018 and updated in 2024) and the Accelerated Capital Cost Allowance (first introduced in 2005 with further improvements in 2018). When combined, these incentives can substantially reduce the cost of acquiring electric mining equipment and improving the entire business case for mining decarbonisation.

The Investment Tax Credit (ITC) allows businesses to claim a tax credit equal to 30% of the capital cost of eligible clean technology equipment. This includes electric and hybrid-electric mining equipment, energy storage systems, and renewable energy installations. The credit directly reduces the amount of income tax payable, providing an immediate financial benefit to mining companies that invest in sustainable technologies.

The Accelerated Capital Cost Allowance (ACCA) enables businesses to depreciate eligible capital assets at an accelerated rate. Specifically, Class 43.1 allows for a 30% declining balance rate, while Class 43.2 offers a 50% rate for more advanced technologies. These accelerated rates enable businesses to write off the cost of their investments more quickly, reducing taxable income in the short term to create optionality for further fleet investments.

It is even possible to integrate the ITC and ACCA in a straightforward way for equipment that qualifies for both the ITC and ACCA. This typically includes electric haul trucks, loaders, drills, and other clean technology machinery used in mining operations. Miners can then calculate the ITC by taking 30% of the capital cost of the eligible equipment and claim this as a credit on the tax return for the year the equipment is purchased and put into use.

50 Sandvik's global order book is +15% battery electric haul trucks – direct quote from company representatives

51 BloombergNEF

Once the ITC is claimed, the adjusted cost basis for ACCA is determined by subtracting the ITC from the original capital cost. For instance, if a mining company purchases an electric haul truck for $1 million, the ITC would provide a $300,000 tax credit. The adjusted cost basis for the ACCA calculation would then be $700,000. Applying the ACCA rate, assuming the equipment qualifies for Class 43.2 (50% rate), the first-year deduction would be 50% of $700,000, resulting in a $350,000 reduction in taxable income.

The financial impact of integrating these incentives is substantial. The ITC offers immediate tax savings by reducing the amount of tax payable, while the ACCA provides ongoing deductions through accelerated depreciation, providing the opportunities to bring forward depreciation to reduce short term tax expenses. This combination of immediate and long-term financial benefits makes investing in electric and other clean technologies highly attractive for mining companies.

By having the opportunity to access the ITC and ACCA, Canadian mining companies can significantly lower the cost of electrifying their operations. The immediate tax relief from the ITC and the ongoing deductions from the ACCA together create a strong incentive for mining companies to overcome the capital investment hurdle and progress with decarbonisation - incentives that are not yet available in Australia's mining industry.

Integrating the ITC and ACCA not only provides significant financial benefits to Canadian mining companies themselves but will also accelerate the industry's decarbonisation efforts. By reducing the net cost of acquiring electric equipment and its associated infrastructure, these incentives encourage greater investment in decarbonisation. This shift towards cleaner technologies will reduce greenhouse gas emissions, create healthier workplaces, improve energy efficiency, and help Canada achieve its climate goals more rapidly. In the long term, these policies will contribute to a more sustainable and competitive mining industry, setting a strong example for other sectors and countries to follow in the global effort to combat climate change.

One of those will, hopefully, be Australia.

Big challenges in the transition that could be improved through good policy work:

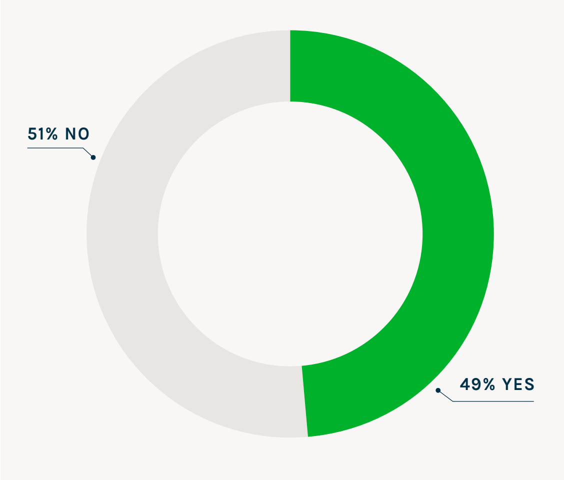
Throughout the Consortium's four years, many discussions have centred on the potential for good policy that could help with specific challenges. This could either be because the current policy suite specifically disincentivises decarbonisation (such as the diesel fuel rebate), is not well suited to the nature of the challenge or are in place but not ambitious enough (such as diesel particulate exposure limits).

Challenge 1: Diesel particulate exposures

Australia does not currently have a specific, enforceable national standard for diesel particulate matter exposure in workplaces. Instead, the regulation of DPM is addressed through broader occupational health and safety frameworks and guidelines provided by Safe Work Australia and individual state and territory regulatory bodies.

The current approach has been very detrimental to Australia's mining workforce, particularly those in underground operations. Prolonged exposure to DPM can lead to respiratory issues and lung cancer, with studies indicating a 1.5 to 2.5 times higher risk of lung cancer in exposed workers.[52] A health-based exposure limit is crucial to mitigate these risks, ensuring worker safety and aligning with the stated values of both governments and corporate boards.

Will health risks drive the transition to electric vehicles on mine sites more than carbon emissions?



Source: EMC survey 2024

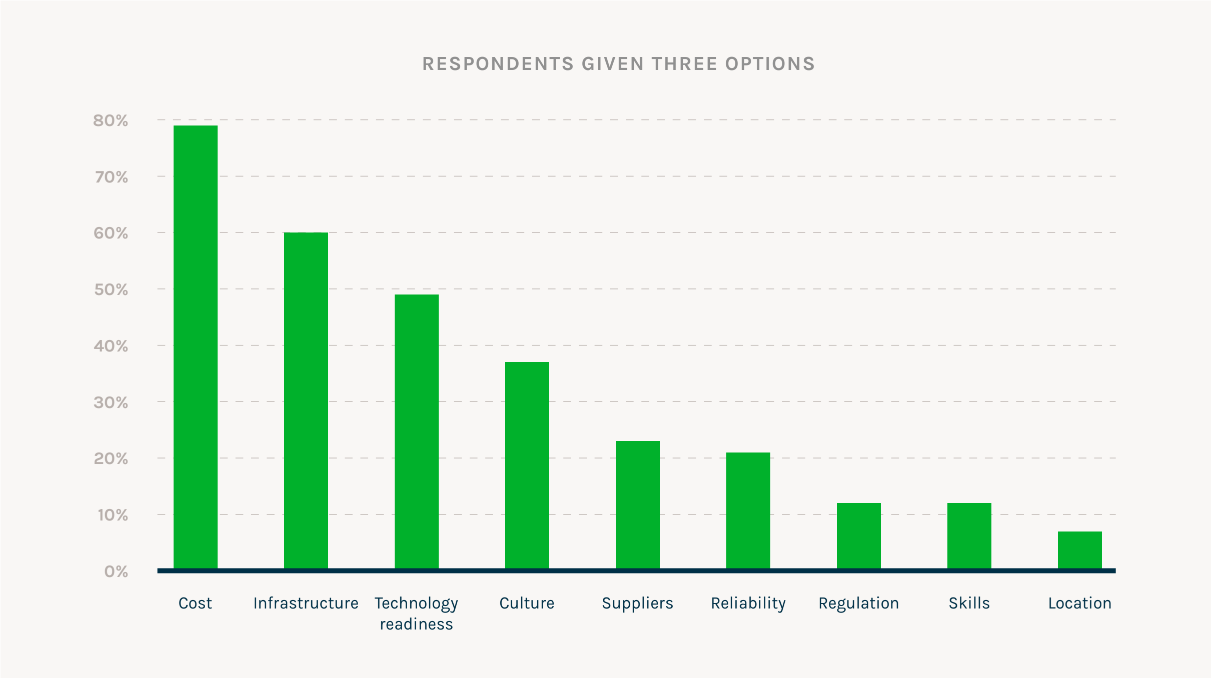
52 Safe Work Australia
https://www.iea.org/data-and-statistics/charts/average-co2-intensity-of-power-generation-from-coal-power-plants-2000-2020

Challenge 2: Diesel fuel rebate disincentivising electrification

Australian fuel tax policy means that Australian mining companies pay zero tax on diesel. This significantly lowers the cost of diesel and other fossil fuels for mining companies, create a financial disincentive for the electrification of the mining industry. By reducing fuel expenses, these subsidies contribute to making it economically challenging for mining companies to invest in electric technologies, which typically require higher initial capital.

The lower operational costs of diesel-powered equipment, due to tax policy, diminish the immediate financial incentives for transitioning to cleaner alternatives. This perpetuates reliance on fossil fuels, hindering progress toward sustainable practices and delaying the adoption of cleaner, more efficient technologies in the mining sector.

What are the main challenges for transitioning mine sites to electric?



Source: EMC survey 2024

Challenge 3: Price discovery for carbon content in metals products

The lack of a green premium in metals commodity markets poses a significant challenge for mining companies aiming to decarbonise. A green premium refers to the additional price consumers are willing to pay for metals produced using environmentally friendly methods. Without this premium, there is little financial incentive for mining companies to invest in lower-carbon technologies or sustainable practices.

Without a green premium, the costs associated with adopting cleaner technologies—such as electric mining equipment or renewable energy sources—are not offset by higher selling prices for greener metals. This makes it difficult for companies to justify the additional expense of transitioning away from traditional, higher-emission processes. As a result, mining companies may face increased operational costs without a corresponding increase in revenue, which can deter investment in decarbonisation efforts.

The absence of a green premium also undermines market signals that encourage the adoption of sustainable practices. If consumers do not differentiate between green and conventional metals in their purchasing decisions, the economic pressure to reduce carbon emissions and invest in green technologies is weakened. Consequently, this hampers the overall progress toward a more sustainable and environmentally friendly mining industry.

Challenge 4: Public grant-funding approach for decarbonisation projects

A grant funding approach for decarbonising mine sites is often suboptimal due to the uncertainty surrounding grant approvals and funding availability. When grants are not assured at the time of project approval, mining companies face significant financial uncertainty, which can delay or deter investment in crucial decarbonisation initiatives. Additionally, many grant funding programs require projects to be deemed "uncommercial," meaning they are not expected to be financially viable without external support.

This requirement can be challenging to reconcile with the need to present the project as essential to company boards, who may prioritise commercial viability and immediate returns. The difficulty in aligning grant conditions with corporate expectations can lead to project delays, increased costs, and missed opportunities for advancing sustainability. This unpredictability undermines the ability to effectively plan and execute long-term decarbonisation strategies, ultimately hindering progress towards greener mining practices.

Challenge 5: Portfolio logic to company decarbonisation investment

Mining companies often use a portfolio marginal abatement curve to prioritise decarbonisation projects based on their overall cost-effectiveness and impact. While this method is valuable for assessing broader strategies, it can sometimes overlook important site-specific opportunities that may not have the same scale of impact but are crucial for individual mine sites. By concentrating predominantly on aggregate metrics, companies might miss unique, local initiatives that can drive significant progress and build strong support from site managers and workers.

Policies that focus on site-level decarbonisation, such as the Safeguard Mechanism or the introduction of a carbon price, are likely to be more effective. These approaches incentivise targeted actions and innovations at the individual site level, leading to increased engagement and faster progress toward achieving decarbonisation goals. Emphasising site-specific opportunities can enhance overall sustainability efforts and ensure a more comprehensive and impactful transition to greener practices.

Challenge 6: Undifferentiated underground mine ventilation regulations

State mining regulators seldom differentiate between diesel and electric equipment when drafting ventilation requirements, significantly impacting the effectiveness of decarbonisation efforts in the mining industry. Diesel-powered equipment emits substantial quantities of diesel particulate matter and other pollutants, which necessitates rigorous ventilation controls to ensure worker safety. In contrast, electric equipment produces no such emissions, reducing the need for intensive ventilation.

By failing to differentiate between these types of equipment, regulators impose unnecessarily stringent ventilation requirements on electric machinery, leading to increased operational costs and complexity for mining companies. This lack of differentiation impedes the adoption of electric equipment, hindering progress towards reducing overall emissions. Properly distinguishing between diesel and electric equipment in regulatory frameworks would support the transition to cleaner technologies, enhance cost-effectiveness, and align ventilation requirements with actual safety needs.

Challenge 7: Patchwork of federal decarbonisation incentives

Australian mining companies face considerable challenges when investing in decarbonisation due to the fragmented nature of federal policies, grants, and incentives. For example, the Clean Energy Finance Corporation (CEFC) and the Australian Renewable Energy Agency (ARENA) offer various grants and funding programs, but their differing criteria and application processes creates confusion. The Australian Government's Safeguard Mechanism imposes emissions reduction requirements, yet its interaction with other policies can be complex.

Additionally, the lack of coherence among these initiatives means companies must navigate a maze of regulations, each with its own focus and compliance demands. This patchwork approach increases administrative burdens, risks missed opportunities, and creates uncertainty around policy stability, complicating long-term planning. A more unified and consistent policy framework would simplify compliance, enhance financial support, and more effectively assist mining companies in meeting their decarbonisation targets.

Challenge 8: High upfront capital cost of electric technology

Australian miners face a significant policy challenge when decarbonising due to the high upfront capital costs associated with electric technology. Transitioning from diesel to electric mining equipment involves substantial initial investment, which can be a major barrier for many companies. Although electric technologies offer long-term operational cost savings and environmental benefits, the high capital expenditure required for equipment, infrastructure, and supporting systems can be daunting.

Current policies and incentives, such as grants from the Australian Renewable Energy Agency (ARENA) and funding from the Clean Energy Finance Corporation (CEFC), may offer some financial support but often fall short of fully covering these substantial costs. Additionally, the complexity and variability of available financial incentives can further complicate decision-making. Without more comprehensive and predictable financial assistance or more substantial subsidies to offset the initial costs, the high capital requirements remain a significant obstacle, slowing the pace of decarbonisation in the mining sector.

The Canadian policy framework is a great case study in this respect, as described at the outset of this chapter.

Challenge 9: Social cost of carbon is generally not directly incurred by companies

In Australian mining decarbonisation, a significant policy challenge is that the social cost of carbon is generally not directly incurred by mining companies. The social cost of carbon represents the economic damage from each additional tonne of carbon dioxide emitted, including health impacts, environmental damage, and climate-related costs. However, in Australia, carbon pricing mechanisms like the former carbon tax were very effective at lower carbon costs, but along with the current Emissions Reduction Fund (ERF), was not able to fully internalise these costs within the mining sector.

As a result, mining companies often do not face the full financial impact of their carbon emissions, which diminishes the immediate economic incentives to reduce their carbon footprint. Without a direct financial cost for their emissions, the motivation to invest in expensive decarbonisation technologies, such as electric mining equipment, is weakened. This lack of internalisation means that while companies may adopt greener practices, the absence of a direct economic driver can slow the overall pace of decarbonisation in the industry.

Conclusion

Conclusion

When we look back on this period of transition as an industry, we will probably wonder what all the fuss was about. The benefits of moving to fully renewable, electrified mining operations will appear so self-evident as to make any concerns hard to understand. At that stage, mine workers will have grown up with clean energy and battery electric cars and will be at home in a digitally dense world in which artificial intelligence and generative helpers are an intrinsic part of life. The thought of using equipment powered by thousands of micro-explosions every second while carrying around a tank of highly flammable liquid in underground mining environments will seem as crazy then as underground miners and ponies working side by side does today.

As it stands today, most of the building blocks for a fully decarbonised, electric, healthy and attractive industry are being put in place. Renewable energy technology is well established, and miners are becoming comfortable committing to powering their businesses with it. Storage technology is rapidly improving in cost and performance, with the Cambrian explosion of long duration energy storage technologies rapidly moving up the technology readiness level ladder as the leading technologies become clearer. Equipment is riding the wave of technology development driven by the global battery electric vehicle industry, while providing many opportunities for mining-specific businesses and technologies to flourish. The software to support an electric mining industry has seen a step change over the past four years, with highly sophisticated simulation, energy management and energy optimisation businesses increasingly gaining traction in a rapidly digitising industry.

Many mining companies are quickly reaching the same conclusions about the solid strategic and economic case for accelerating the electrification of their projects and sites, a fantastic summary of which is provided in chapter four of this report. With every passing year from here, the economic assumptions will continue in their direction of travel, making the choice to continue with a fuels-based mining operation increasingly untenable to returns-focused shareholders.

The transition is coming – the speed is up to us.

Emission reduction targets		Proliferation of renewable energy	
2020	53% of global emissions were covered by net-zero emission targets	35%	Of Australia's total electricity generation comes from renewable energy (doubled since 2017)
2024	88% of global emissions were covered by net-zero emission targets	82%	Reduction in the cost of solar PV since 2010
Uptake of electric vehicles		**Phase out of fossil fuels**	
93%	Growth rate in the Chinese EV market since 2021	75%	Of planned coal plants globally have been scrapped
35%	Of the Chinese new car market will be electric by as soon as this year	6:1	In OECD countries, cancellations of outnumber new coal plants 6:1
Access to capital		**Regulatory landscape emerging**	
40x	Investment in the energy transition is up 40x since 2004	40%	Of global GHG emissions are now subject to a mandatory carbon price
$150t	In assets under management within GFANZ (Glasgow Financial Alliance for Net Zero)	x2	Volume of climate based litigation has more than doubled since 2017

Just like the salmon swimming upstream, having a clear direction of travel doesn't make the journey any easier or less uncertain. The Consortium was started by a collection of people who could clearly see the direction we needed to go, and who understood that it was a journey all the more difficult if taken alone. Together with hundreds of new colleagues across the industry, the participating companies in the Consortium created the vanguard of investment, research and trials that have made the shift to electric credible and inevitable to the rest of the industry. Where the participants in the Consortium have led, the rest of the industry is quickly following.

In working together to navigate a path to full electrification, individuals and companies in the Consortium tried an incredible range of innovative and ambitious initiatives together. In normal times, many of these would not have seen the light of day. In this period of transition, however, not only did they get started, but they all had several companies working together – such is the power of collaboration when coupled with aligned intent.

There remain many challenges to be overcome by all parts of the industry. Policymakers need to establish a more consistent and intentional policy framework to incentivise movement – the inflection is close now, and well-designed incentives will help push through the final barriers. Financiers need to develop an informed nuance in how they discuss capital allocation with mining boards and executive teams – being careful with capital is a given, but not funding the necessary steps to decarbonise these businesses is economic recklessness for their shareholders. Suppliers are quickly proliferating to meet the more and more specific needs uncovered by electrification – all while designing, testing and rolling out new and more creative business models. And miners themselves need to take a deep breath and commit to the journey of electrifying their businesses.

Finally, but most importantly, it is up to individuals within the industry to build a better industry for ourselves. An industry that is cleaner, safer and healthier. An industry that does not accept the working environment of today for our colleagues now and into the future.

If we are to make mining into the industry we all want it to be, then it is up to us.

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