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State of Play: Electrification

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About State of Play™

The State of Play platform was initiated by VCI in partnership with The University of Western Australia in 2011 and is now the largest mining research platform on strategy and innovation in the world. Our ambition was to create a platform to support industry discussion of innovation and performance at a strategic level, develop macro-level insights into the industry ecosystem, and more clearly articulate effective strategy execution and business design for the industry.

Since its inception, State of Play has surveyed several thousand mining and service company senior executives across six continents and over a hundred countries, developing over a million individual data points over time that paint a diverse and fascinating picture of the industry and its evolution.

About VCI

VCI is a global management consulting company that focuses on the resources industry. Our core focus areas are strategy, innovation and organisation. We work with senior leaders to overcome their most difficult and pressing challenges with a collaborative and open approach. VCI has built its reputation based on a deep curiosity and applying creative methods to difficult problems. More can be found at **www.govci.com**

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About our sponsors

The Future Battery Industries Cooperative Research Centre

The Future Battery Industries Cooperative Research Centre is enabling the growth of battery industries to power Australia's future. We bring together industry, researchers, governments and the community to ensure Australia plays a leading role in the global battery revolution.

Jacques Eksteen, Chief Operating Officer
www.fbicrc.com.au

METS Ignited

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

Adrian Beer, CEO
www.metsignited.org

Project 412

Project 412 believes technology should be transformative, producing greater productivity, higher levels of safety and better consumer engagement. Their aim is about building a better system than the one it replaces by locating suitable technologies, locations and partners that can come together to deliver world class outcomes.

Paul Lucey, CEO
www.project412.com.au

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Our Method

Early in 2020, State of Play partnered with the Future Battery Industries Co-operative Research Centre, METS Ignited and Project 412 to undertake a series of research activities on electrification in mining. This research aimed to understand the drivers and barriers of mine electrification, identify the key enabling technologies and enable collaboration to accelerate its adoption. The research consisted of:

- 450+ individual surveys, which targeted mine electrification specifically, as well as strategy and innovation at a broader industry level.
- 5 industry webinars and workshops, which involved 40+ companies who interactively brainstormed ideas spanning the benefits, challenges and collaboration opportunities facing mine electrification.
- 5 interviews with identified thought leaders.

Executive Summary

Mine electrification is a foundation enabler for the clean energy transformation of mine sites.

The mining industry sees it as one of the most pressing transformation imperatives for the industry, facilitating precision automation and the digitisation of mine operations, whilst improving environmental and health outcomes. Of the industry executives surveyed:

- 57% expect the energy transition is the global trend that will have the biggest impact on the industry over the next 15 years.
- 89% expect mine sites will electrify within the next 20 years.
- 61% expect the next generation of mines will be all electric.
- 83% expect renewable energy technologies will significantly change mining operations over the next 15 years; and
- 98% view mine automation is the technology that will benefit the most from electrification.

The economic, health and environmental opportunities for those businesses who drive this shift is large, but not without its challenges.

Electrification is the rare trifecta that hits all three areas of value for the mining industry, giving its transition a sense of inevitability throughout the industry. Of survey respondents:

- 91% expect the shift to an electrified system will create opportunities for new business models;
- 53% would electrify their mine sites for cost reasons;
- 79% expect there will be a health-related industry class action in the next 15 years;
- 71% view processing and 68% view extraction as having the greatest leverage in decarbonising the mining value chain;
- 46% expect innovation in carbon emissions and 42% expect innovation in diesel replacement will have the greatest environmental benefit in their business; and
- 86% expect transparency of the source of raw materials will become a significant driver of mining company value.

Whilst the need for mine sites to shift to electrification is approaching consensus, technology uncertainty remains a significant challenge.

In key areas of the value chain, miners are faced with distinct choices of which technology to invest in (e.g. what type of battery storage technology, swap versus fast charging, etc.). Of survey respondents:

- 60% believe miners should begin transitioning to an all-electric system with installing renewables, while electrical infrastructure is second with 37% and heavy mobile equipment third with 32%;
- 87% expect solar will become the most widely used energy source in the industry in the next 15 years, followed by gas, wind and diesel (58%, 44% and 39%, respectively);
- 76% expect remote mine sites will use batteries to supplement renewables, followed by diesel with 53% and demand management at 42%;
- There is no consensus as to which energy source will power heavy mobile equipment between lithium batteries, hybrids and diesel (28%, 21% and 18% respectively); and
- 54% expect infrastructure is the main challenge for transitioning mine sites to electric.

The mass adoption of electrification technology and storage systems to power mine sites has so far been slow.

It is clear that as an industry, this knowledge gap will need to be confronted largely through testing and piloting, which allows for the development of case studies for application, economic models and best practice guidelines. Of survey respondents:

- 88% see cost as being the major risk of electrifying a mine site;
- 63% report that risk aversion is holding back the implementation of electrification technologies;
- 18% are willing to accept increased risk in asset design to increase financial returns; and
- 41% are primarily focusing their innovation efforts on energy.

The industry should focus on collaborating to overcome the barriers that are beyond the capacity of any one individual company to address.

Such efforts will require the mobilisation of policy makers, miners, service companies, investors and researchers in order to achieve the scale, capital and influence to drive success. Of survey respondents:

- The preferred partnering approach for achieving breakthrough innovations is collaborating with selected partners (65%).
- The majority believe the best way the government can support innovation is through regulation and collaboration (#1 and #2, respectively).
- 85% believe broad industry standards for battery types are required.
- 52% see miners as the biggest group driving investment in electrification followed by suppliers and investors (39% and 38%, respectively).
- 60% believe the industry should focus its health risk innovation on airborne particulates.

Contents

Introduction

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 an inflection point in the shift towards full electrification of the world's mining industry.

The opportunities that cheap, 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 and traditional diesel supply chains will be largely superseded.

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

At a regional 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.

Forces

Advances in digital integration, stationary storage, transport and supporting infrastructure are unlocking the opportunity to design mining's energy system as a single platform. With full value-chain visibility and advanced energy control, mines are able to optimise, capture and re-use energy, structurally reducing overall operating costs.

Society's growing environmental concerns are central to the often-poor perception of mining globally – which is becoming more important as the capacity for social influence grows. Electrification will reduce diesel particulate emissions, improving health and safety outcomes, and reduce carbon emissions. Carbon emissions from non-coal mining operations represents around 10% of the industry's total contribution (methane leakage from coal mines makes up the other 90%)[1]. Electrification will also accelerate development of electrical infrastructure proximate to operating assets, enabling communities to generate wider economic benefits.

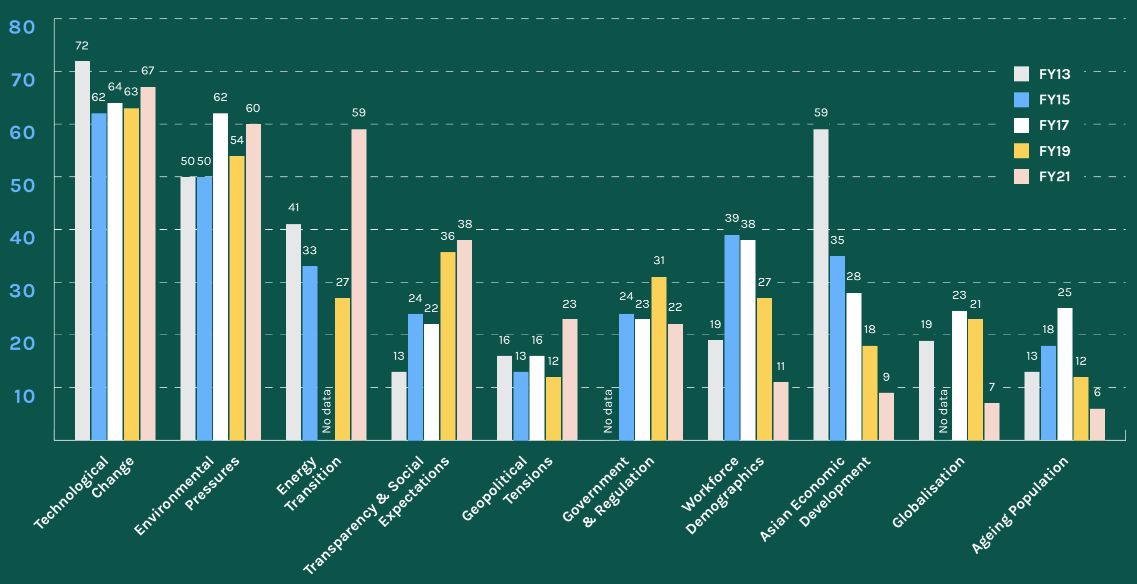
Mining is responsible for extracting the minerals required to support the transition to a clean energy system. These include but are not limited to rare earths (for wind turbine magnets), lithium, nickel, cobalt, lead, manganese, aluminium, graphite and vanadium (associated with batteries), copper (ubiquitous in electricity transmission), silver and silicon (concentrated in solar technologies) and iron ore (structural material). For miners who operate in these commodities, there is a strategic imperative to do this in a way which reduces environmental, health, social and cultural impact. Transparency will play a key role in ensuring the electrification technology supply chain meets these growing expectations. In the near-term, companies who comply may derive a market premium, whilst in the longer-term it may be a condition of supply.

1 McKinsey - Climate Risk and Decarbonization, 2020

GLOBAL TRENDS - LONGITUDINAL

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

BY % OF RESPONDENTS GIVEN THREE OPTIONS



People

Creating and capturing new sources of value is an entrepreneurial challenge. In this report we have deliberately focussed much of the discussion on the economic benefits and technology opportunities driving the change to electrification. To complete the picture, it is important that we also understand how a new energy system will drive changes in the demand for people within, and servicing, the industry's businesses.

Electrification will bring about a number of implications for the mining workforce and its capabilities. Many of these will reinforce those resulting from the broad digital transformation trend, with some specific additions. Both require a new mindset, new leadership approach and new skills at multiple levels within businesses.

MINDSET SHIFTS ASSOCIATED WITH ELECTRIFICATION

Diesel mine →	Electrified mine
Siloed →	Systemic
Point-to-point →	Networked
Centralised →	Distributed
Intuitive →	Analytical
Equipment focussed →	Service oriented

Traditionally, mining companies operate with siloed, business unit level accountabilities which are deliberate in controlling concentrated sources of energy to power operations. An all-electric mine managed systemically, coupled with a highly networked energy source will require a significant cultural shift to a more integrated operation.

The second challenge centres on the studies and project skillset required to construct, or transition to, an electrified mine. Studies teams need to be comfortable with investing in maintaining technology optionality (given how quickly technology can shift) and adapting to a dynamic external energy system that may ultimately integrate with the mine's electric technologies. Project teams' ability to formulate high value electrification options with their suppliers in development studies is critical.

The third challenge lies in transitioning to a new operational and maintenance skillset required to run and sustain an electrified mine site. On face value this is the largest organisational change, demanding a sharp increase in electrical and electronics technicians and data-based diagnostics capability. Resolution will require retraining and close attention to apprenticeship programs, on which the industry is currently very focussed.

As a system shift, the transition to a new energy platform requires several things of the industry which no single company can deliver. Collaborative testing and piloting of developing technologies to increase information and understanding will enable mass adoption. Making the case to governments to create regulatory changes and promote a degree of standardisation to support the shift is a collective responsibility for the whole industry.

Value

Electrification creates enormous opportunities for operational cost savings, innovative mine designs and resilience against uncertainty. The value upside of this not only increases productivity in existing assets, but also improves a company's ability to unlock deeper and more remote ore bodies.

The transition offers the ability to operate mines on a new platform. With a strong digital architecture and a new operating model, faster, better and more decentralised decisions can be made for greater optimisation and efficiency.

Mining companies who successfully implement these technologies will have a competitive advantage. There is no denying that the energy transition is real and is here. Strategic positions will need to be taken to create future optionality, otherwise companies will run the risk of losing years of economic value and the potential of creating lasting advantage over competitors.

SIZE OF THE PRIZE FROM MINE ELECTRIFICATION

Operational Cost Savings

7–15% reduction in OPEX, comprised of:
30–50% energy cost reduction
25% maintenance cost reduction
40% ventilation cost reduction

Emissions Reduction

100% reduction in scope 1 & 2 emissions
26% reduction in all emissions
increased maintenance cost reduction
increased ventilation cost reduction

Diesel Particulate Exposure

40+ toxic pollutants in diesel exhausts
1.2m Australian workers exposed per year
2nd largest Australian carcinogen
230k Australians in the mining industry

Energy's bigger picture

The way the mining industry approaches energy generation, consumption and management is undergoing a significant transformation. Low-cost renewable energy coupled with advances in digital technology is driving the shift to a common, all-electric power system.

53% of the industry believe systemising the approach to energy, whether it be on-site or externally, will underpin the next step forward for mining technology. An all-electric system allows the mine to be designed and integrated as a single platform, creating new management opportunities for operational optimisation, technology models and integration with external networks.

Moving from the legacy, layered mining energy platform to a flatter, integrated system unlocks a decentralised decision-making capability for energy optimisation, with value being derived from the ability to forecast and manipulate energy generation, use and capture. The ability to integrate with local energy networks supports further resiliency in the system and promotes a virtuous cycle network effect whereby infrastructure costs can be shared, and community benefits realised.

System integration

Optimisation and electrification are inextricably linked. 66% of the industry believe energy optimisation and usage technologies will greatly benefit from electrification. Currently 66% of all energy produced for industrial operations is wasted in the form of heat, noise or vibration[2]. The ability to identify and address inefficiencies in the mining energy system will greatly increase productivity – it will, however, require a greater commitment to digital technology and decision support integration.

The architecture employed with system integration captures data on energy demand, conversion efficiency, generating capacity, condition variability and system stability at a network and individual input level. Generation, stationary storage and mobile equipment create the backbone of this architecture.

System integration has very different considerations for greenfields and brownfields mines. Our data suggests that retrofitting legacy systems and transitioning existing infrastructure and equipment is the biggest challenge that must be overcome. Sequencing this transition appropriately is a critical strategic choice. 61% of the industry believe the first and most important step in this process is in developing renewable energy generation capacity.

> **"A world where the value chain was once quite fragmented is clearly being changed by the technology enablers of electrification, automation, digitisation – which are helping connect process steps which in the past have been quite discrete"**

Optimising performance

Renewable energy generation is limited by its intermittent nature, however integrating it with a form of energy storage such as batteries creates security and resiliency in the energy supply. The data captured from the energy distribution process can be used to monitor and forecast variable energy demand and supply throughout the day. With this information, operators can influence their energy consumption to produce desired changes in load shape. Not only does this support system stability, but it allows the system to proactively respond to changes in energy prices or operational adjustments.

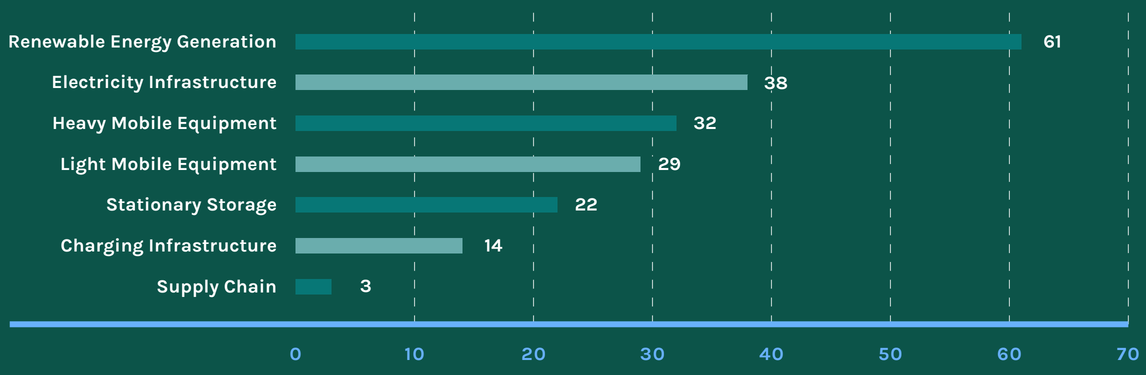
For example, integrating mobile electric equipment into the system places significant but predictable charging requirements on overall energy demand. Using the data gathered on system demand and capacity combined with vehicle performance, decisions can be made to manage the overall system, through timing charging periods to align with surplus energy supply, using mobile equipment to store energy or feeding back excess mobile capacity into the grid.

Modular renewable energy is easier to transition. Whilst there is no cost-free way to navigate existing sunk capital or financial commitments, renewable technologies allow for cost-efficient scale up and down as needed. Even if the site relies on coal power today, supplementing it with growing renewable energy capability, or even switching fully to the renewable system can be achieved with close to zero operational impact and can be directly tied to environmental performance outcomes.

ELECTRIFICATION TRANSITION

We asked: Where should mining companies begin in transitioning to an all-electric system?

BY % OF RESPONDENTS GIVEN TWO OPTIONS



Next-generation technology models

A single electric energy system enables the acceleration of other technologies such as automation – the number one beneficiary of electrification. 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.

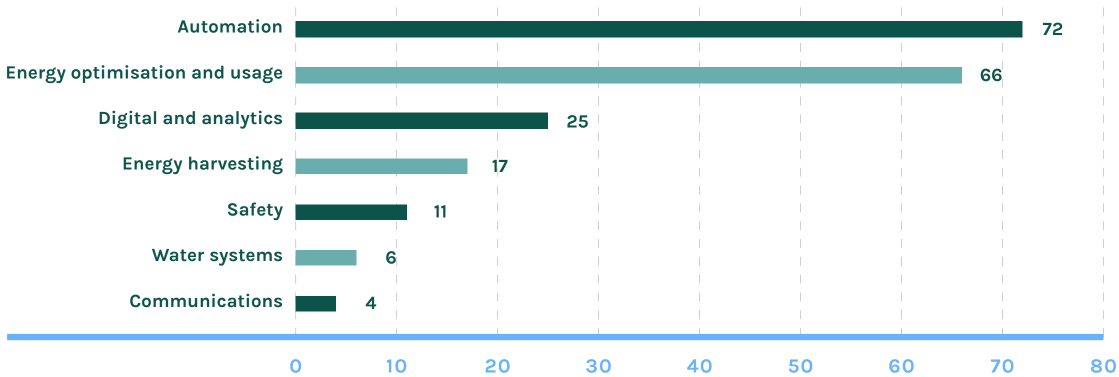
The increased data insights from an electrified system means that value can be more effectively quantified. With better data, a manager can definitively track wear and tear on equipment or energy wasted in a process for example. In this system, services companies who can improve the life of equipment or reduce energy inputs without reducing output can demonstrate the value of their services in quantifiable data. Across more digitally mature industries this is enabling 'servitisation' business models, whereby services companies do not sell equipment but charge for use per unit of performance. Under this model, services companies sell the value of their service rather than individual pieces of equipment.

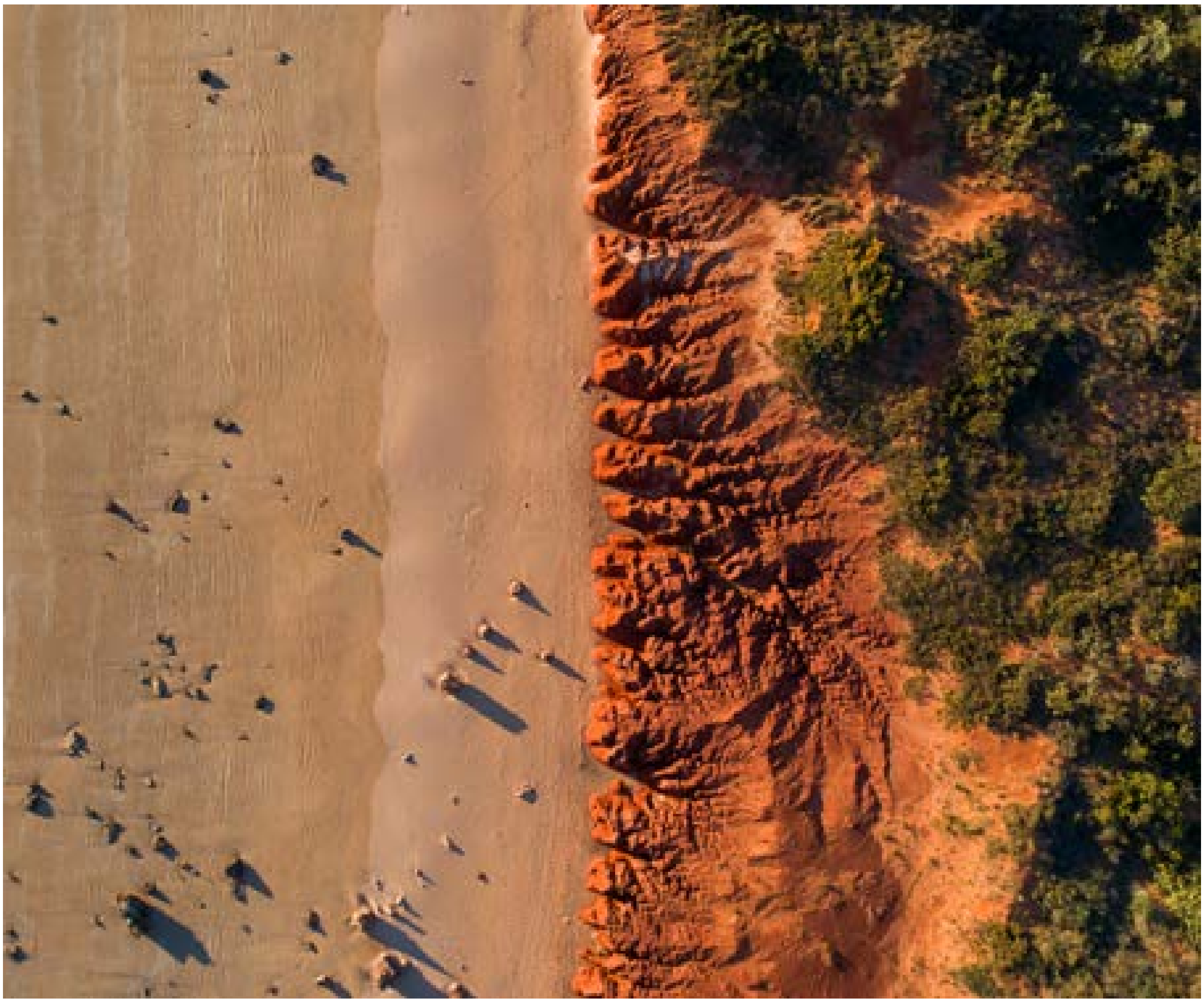
Servitisation models incentivise services companies to improve the value of their service rather than just reducing cost. Given the significant transition required for electrification to be successful, servitisation business models may be the most effective for implementing new energy technology.

TECHNOLOGY BENEFITS FROM ELECTRIFICATION

We asked: What technologies will benefit the most from the transition to mine electrification?

BY % OF RESPONDENTS GIVEN TWO OPTIONS





External networks

Often operating in remote and harsh conditions creates unique opportunities for innovative approaches to energy generation and networks. In many cases today, it is more economically viable for sites to generate power independently than to invest in transmission lines to connect to the grid. However, with this independence comes challenges around system resiliency.

Where deposits are geographically concentrated, or where companies operate in relatively close proximity, there are opportunities for the emergence or strengthening of local energy networks, which group distributed energy sources into one regional load. Linkages to a centralised network creates greater marginal benefits than as individual subsystems and improves security of energy supply and stability for every asset.

In addition to improved energy security, sharing storage and distribution infrastructure makes more energy available to each decentralised user. Operational expenditure (including maintenance) is localised and shared across users, reducing the net cost to each individual user. Once integrated, new innovative trading models such as peer-to-peer trading and off-take agreements can develop. Drawing renewable energy from a larger area can also reduce some of its variability increases energy utilisation.

The electrification network extends beyond mining operations. Due to its remoteness, mining's localised impacts are often concentrated on communities with limited access to advanced technologies. Establishing local clean energy generation infrastructure, which is underpinned by the mining companies, makes the marginal cost of energy provision available to local communities at a cheaper price, protecting them against exposure to high cost diesel and global market volatility. As more and more systems are added to the network, the total demand on the energy generator increases, which enables these cost savings to get larger per unit.

Seeing is believing

Technology adoption typically follows an s-curve. Early in a technology's maturation there is minimal uptake and it may be considered a concept or prototype technology. Research and development efforts continue until at some point the implementation risk is low enough to meet a certain company's appetite for adoption. As more companies adopt in the early stages, more proof and belief are created, strengthening the business case for implementation in follower companies. Finally, an inflection point is then reached, whereby the technology moves from being considered as "new" to being considered the "best" option, and mass adoption begins.

Mine electrification technology is currently undergoing this maturation process. 49% of mining CEO's believe it will take existing mines on average 5-10 years to electrify. Much of the technology for full electrification of mine sites is available today, however a significant knowledge gap exists across industry relating to the capability of electrified mines and the strategy for implementation. Our research suggests that industry level understanding is currently slowing electrification's movement along on the adoption s-curve.

Evaluating technology options

As a technology system early in its maturation, the need for testing and piloting to understand the performance characteristics and impacts of electrification on the mining process is critical. Adding to the complexity, there are multiple scenarios that may play out both on generation (e.g. solar, wind, hydro, nuclear), distribution systems (e.g. fast charging, network design) and storage (e.g. lithium batteries, flow batteries, pumped hydro) among others. Given the uncertainty in the capability and implications of each technology and which technology path will prove optimal, the lack of commitment is unsurprising.

The optimal approach is likely to be a bespoke solution for each site. Mining operations are often conducted in harsh and unforgiving environmental conditions. Temperature extremities can range from -45 degrees celsius in the Arctic to over 55 degrees celsius in deep underground environments[3].

3 The National Institute for Occupational Safety and Health (NIOSH)

The requirements for characteristics of different electrification technologies may be different for each specific environment. For example, a Li-ion battery may be economic to support a batch process at a gold mine (e.g. gold room processes) while a redox flow battery may be more suited to a long-life continuous iron ore production. Continuous charging systems may fit some underground mines better with their consistent roads, while swap and go may work better with a constantly evolving open pit environment.

> **"Currently even new mines aren't adopting new methods just because they aren't the easiest, most proven ways at the feasibility study stage"**

The choices across generation, storage, charging and mobile technology may require different capital expenditures and introduce new energy cost profiles, load shapes, optimisation opportunities and skills needs across the value chain. Assessing these options will have far-reaching mine design implications across both greenfield and brownfield assets. The earlier the applicability and viability of each option is understood in development or transition; the cheaper implementation is.

The barrier to effective assessments of potential electrified systems is the knowledge gap. Many technology options are still highly contested and will require further on-site testing and piloting in collaboration with equipment manufacturers to develop certain solutions. A greater understanding will help provide certainty to companies that they are not investing in a "white elephant" – a technology that doesn't achieve wider adoption and therefore lacks ongoing innovation and technical support. Once committed, changing some technology choices can be costly.

Understanding economic value

42% of the mining industry believe risk aversion is one of the biggest inhibitors to electrification. Our data suggests that operating and capital cost is seen as by far the biggest risk in electrification. Reducing economic uncertainty is therefore key to accelerating the development of electrified mining systems.

Mining is an industry where there are already high inherent levels of risk, especially at the development stage. Operators are unlikely to take risks on technologies with relatively unknown payoffs. Our data suggests that only 21% of the industry are willing to accept increased risk in asset design to increase financial returns. Testing and piloting can create certainty around value assumptions and a stronger business case for implementation.

However, opportunities for piloting and testing in a mining setting are costly and hard to create. Halting a continuous operation for testing is not economically viable. There is a number of closed and unrehabilitated sites which could potentially be used for piloting, but access can be challenging.

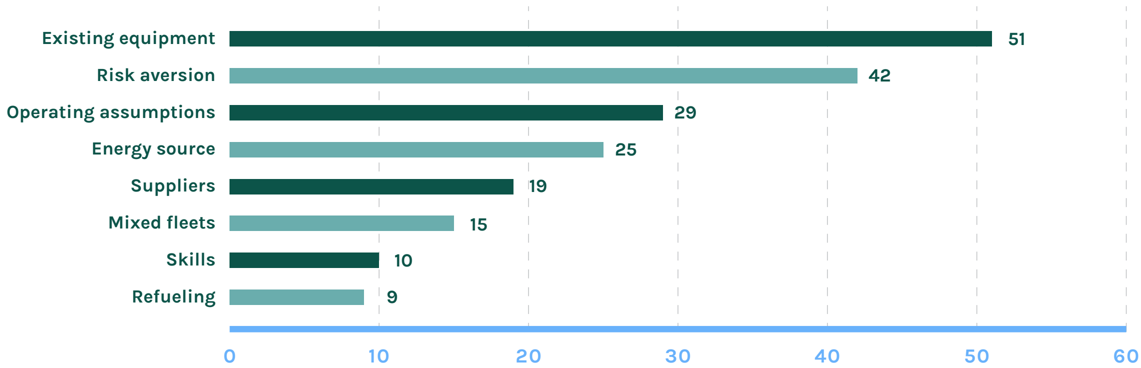
Accelerating industry wide understanding of the economic benefits will require an innovative, and likely collaborative, approach between industry. For example, a consortium whereby members take equity stakes in a low-value mine near the end of its life may provide opportunities for quality testing, whilst spreading the cost between parties.

Sharing the results of testing and piloting in a transparent manner will benefit the whole industry, however companies will balance the advantages of broader communication in driving adoption and innovation, with the perceived advantage of retaining intellectual property. Either way, our experience and data has shown that biasing towards leading innovation is strongly correlated with business success.[4]

ELECTRIFICATION INHIBITORS

We asked: What is holding back the implementation of electrification technologies?

BY % OF RESPONDENTS GIVEN TWO OPTIONS



Building knowledge and awareness

Once electrification technology options and economic value are well understood in various applications, the industry can focus on facilitating adoption and exploring the capacity to build brand and publicity.

A new energy system will require new skills, training and education. The systems will need to be designed to integrate energy technology with every aspect of a given asset, which requires skills broader than those of traditional mine designers. Data and analytical capability will be integral to monitoring and forecasting energy usage and optimisation, whilst maintenance of machinery will move from reliance on diesel mechanics to electrical engineers.

For greenfield assets, the studies team will need to design mines centred around an intermittent energy generation system supported by large-scale storage. For brownfield assets, operators will need to know how best to sequence the transition to a new energy system, overcome sunk capital and adapt to new operating models.

Sharing case exemplars and stories of successful implementation can provide brand advantage for first movers, whilst also accelerating adoption momentum amongst other players. Publicity can mitigate community perceptions of mining as environmentally damaging and reliant on fossil fuels.

DEEP DIVE: MAJOR CAPITAL SPENDS

ENERGY GENERATION

There are many examples of mining companies and sites employing renewable energy generation technology to supplement or replace existing fossil fuel solutions. 2019 was identified as the tipping point for mining companies materially committing to develop onsite renewable energy projects[5].

Projects that have been developed, as well as those in the pipeline reflects the increased trust in the possibilities that clean energy brings. Australia and Sub-Saharan Africa has emerged as two epicentres of clean energy projects, driven by their remote resources and significant solar opportunities. Some of the most notable projects include:

- Rio Tinto is developing a $98-million solar plant at its new Koodaideri iron ore mine. The 34MW facility will deliver 100% of the site's electricity requirements during peak generation hours and approximately 65% of the mine's average electricity demand. It will be supported by a lithium-ion battery storage system and is predicted to reduce Koodaideri's annual CO_2 emissions by ~90,000 tonnes.
- Gold Fields is introducing a hybrid energy project at its Agnew gold site. Energy will be generated through wind (18MV), solar (4MW) and a gas plant (16MV), with the potential for 100% renewable energy during periods of high winds. The estimated annual emissions saving is ~40,000 tonnes of CO_2.
- OZ Minerals plans to power its proposed $1 billion open-pit West Musgrave Copper Nickel mine in Australia on up to 80 per cent renewable energy. Through a mix of solar, wind, battery and diesel, the site is expected to become a leading, fully off-grid mine powered largely by renewable energy. This will eliminate the emission of more than 220,000 tonnes of CO_2 emissions per year.
- Newmont Goldcorp has deployed a mobile solar array to its Akyem gold mine in Ghana. The solar photovoltaic tracker is a modular and prefabricated solar generator designed to be quickly deployable and scalable in 30kW segments, allowing the location of the array to be flexible as changes in mining activity occur.

5 THEnegy, 2019

What is electrification worth?

Mining companies invest large amounts of capital for long-term payback on the basis of uncertain markets and ore bodies that are not fully understood. It is a risky business. Any technology innovation which can increase margins, reliability, resource recovery and adaptability is therefore highly welcomed by industry leading companies. Electrification is one such innovation.

Capital expenditure

Arguably, the most significant barrier to mine electrification is capital – both in terms of the cost of new systems and the sunk cost of capital already invested in old technology. Fortunately, the capital costs for electrification are decreasing due to cross-industry innovation and the benefits of economies of scale with increased penetration.

Currently, full mine electrification requires more up-front investment than traditional fossil fuel systems. Electric vehicles remain more expensive than traditional combustion vehicles, require more supporting infrastructure and the cost of integration is not yet well understood. However, technology is quickly approaching price parity in a number of these areas.

Recently the total life-cycle cost of renewables has become less than the incremental cost of diesel generated power at remote sites, meaning installation of renewables as part of the energy solution has become commonplace. The economics of installing energy storage systems to support the intermittency of renewable generation remains more challenging. However, it is forecast that in the next decade it will be cheaper to build new solar, wind or energy storage systems than continuing to operate existing coal or gas fuelled power plants[6].

> **"The business case for battery electric requires us to capture the full potential in the infrastructure reduction, given the less diesel particulate matter that will be generated"**

For both greenfield and brownfield assets, additional capital expenditures are required to develop the appropriate infrastructure (such as charging and heat management) to support a fully electric operation. How material the additional investments will be and whether the benefits in mine design outweigh these remains uncertain. For example, reduced ventilation and refrigeration requirements under an electrified system, which form approximately 10% of capital costs of an underground mine, could create greater capital and operational savings than the cost of implementing charging infrastructure.

Light battery electric vehicles are approaching total lifecycle price parity with internal combustion vehicles as global competition and manufacturing scale ramps up, led by China's BYD and America's Tesla.

Mining OEMs will benefit from the subsequent affordability of these technologies however also face competition from new entrants such as Proterra. Miners and investors will be the ultimate beneficiaries of reduced costs of mining specific mobile electric vehicle technology.

With fewer parts and a higher degree of automation, electric vehicles may become much smaller than traditional combustion options. Scale reversion may also occur in both the quantity and size of mine drifts and shafts required. As a smaller and lighter overall system, initial development capital outlay may be reduced.

Operating costs

The energy intensity of mining operations is one of the most significant operational challenges facing companies. Material handling and heating, ventilation and mineral processing represent somewhere between 15-30%[7] of the operating cost of a mine. As mines continue to extend deeper, this cost will only increase. Combined with the growing coverage of carbon pricing regulations and diesel particulate requirements across key mining jurisdictions, the shift to a clean, electrified system appears the most economical technology path and puts the least amount of capital at risk of being stranded by policy shifts.

6 Ramez Naam, 2020
7 Paul Mitchell, Global Mining & Metals Advisory Leader, EY

MAJOR AREAS FOR OPERATIONAL COST SAVINGS THROUGH ELECTRIFICATION

Energy generation	Large scale solar PV can be generated for as cheap as $44 per MWh[8] and is approximately 40%[9] cheaper than diesel. Solar offers opportunities for cheap scale-up and modularisation.
Energy wastage	Conversion efficiency of electric vehicles is 77% compared to 12-30% of internal combustion engines.[10] Demand management and optimisation can reduce waste and consumption, opening up opportunities for surplus generation to be sold back or traded with the grid for revenue.
Cost of diesel	30-50%[11] of the total mine site energy usage is related to the diesel usage of mining vehicles. The self-sufficiency that renewable energy generation provides protection against external diesel and other fuel price volatility.
Transport	Replacing diesel onsite removes the need to pipe or truck in diesel to remote sites.
Maintenance and servicing	Adoption of electric mobile equipment fleets can drive reductions in maintenance, operational downtime and warehousing costs by 25%[12].
Ventilation	Reducing the need for the dilution and removal of diesel emissions and heat from underground environments will significantly reduce costs. Electric vehicles and machines offer: ✔ 40% cost savings in ventilation[13] ✔ 30% saving in cooling of vehicle fleet[14]

8 ARENA - Historical Large-scale Renewable Energy Target supply data, 2020
9 US Energy Information Administration
10 Australian Energy Council, 2020
11 University of Adelaide, 2020
12 Newmont Goldcorp, 2019
13 University of Adelaide, 2020
14 University of Adelaide, 2020

Resource growth

Electrification will structurally lower both the development and operating costs of assets, promoting the ability to reach more technically remote ore bodies and opening up opportunities to access sensitive operating locations - all of which are likely to combine to unlock new resource prospects.

Reduced operating costs inherently increase the product margins realised by mining companies. In the mine planning stage, the ore body is geologically analysed to provide information on economic viability of extraction. Electrification, and the reduced operating cost it enables, can create reserve growth by allowing portions of the ore body which may have once been uneconomic due to location or grade to become profitable. New reserves will extend the life of mine and may reduce the risk associated with geological uncertainty of grade or extraction margins.

> **"Productivity, or rather mining economics, is still the primary driver for any technology change. If applying new technology allows you to lower your cost...it tends to make sense"**

More innovative mine designs, coupled with changes to the way they are operated, may also increase the capacity for companies to reach resources which were once technically stranded. For example, extremely deep ore bodies are subject to a significant increase in cooling requirements and ventilation infrastructure to make extraction safe for both people and equipment. Reducing such costs can promote the economic viability of the resource.

Mining is not always remote. Operations often impact the local communities surrounding it through noise, pollution and contamination. With electrification, the social license to operate within sensitive communities can be strengthened. There are already case exemplars where electrification has been a key factor in achieving mine approvals in sensitive areas, including Newmont's Borden mine in Canada.

Environmental and health impacts are reduced by eliminating diesel, which in turn decreases its carcinogenic pollution and greenhouse emissions. Light and heavy battery electric equipment is much quieter and the power network and economic benefits to the community will be enhanced by making the marginal cost of energy provision cheaper.

Studies

Large-scale adoption of electrification technology in mining is only possible if the studies team and design process is willing and able to support its implementation. As described, the transition to a fundamentally new electrical energy system provides a step-change in value creation and therefore requires a more focussed approach than just continuous improvement. Successful implementation will require a new set of skills, specifically in electrical and system design capability, and may potentially result in a new technology risk appetite.

As an industry, mining is exposed to large amounts of market and regulatory risk, especially at the development stage. As mentioned in previous chapters, the willingness of risk-saturated miners to take significant technology risks in asset development is famously low. Success in mine electrification may require a completely new approach to study design.

If, after weighing up the technology options, electrification does not meet the risk appetite of incumbent studies teams, then there are a number of alternate pathways which could be adopted to embed the option to implement electrification in the future. A parallel external study could be undertaken, a development program undertaken with the purpose of building understanding or even the recruitment of a new studies team.

Companies should pursue alternate avenues to implementation, as reverting to the traditional development processes has a strong likelihood of destroying shareholder value, and certainly community value.

Reward for responsibility

The power of social influence is proving to be a driving force of today's global change. As an industry that plays an important role in the countries and communities it operates in, mining's brand is at the forefront of activist attention.

In particular, the energy intensity of mining places mounting pressure on companies to decarbonise their operations, as those who do not comply are increasingly forced to compete for finance, talent and access to resources.

Electrification provides the opportunity for the industry to take a big step towards carbon neutrality (outside of coal) and reposition as a pioneer in the clean energy transition. It will help mitigate some of the industry's biggest risks, namely environmental and health impacts and the subsequent cost of finance and achieving social licence.

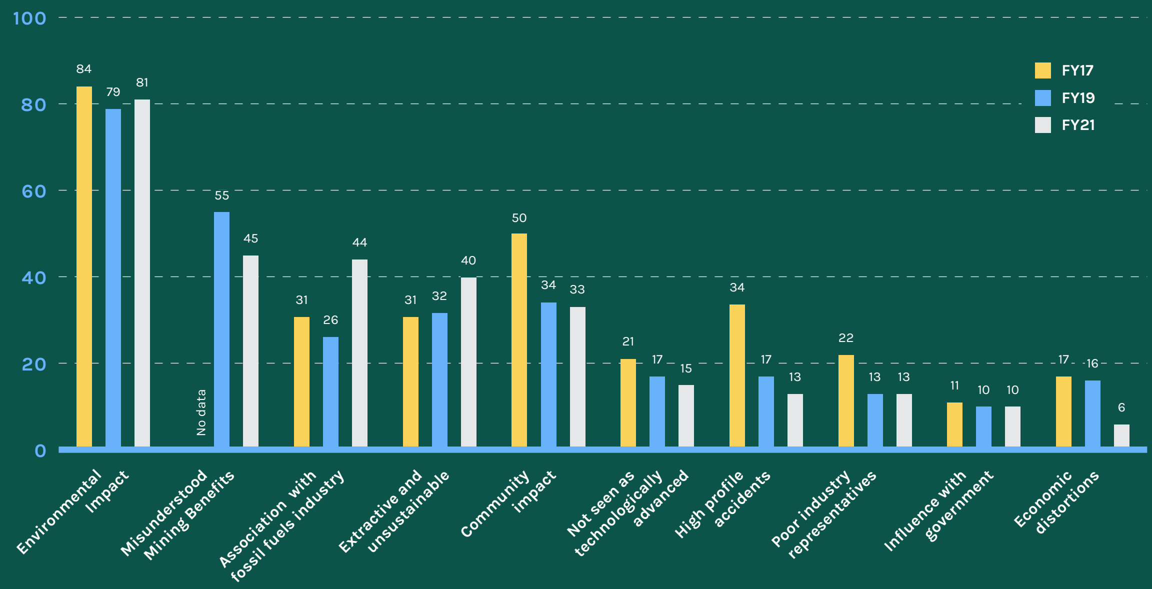
Social licence to operate

In 2013, only 13% of the mining industry believed that transparency and social expectations would be a key driving force for change over the next 15 years. Today, 38% of the industry are of this belief. Coupled with being responsible for 6% of the world's Scope 1 emission generation[15], the scrutiny placed on mining from the communities they impact is unlikely to go away and if anything, will only get stronger. The implications of this, including that of permitting, approvals, rent extraction and sovereign risk are significant.

WE ASKED: WHY IS MINING PERCEIVED NEGATIVELY IN SOCIETY?

We asked: Why is mining perceived negatively in society?

BY % OF RESPONDENTS GIVEN THREE OPTIONS



In the simplest terms, a mining company's most important value creating activity is gaining preferential access to high quality resources. There is a strong recognition amongst both mining companies and the community that a responsible approach to managing environmental and community impacts is a minimal condition for sanction to operate. Companies that fail to build the technical and socio-economic development competencies to develop a resource in this way are increasingly at risk of being replaced by those who can.

The adoption of electrification technologies demonstrates a concerted effort to act responsibly and provides a platform for companies to market their brand to improve their reputation within the community. Electrification is seen as an enabler for emissions reduction, health and safety improvements and technological advancements. With facilitated efforts, the flow-on effects for local infrastructure from mine electrification can create transformative action in the region towards clean energy, creating a number of new opportunities and jobs whilst demonstrating good corporate citizenship.

Electrification is well-understood globally to reduce emission production and improve health outcomes. The mining companies who adopt the technology first will open themselves up to greater investment opportunities, broader market support and positive community relationships, which may ultimately combine to form a powerful source of competitive advantage.

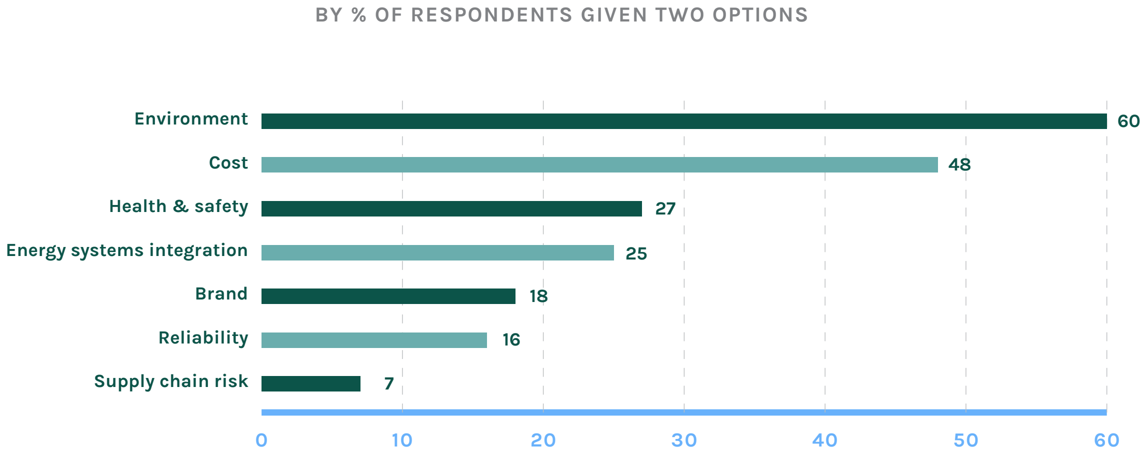
> **"If your electricity is produced by fossil fuel, then you're not in the right place from an ecological point of view"**

Health and environmental impact reduction

Our data shows that 65% of the mining industry believe the next generation of mines will be all-electric, with 86% believing the main rationale behind this is in improving health and environmental outcomes.

ELECTRIFICATION RATIONALE

We asked: Why would you electrify a mine site?



Electrification provides opportunities for impact reduction across all aspects of the value chain, including transporting fuel to site, energy inputs into mineral processing and transporting the product to customers. Switching to renewable energy generation can decarbonise operations, and in some cases even eradicate many of the harmful processes associated with the current technology applied in mining.

> **"The only safe emission limit, we believe, is zero"**

The impact of harmful exposure to particulates from diesel energy generation is a serious concern. The diesel particulate matter emitted from both vehicles and generators, especially in underground mines, pose both short and long-term risks to health, from minor effects such as headaches and nausea all the way to serious illnesses such as cancer. In Australia alone, 1.2 million industry workers are exposed to dangerous levels of diesel particulate matter. Additionally, more than 40 additional substances released from a diesel exhaust are considered hazardous air pollutants[16]. The long-term health effects from these pollutants could be tied directly to mining exposure. Indeed, 80% of the industry believe there will be a major health-related industry class-action over the next 15 years, with diesel particulates being the second highest health risk. If there is a competitive alternative available, the barriers to adoption may fall away in the face of this risk.

To limit global warning and remain on track to meet the Paris Agreement Goals, the mining industry as a whole would need to reduce CO_2 emissions by at least 50% by 2050. An all-electric site, which would use electricity generated from renewable sources, employ battery electric mobile equipment and be supported by renewable storage technologies has the ability to provide a 100% reduction in Scope 1 and 2 emissions (26% of total) as well as a considerable reduction in Scope 3 emissions through supply chain simplification and innovation. For the average mine site, this would equate to approximately 450 megatons of CO_2 equivalent per year.[17] Whilst there still remains a lot of work to achieve full decarbonisation, electrification is one the of the first and necessary steps in doing so.

Socially responsible investing

Socially responsible investing has been prevalent for a number of decades, however the movement has only in recent years gained significant mainstream support. Since 2014, the number of managed investments deploying socially responsible investing strategies has grown by 30% year on year.[18]

The increase is strongly supported by the growing influence of pension and superannuation funds who represent members increasingly dedicated to investing according to ethical guidelines. Today, this type of investing is estimated to be worth over 25% of all professionally managed assets around the world, equating to a total of US$30 trillion.[19] Social sentiment of this degree drives powerful consumer pressure and regulatory reform, which manifests in share prices, dividends and executive remuneration.

> **"Mining is well equipped to access alternative sources of capital like green and ESG bonds through their role in low carbon technology"**

The growing divestment in fossil fuel industries has squeezed access to capital for several mining companies, specifically coal miners. In 2016, the world's biggest coal miner, Peabody, filed for bankruptcy. In 2019, Glencore announced that it will remove all further coal investments from its long-term strategic plans. Blackrock, the world's largest fund manager, pledged to reduce exposure to thermal coal by US$1.8 trillion. The divestment pressure exists beyond coal. Just this year, Australian industry superannuation fund HESTA announced it will divest pure play thermal coal miners immediately, reduce its emissions footprint by 33 per cent over the next decade, and dump all carbon-emitting companies by 2050.

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16 Safe Work Australia - Guide to Managing Risks of Exposure to Diesel Exhaust in the Workplace
17 Mckinsey – Climate Change and Decarbonization, 2020
18 GSI Alliance – Global Sustainable Investment Review, 2019
19 GSI Alliance - Global Sustainable Investment Review, 2019

WIND AND SOLAR SHARE DOUBLED SINCE 2015[20]

WIND AND SOLAR AS % OF TOTAL GENERATION

20 Ember: Coal to Clean Energy Policy

DEEP DIVE: MAJOR CAPITAL SPENDS

MOBILE EQUIPMENT

Mining companies around the globe are beginning to prioritise operational decarbonisation and pursue initiatives beyond simply renewable energy generation. The introduction of electric vehicles into the mining fleet has become a pertinent topic and currently stands as the most accessible entry point into mine electrification.

A number of manufacturers and suppliers are emerging as the race to achieve price parity, especially for that of light vehicles, begins to significantly ramp-up. Some notable exemplars where mobile electric equipment has been adopted includes:

- Newmont Goldcorp's Borden mine in Ontario Canada has committed to an all-electric fleet of mining equipment, made up of approximately 35 light vehicles as well as several heavy haulage vehicles. This alone is expected to reduce 5000 tonnes of CO2 per year, whilst reducing ventilation requirements by 50%.
- Glencore's Sudbury Integrated Nickel Operations are anticipated to operate solely electric vehicles as part of its Onaping Depth Project. In addition, their CSA operation in Australia, is already operating a fleet of electric loader vehicles and production drills. As both sites are extremely deep operations (2600m and 1700m respectively), the sites are expected to save significant costs in ventilation and refrigeration.
- BHP is piloting the use of light electric vehicles (LEVs) at their underground Olympic Dam site in South Australia and their Broadmeadow site in Queensland. To date, the trial has shown the LEV can travel up to 100 kilometres on the surface and 60-70 kilometres underground before requiring recharging. The LEV also utilises an inbuilt charger to recharge a quarter of the energy consumed each trip when parked. Once proven, BHP will look at the potential of rolling these out at their other sites.

Electrify to simplify

Over the last several decades, the world has become increasingly interconnected. Mining has taken advantage of globalisation and used it as a launching-pad for rapid growth across many commodities. However, the Covid-19 pandemic and US-China trade war has highlighted how complex international supply chains can also create systemic vulnerabilities.

State of Play data indicates that the biggest forms of change within the mining industry over the next 15 years are expected to come from a combination of energy, extraction technology and supply chain disruption.

The mining industry assembles a vast array of external suppliers to produce materials that are embedded in most aspects of everyday life. Electrified technologies implemented into the mining supply chain will have far-reaching impacts and may create an opportunity for a number of stakeholders across the value chain to initiate transformation, particularly in the area of environmental and socially responsible sourcing.

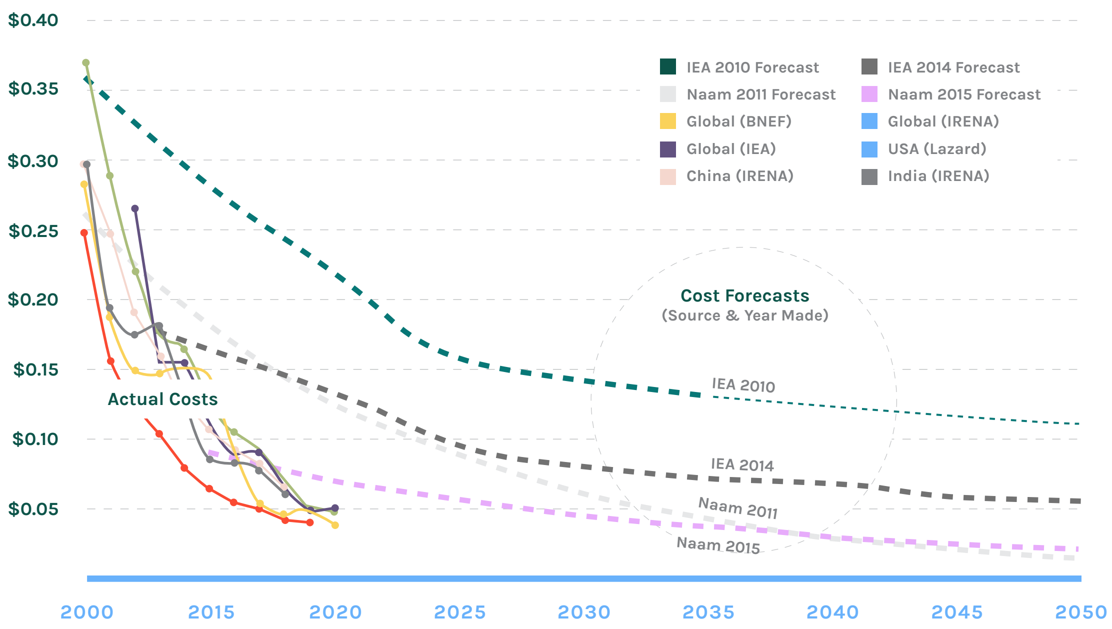
Energy independence and resilience

Mining companies rely on a predictable supply of personnel, equipment and materials in an uncertain and unstable market. Supply chain resilience is therefore vital to mining's continued success. Electrification creates opportunities for supply chain simplification and independence across energy generation, workforce and maintenance.

Traditionally, mining companies have often relied heavily on either external suppliers or on-site fossil fuel generation to meet energy demands, which form up to one-third of overall cost-base. Reliance on external power networks leaves mines highly exposed to price volatility and fluctuations of global energy markets. On-site renewable energy generation and storage enables companies to generate their own predictable supply of cheap power, irrespective of what is happening in oil, coal or gas markets.

Electrification also places a ceiling on energy costs. The world has consistently underestimated the speed of capacity growth and price reductions in renewable energy generation. After decades of price convergence, the lifecycle costs of renewables at many mine sites are less than the incremental costs of sourcing power via diesel generation. Furthermore, we are almost at the point where building new renewable power systems in many regions is cheaper than continuing to operate existing coal or gas fired plants.

UTILITY SCALE SOLAR PRICE PER kWh



Source: Rameez Naam, 2020

Resilience is further amplified by reduced maintenance requirements. Electrified technologies, in particular mobile equipment, have a much lower maintenance requirement than that of traditional internal combustion equipment. With 80% fewer moving parts and fluids, electric engines are more reliable and require less maintenance and replacement, mitigating that supply chain risk.[21]

Supply chain maturity

Covid-19 has been a powerful example of how different supply chains can hamper productivity. As a result of the pandemic, global supply chains which were once highly efficient are now perceived as unstable and fragile. Many companies have experienced unexpected bottlenecks in their supply chains, as well as disruptions to their workforce.

The supply chain for the electrification of mine sites is relatively immature, which poses many challenges, but also creates opportunity for improvement and innovation. As it stands today, the procurement and sourcing capability of electrification equipment is in its infancy. The ability of mining companies to create a fully electric mine site is highly dependent on the availability and reliability of sourcing this equipment, and therefore requires greater attention by the industry to underpin its growth.

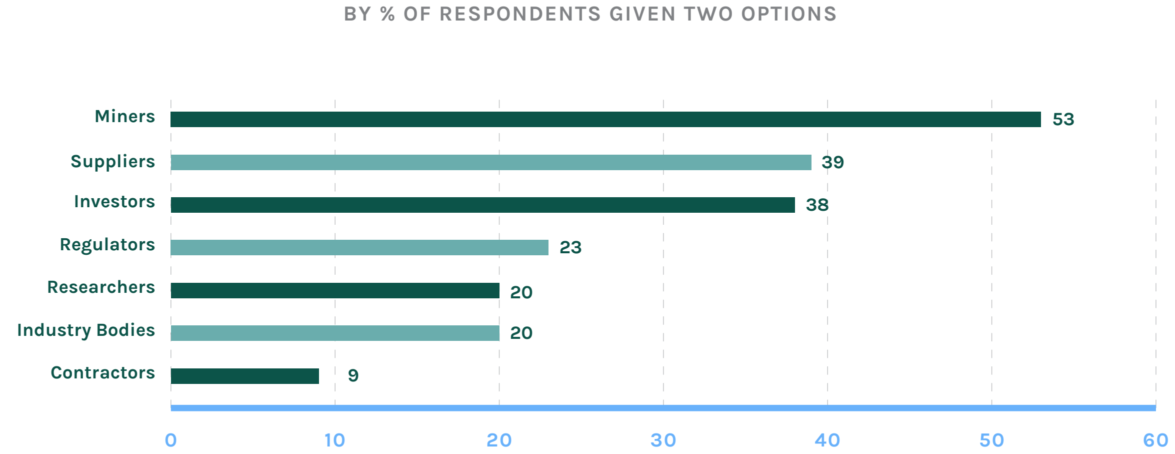
> **"I think the mining houses will lead the change, and some of that will be a response to broader change and expectations in society"**

In consumer facing and digital industries, suppliers predominantly drive new product innovation and adoption. In mining however, the capital required to develop physical technology is considerably larger and arguably riskier. Before manufacturers commit to investing in research and developing the required infrastructure for large-scale production, they need to know that the demand and scale for growth will exist. Electrification will be demand-led – 53% of the industry believe that the miners are driving investment in electrification the most, compared to 39% for suppliers.

21 Parliament of Australia – Electric Vehicles Report, 2018

ELECTRIFICATION INVESTMENT

We asked: Who is driving investment in electrification the most?



Miners will need to communicate clearly and work closely with their suppliers to ensure that the electric technologies they want for their operations are either available or being developed. 92% of the industry believe this will bring about new business model opportunities, namely servitisation. If suppliers and miners can identify and support innovative ways to promote electrification, implementation costs will come down commensurately and enable mass adoption.

> **"We will most likely end up selling the battery as a service to customers, so they pay by kilowatt hour as opposed to investing outright"**

Transparency and provenance

More than ever, end-consumers want to know where their goods came from, and how they got there. Consumer driven demand for responsible products is expected to be a driving force of change for miners and their downstream suppliers. Our data suggests that renewable energy, electrification and supply chain traceability will be key innovations in meeting these demands.

Miners may need to recognise that they are also a part of someone else's supply chain. Selling products into an industry which is highly sensitive to consumer preferences may attract "green" premium commodity pricing for minerals mined responsibly. Conversely, those who ignore the final customers standards may miss out on such market opportunities. However, there is the chance that we see this premium disappear, as this type of responsibility becomes a potential condition of supply.

Battery minerals miners are likely to be the most exposed to this phenomenon as a key player in the development of clean energy worldwide. Investment in these new energy systems is partly driven by environmental consciousness which tends to hold industries more accountable for environmental impact. As battery minerals producers look to run their operations cleanly, electrification will be a big lever of change. The industries most exposed to clean energy simultaneously have a significant opportunity and significant need to electrify and will likely pull the rest of the mining industry along the journey.

Proving the provenance of the minerals will be key in creating a transparent market where these kind of consumer preferences can come to life. We are already seeing examples of this with regards to human rights. In 2016, the cobalt supply chains of seven of the world's leading electric vehicle manufacturers were exposed for their failure to meet the United Nations human rights standards. As a result, they were placed on the European Union's investment blacklist. We may yet see this level of backlash for supply chains which consistently produce dangerous amounts of carbon emissions, local environmental pollution and damage or other forms of negative environmental or social impact.

> **"Even if we want to go all-electric as a society, our electric cars will need more mines. But we need more mines in the right way"**

Role of Government

Over the past decade, a global ecosystem has begun to emerge to underpin the innovation and scaling of electrification technologies. As a relatively new ecosystem, the roles government and regulation play are important for its sustained success, both from a global adoption and local economic development perspective.

As no one country has yet established itself as the global manufacturing centre for electrification technology (although China is getting there quickly), the opportunity to lock up first-mover market share through government support is still significant. Around the globe, governments are moving to develop incentive schemes, research and skills support for local manufacturers and operators to nurture capability development within their jurisdiction.

The ability for government to mobilise investment in electrification is dependent on policy predictability and clarity. Rewarding first movers by removing competing technology subsidies, creating new tax rebates and providing research and development grants can help reduce the perceived risks associated with new technology deployment. Furthermore, transparency in the timing of future planned policy changes and targets will help guide industry players to develop their own roadmaps for investment.

Transitioning to a new mining energy system across the industry will require some forms of standardisation, however these efforts should prioritise safety and allow the market to guide which technology should be prescribed as 'best'.

Economic development

The economic opportunity for countries who drive the shift to electrified energy systems is significant. Regions who fail to create local capability will be forced to rely on their global trading partners and may ultimately pay a price for doing so.

China is already leading the way in both battery manufacturing and electric vehicle deployment. The subsidies they provided exclusively to domestic suppliers through their New Energy Vehicle Program (NEV) which began in 2009, bolstered this capability through policy certainty and a commitment to investment. As a result, there are currently over

300 electric vehicle start-ups in China. In a manner that resembles China's ascent to become the globe's renewable energy manufacturing superpower, there is a risk that if these early and significant investments into electrification technology manufacturing continue, we will again see overproduction. This may price other competitors out of the market, as has happened in many other sectors like solar panels, light metals production and magnets and materials based upon rare earths.

Beyond China, other nations still have a significant opportunity, particularly mining focused nations, to take leaderships roles in the future electrification economy. Bespoke local manufacturing capability that can service niche electrification technologies is less likely to capture economies of scale in one nation alone. Identifying the technologies where learning rates are likely to be globally dispersed will be critical to deploying government investment effectively.

> **"Those who are strong leaders in government have to apply the Nike principle: Just do it, and seek forgiveness later"**

For example, large stationary batteries subject to extreme conditions or specialist vehicle batteries may have supply chains that lend themselves to development and implementation within the region that both their manufacturing and raw materials were sourced.

Government often plays a critical role in helping to develop innovation ecosystems that support these kinds of opportunities. Silicon Valley emerged from US defence spending, and more recently Tel Aviv's vibrant start-up ecosystem has been driven by government matching venture capital deployment. Strategic policy, incentive development and skills support from government can help ensure countries are competitive in electrification technology and services.

> **"We need alignment in government policies on industry, climate change and emissions"**

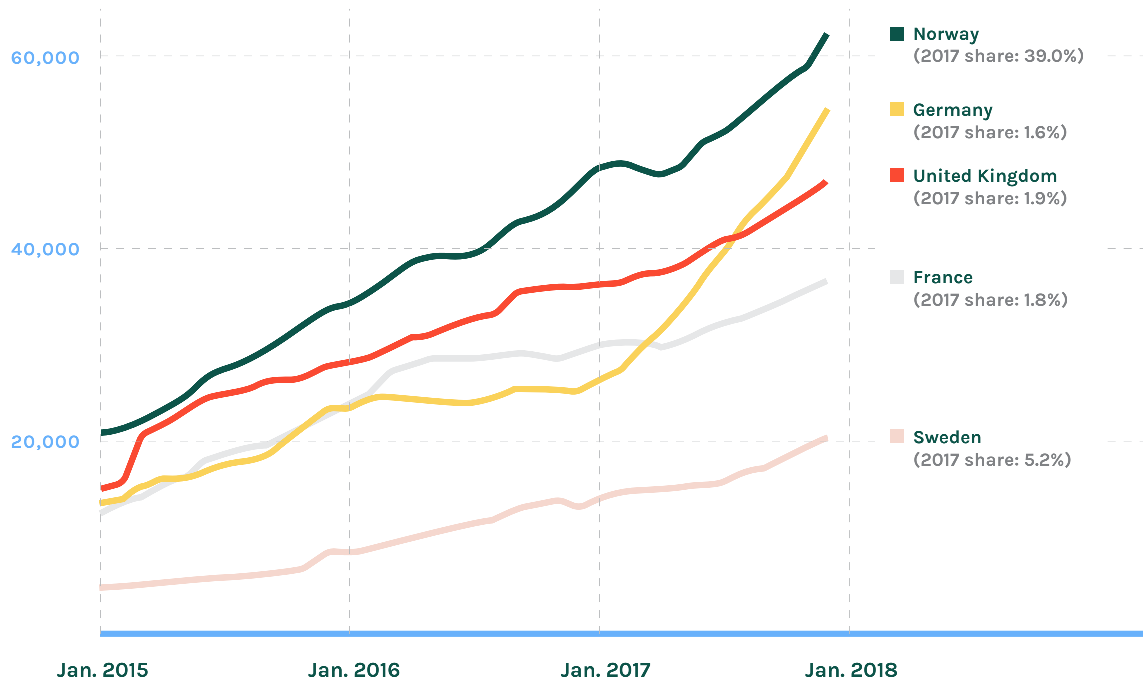
Policy and taxation

Whilst there are many stories of companies pioneering new technologies, the reality is that in most cases, history has rewarded those that follow. The second movers are often able to do this with a better business model and more aggressive, well-funded growth plans. A lot of today's behemoths, from Amazon to Airbnb, lent on the spending, experience and awareness of earlier iterations to achieve their current market dominance. However, if everyone waits for someone else to do the hard, early work, no progress will ever be made.

The role of government in encouraging industry players to bear the first-mover risk plays a key role in catalysing broad industry adoption. Government support does not have to be in the form of direct incentives or subsidies alone – they can motivate the ecosystem by signalling a planned change to policy which is highly correlated with electrification adoption. For example, removing the diesel rebate in Australia, which can be up to 40 cents in the dollar, would have a similar effect to placing a fossil fuel tax on mining businesses. Announcing that this is going to occur in a certain timeframe, would allow companies to strategically position themselves for the transition and to start developing capability in anticipation. We have already seen examples where this has proved successful. The European Union's introduction of CO_2 car and transport emission legislation resulted in a 1-5% increase in electric vehicle adoption in certain countries[20].

20 International Energy Agency – Global EV Outlook 2020

EV REGISTRATIONS OVER 12 MONTH PERIOD



Source: International Council on Clean Transportation

Similarly, the introduction of a price on carbon is an effective way to drive innovation in electrification. Mine sites that want to reduce their risk exposure to future taxation will quickly look to their on-site energy generation and consumption. Electrification provides the foundation for transitioning to a lower emission mine and positions companies to trade permits with those who have lower costs of abatement.

Strict vehicle emissions regulations, specifically targeting diesel particulate matter in underground mines, has the capacity to drive significant change in mining operations. As health and safety continues to be a significant topic in mining, the management of exposure to carcinogens is something government should be considering and enforcing.

Standardisation and waste management

The role of regulation in creating standards for the relatively 'new' electrification industry should prioritise safety and avoid the prescription of certain technologies.

Transparency in technology development can help create more efficient policy implementation. Sharing specific technical characteristics on a data reporting platform to the regulatory body will enable policy evaluations and market design to be effective and conducive to further innovation. It will also enable policy makers to develop safety standards.

Safety standards should clearly outline acceptable levels of performance for each of the technologies, including guidelines on waste management. Poorly vetted technologies, bad manufacturing and dangerous installation will slow industry adoption.

Waste management of electric equipment requires clear standardisation, particularly batteries. On average, within 4-5 years batteries begin to degrade for automotive use, despite having plenty of life for other uses, such as stationary grid support. Landfilling many of these batteries is rightly illegal in many places, as well as being expensive and unethical. The development of a regulated secondary market for batteries will have beneficial downstream effects for the electrification economy. Standardising the process for battery re-use, including transport, disassembly and interoperability may lead to the growth of a high value industry.

In ensuring all products are manufactured to the required standard of safety, competition can be created to encourage innovation and continuous improvement. Regulators should lay the groundwork for a variety of technologies to come to market and should not favour one form of chemistry or application. The market will decipher which technologies apply best.

Electrification technology considerations

1. Renewable energy generation

Clean energy solutions are becoming commercially more attractive, particularly solar PV and wind. Over the last decade, wind energy prices have fallen 70% and solar photovoltaics have fallen 89% on average, with the cost of renewables continuing to trend downwards[21]. The total lifecycle cost of solar is already less than the incremental cost of diesel at most remote mine sites in Australia.

We are now seeing large scale examples of wind and solar energy for mining applications, including OZ Minerals West Musgrave mine, which will operate using 80% renewables, or Rio Tinto's Koodaideri mine, who will provide between 65-100% of their site's energy through solar PV.

For grid scale power, renewables are a source of instability at current levels and the impact of greater EV uptake is uncertain. While EVs will create further demand for energy, their batteries will also help mitigate the variability of renewables. More stabilisation technologies will be needed to supplement the grid, such as the Tesla grid battery in South Australia, or the Alinta Energy Newman battery for an islanded system.

2. Heavy mobile equipment

Today, battery-based heavy mobile equipment remains relatively rare, very expensive and operationally challenging. The choice between capital-intensive battery-swap systems versus a less costly but more complex continually charging system remains unresolved. The emergence of innovation from outside of the mining industry is likely to filter through, with companies such as Proterra and Tritium developing heavy electric vehicles which may further the next generation of haulage.

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21 Ramez Naam, 2020

The likely grid impact of charging requirements may require modifications to the mining process and will demand more testing and piloting to ensure further understanding of these implications. However, the opportunity to redesign this equipment, which is traditionally quite large, paves the way for scale reversion which will be a significant enabler for mine development cost reductions.

3. Electricity infrastructure

Transmission and distribution systems need to be both smart and flexible in a clean energy system. Where this is not yet viable, battery technology will pay a pivotal role.

The current level of planned infrastructure integration for clean energy solutions is sitting somewhere between 'just in time' and 'just too late'. Static progression is largely driven by the energy market being unchanged for fifty years coupled with the long-life assets that were designed to support this unchallenged generation and distribution system.

The take up of renewables has been significant over the last five years as prices decrease and technology improves. Uptake speed has been in excess of what utilities have planned for in their long-term planning cycles. Only now are utilities looking at system-wide integration systems, of which will require further advancements in algorithm-based optimisation technologies. Similarly, this will also need to occur within remote systems, however on a much smaller scale.

4. Light mobile equipment

Light vehicles are arguably one of the most accessible entry points into mine electrification, clean energy conversion or clean energy options. Light vehicles allow resource companies, service providers and OEMs to trial and understand mobile electric equipment's general impact and charging infrastructure requirements with a low-level grid impact.

Safescape's Bortana EV is an example of a robust light vehicle designed for and trialled at some mining operations, with a battery pack and battery & energy management system developed and fabricated by 3ME Technologies.

Affordable mining solutions remain some way off and there are still range challenges in operating remotely. However, as this technology is bolstered by the economies of scale in EV manufacturing, we expect to see acceptably priced light mining vehicles in the 5-year time frame.

5. Stationary storage

Fixed grid batteries are generally larger and cheaper than mobile batteries, but there are a range of different physical and chemical types. It is unclear which of flow batteries, solid state batteries, liquid metal batteries, hydrogen or any other unique chemistry type will prove most effective in a mining context. The type of battery is likely to be highly dependent on the environmental conditions they operate in, as well as their charging system.

Fixed batteries may also be applied to discrete tasks such as rotating mills or underground fans. These batteries may also be tethered to and moving with large scale earth moving equipment. Further research and testing is required to understand which are best suited to each application within the mining process.

We are only in the early stage of grid style battery deployment. The vast amount of different battery options makes it difficult to predict and a matter of technical debate. We anticipate that in 5 years' time the front running technologies will have emerged and most deployment challenges will be understood.

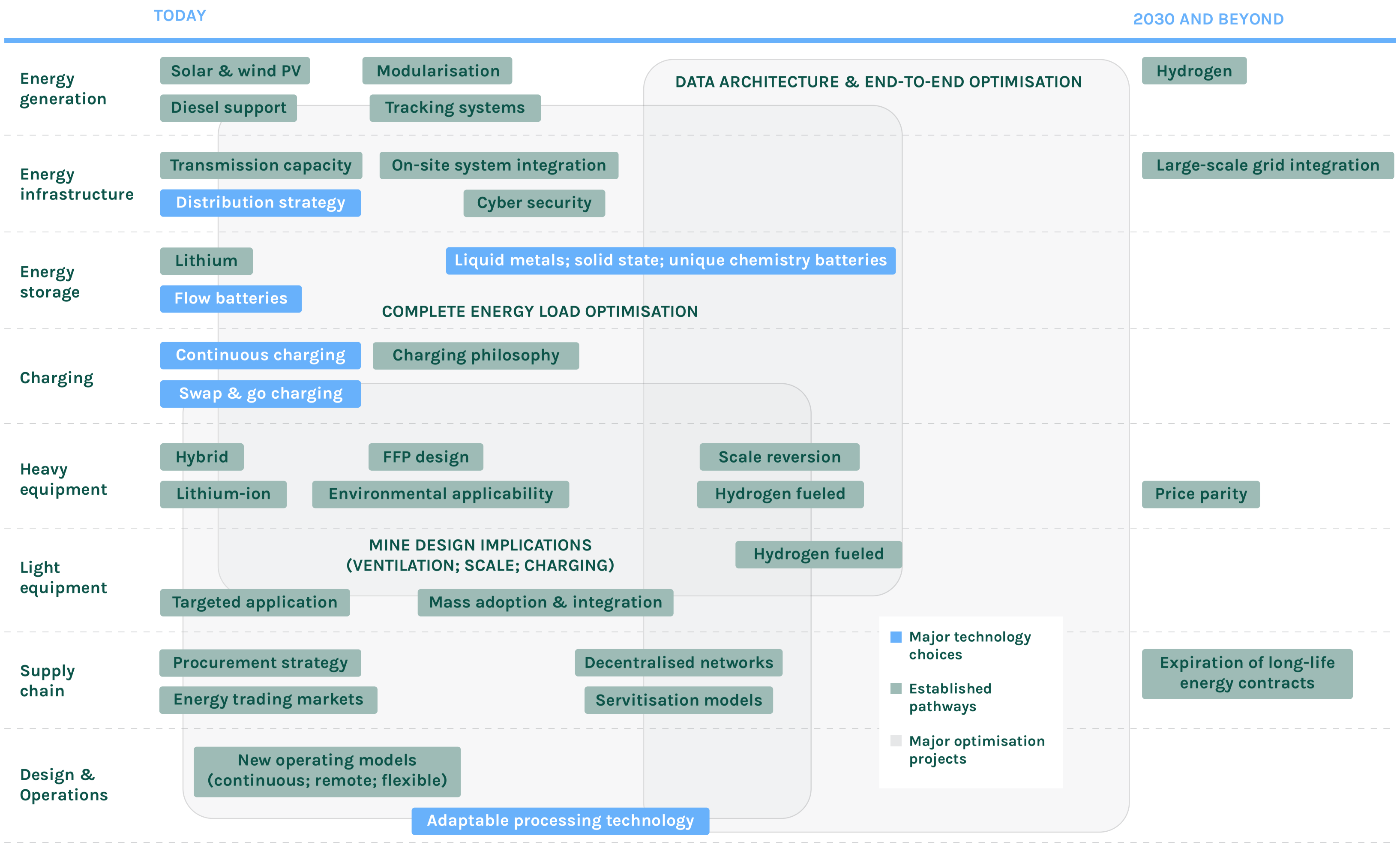
6. Charging infrastructure

Battery electric equipment will require some degree of fixed charging infrastructure, which will require careful mine design consideration. Methods to deliver charge are not yet standardised across industry, therefore the recharging process is highly dependent on the site's charging strategy.

Strategic placement of charging stations to leverage regeneration opportunities should be considered. The charging location will also become a localised heat source and will require ventilation. The mine may have one charger associated with a specific piece of equipment, or one charger for multiple pieces of equipment – which needs to be considered in design.

Charging is a significant source of energy demand, meaning the timing and location of the charging will impact how much energy is required and where at any given time. With enough data these impacts can be reviewed, assessed and integrated with operating schedules for greater efficiency.

OUR ILLUSTRATIVE ROADMAP:



Source: State of Play & FBI CRC Electrification Barriers Workshop

Conclusion: A new way of operating

With an electrified system comes the emergence of a new wave of operating model and business model possibilities, built on new operating assumptions. Traditionally, mining companies have employed a top-down, hierarchical operating structure. Whilst this suits a siloed operational philosophy, it hampers the ability to leverage the value that digitally integrated platforms make possible. Operating models are fundamentally the product of the value assumptions that underlie them – electrification combined with deep digital integration provides an opportunity to dramatically shift many of these assumptions. The most agile and adaptable businesses will be the first to take full advantage of these.

Electrification paves the way for companies to operate remotely more effectively and with higher safety standards. Electric drive vehicles benefit from more precise control, zero toxin emission, reduced hazardous chemical requirements and reduced fire risk. The next step change for safety will be achieved when people are entirely removed from harm. Such benefits will only be realised when full automation and remote control becomes technically feasible, something which the industry agrees electrification is accelerating.

The design of electric equipment allows for a significant simplification of a site's maintenance requirements. With 80% less parts than a traditional combustion engine, electric vehicles will require less frequent servicing and will reduce storage and warehousing management loads. As maintenance is one of the riskiest activities in mining operations, this reduction disproportionately improves safety. The servicing skillset will also transition from diesel mechanics towards electrical engineers and electricians.

Electrified systems provide larger, integrated and more granular data flows than internal combustion and analogue systems. The ability to fully leverage this information through remote operation, vehicle and mobile equipment autonomy, better decision-making and optimisation will both support and require a digitally-enabled workforce.

Finding the right people to execute within this digital model is highly competitive, both locally and globally. Off-site operations based in densely populated areas can increase the exposure to skilled labour and promote talent retention more so than an isolated asset. These workforce models offer the advantage of reduced travel expenditure, underpinning a leaner operating structure and the realities of a pandemic-ravaged world.

The large-scale benefits of electrification can be fully realised if the entire asset is on one network, with clear data flows across the whole asset. Designing an operating model as one holistic system, rather than a number of operational unit levels, makes the system more adaptable.

A singular, electrified system enables precise, variable control over generation assets and mining equipment. Under an integrated energy operating model, the site can respond to intermittent renewable energy through demand management flexibility and phase shifting. Integrating this with energy storage systems or changes to the mining process can create further value upside.

A more adaptable mining energy system will also create opportunities for market-led value capture and creation. As an industry subject to high levels of volatility and exposure to external world shifts, the ability to control production rate and energy consumption will create competitive advantage. Furthermore, as an integrated system the business can readily employ energy trading and reverse auctioning, both internally and externally. Responding to market signals and leveraging market incentives in this way will require a combination of awareness, new skills and cultural support.

Electrification is well placed to create real value, not only for the mining companies themselves, but for the broader community too. Combined with the growing digitisation of industry, the transition to an electrified system will have lasting impacts on operating and business models around the globe.

The State of Play team