UNDERGROUND MINING
AND THE CHARGE TOWARDS ZERO-EMISSIONS FLEETS

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CHARGING TOWARDS ZERO-EMISSIONS UNDERGROUND

LESSONS FROM EARLY ADOPTERS OF BATTERY-ELECTRIC FLEETS IN THE UNDERGROUND MINING SECTOR

by Jake Harris

Underground miners frequently turn to technology, innovation and creative engineering to add value to their operations and address the unique challenges associated with working in some of the Earth's harshest environments.

Now, with attention in company and investor boardrooms aboveground focused on the issue of climate change, the question is being asked: what progress are operators of underground mines making in the push towards zero emissions?

The accepted wisdom is that mine operators will need to invest in two key areas to achieve zero emissions: (a) the electrification of mine fleets (whether through battery-electric technologies or close alternatives such as hydrogen-powered fleets or trolley-assist systems); and, (b) charging or powering these new fleets with zero-carbon energy sources such as wind, solar or nuclear.

Battery-electric fleets are the most obvious solution for underground miners, given that passenger battery-electric vehicles (BEVs) from the likes of Tesla have already become a feature of everyday life in cities around the world.

While global supply-chain issues make it difficult to reliably order electric fleets on a large scale, mining companies with a green focus and the budget to back it up are moving to purchase early market offerings. These miners are also turning their attention towards what these new mobile low-emission technologies can deliver for their projects. While some of the value is obvious, other benefits are hidden further down the implementation road map.

This white paper will shine a (renewably powered) light on the value that a battery-electric underground fleet can offer an underground project, highlighting some of the early adopters along the way. Industry specialists have been interviewed for their unique insights in scoping and manufacturing these systems and in implementing the systems within busy, operating mines.

Drivers of change

The world has awoken to the realisation that a dramatic reduction is required in CO2 and other greenhouse gas emissions to tackle climate change. When it comes to heavy industrial activities like mining, investing in battery-electric fleets is one of the best ways to reduce emissions over the lifetime of a project.

Indeed, 47% of mining companies profiled in the *Mining Magazine Intelligence* 2022 Future Fleets Report cited emissions reduction as a key driver in their investment in battery-electric equipment.

Capital costs for battery-electric mobile fleets are 25 to 75% higher than for their diesel equivalents, according to the Future Fleets Report. Yet underground miners are showing an increasing enthusiasm for battery-electric technology out of not only the need to reduce emissions, but also due to a range of other operational benefits.

Investor relations

Shareholder and investor relations are a major driver in the push towards zero-emissions technologies. As Bob Corker, former chair of the US Senate Foreign Relations Committee and now a special advisor to Jefferies Financial Group, has said: "If corporates want to be in good stead with their shareholders, they must address ESG (environmental, social and governance) issues appropriately or their cost of equity will rise."

The ESG responsibilities of large miners will steer their medium to long-term strategies. Aligning their business with a greener, brighter perception of the mining industry will help clean the image of the entire sector and deliver improved environmental outcomes.

Health and safety

For underground miners, any reduction of diesel in the working environment reduces exposure to known carcinogens.

Diesel particulate matter is removed from working areas using complex ventilation systems, but it isn't the only hazard that will be reduced by electrifying the mobile fleet. Heat, which causes daily stress on workers' bodies in the deepest underground mines, can be dramatically reduced when utilising non-diesel equipment.

This helps create a better working environment with fewer long-term negative effects on the health of personnel.

Reduced project OPEX

Reducing dangerous gases and particles from the underground working environment brings with it an additional benefit: reduced costs. Ventilation

accounts for almost 50% of energy consumption in the average 500m underground mine, according to ABB. By reducing the need for ventilation through the use of electric fleets, mine operators can dramatically reduce their capital and operating costs – making for a healthier and more-profitable mine.

Additional profitability through renewables

Powering an electric fleet with a renewable energy source offers cost advantages in addition to the obvious environmental benefits.

For example, traditional fleets are often powered by piped gas or diesel that is hauled to the project by road. The use of electric fleets in combination with renewables eliminates the need to build gas pipelines or periodically haul diesel to remote projects, slashing capex and opex.

State of the market

Mining companies in many different locations around the globe have successfully piloted and adopted battery-electric vehicles, nowhere more noticeably than in Canada.

For example, Kirkland Lake Gold's adoption of battery-electric loaders way back in 2012, followed by a ramp-up to more than 80% utilisation of electrically powered equipment from various OEMs, has seen its Macassa operation in Ontario progress deeper than was previously ever imagined.

Macassa also operates a series of shafts for ore hoisting, allowing it to use battery-electric trucks for localised haulage within the mine. While there were several key drivers behind Kirkland Lake's approach, the main one was that it eliminated the need for a capex-heavy upgrade of ventilation systems to allow for safe operation of legacy diesel equipment.

Andrew Dawson, product lead for load-and-haul equipment at Sandvik, echoed the sentiment that Canada was leading the pack.

"The Canadians are leading the BEV market and they are pushing past just the trial stage. They are adopting both electrically powered underground drills and load-and-haul equipment into their market at a rapid pace."

Early adoption due to operational constraints and a green approach to the problem has allowed Canadian miners to lead global usage of battery-electric vehicles within the underground mining sector. The electric motors allow for near-instantaneous torque to be delivered to the loader's wheel, allowing for improved load handling and faster tramming times. This, when coupled with reduced moving parts and maintenance requirements, means more time working in active areas, Dawson added.

"Our customer base reports back to us that zero emissions deliver so many operational advantages. However, it is the operator experience and levels of productivity that these machines deliver that is helping drive the uptake in Canada."

Meanwhile, in Australia, miners are exploring battery-electric options in new collaborative ways. A prime example is the Electric Mine Consortium (EMC), which was formed by a group of leading miners and mine equipment, technology and services companies with the goal of delivering the "road to zero emission".

The EMC has attracted participation from businesses across the Australian mining landscape hoping to deliver new systems to the underground sector. Its focus has been primarily on six working groups that cover the broader transition to electrification, including a focus on energy storage, mine design, and electrical infrastructure beyond the battery-electric fleet. This highlights the broader thinking required when a sector looks to make a marked change in its operational approach.

Epiroc, which has delivered around one-third of underground battery-electric loaders worldwide, according to the 2022 Future Fleets Report, and which has a large presence in Australia, is a

> *"The Canadians are leading the BEV market and they are pushing past just the trial stage.*

member of the consortium. Its electrical and mechanical expertise has allowed it to perform successful trials at several sites down under.

"In November 2018 we launched our second-generation battery-electric equipment across the globe and one of our existing Australian clients showed a lot of interest in the loader options," said Brett Kenley, Epiroc's electrified solutions product and sales support lead.

"We shared our product range with the customer at our specialist factory facility in Orebro, Sweden, and were then able to showcase a BEV loader on the production line ready for early trials in Sweden.

"Subsequently, we worked with the Australian-based mine to deliver a battery-electric 14-tonne payload capacity loader for their unique intra-level tramming requirements. The solution allowed for the successful removal of fumes from a high-traffic, high-personnel area surrounding an underground workshop, reducing both diesel particulates from the environment but also dramatically reducing noise for those in the workshop."

This example highlights an early win within Australia for battery-electric load and haul that goes beyond just the trial phase. Case studies such as this will prove to other miners across the country that implementation of battery-electric technologies for heavier fleets is well within their reach.

Beyond the larger drilling and load-and-haul equipment, there have been many advances in the auxiliary and smaller service vehicles seen across the underground landscape.

3ME, a manufacturer of customised battery-electric units in regional New South Wales, Australia, has been working on a series of retrofit-style BEV solutions.

This has included a battery version of the IT (interchangeable tool) that can often be found buzzing around underground mine sites. The machine, which allows the rapid change of multiple tools to the front attachment, has become synonymous with the rapid development cycle currently being delivered by Australian contract miners across the globe. Therefore, it is heartening to witness the full spectrum of mining mobile fleets being reviewed and redesigned for a zero-emission future.

3ME also collaborated with underground mining innovator Safescape to assist with the development of Safescape's popular Bortana underground focused battery-electric utility vehicle (known colloquially in Australia as a 'ute').

"What we uncovered was that electrifying a ute was only one part of the solution [and that] mines still needed vehicles with greater durability, reduced maintenance and improved longevity. This is something we have focused on in the beta-phase build and as we will continue, as we move to production," said Beau McKenna, Safescape's marketing manager.

"There is a misconception that EVs are slower, have less power, and can't handle the sometimes-aggressive environments of the underground. What our customers have been most surprised by is the immediate torque and traction that you get from a 4WD EV that makes light work of inclines and declines, even with a 2-tonne load on the back," he continued. The narrative from Safescape is that the battery-electric revolution is not only changing the power-delivery method to vehicles, but also delivering improved value for miners in other areas of their operations. Chief among this is that the direct power delivery harnessed from electrical motors has allowed for improved performance across the full range of underground equipment.

Kent Swick, managing director of Swick Mining Services, said reducing carbon footprint was the key driver for development of his firm's Gen3 E-rig, the first battery-electric underground diamond drill rig for geological drilling.

"There is no doubt that without a focus in this area there will be penalties for the mining houses either in carbon offsets, taxes or investor support," he said.

"As a manufacturer of rigs, we have had a significant number of inbound inquiries from international operators whose clients are also facing the same issues as ours in our operating regions," Kent continued.

Swick's Futures Department has developed the tramming and battery management side of the design. The chassis and the drilling components should come into a final engineering design around the middle of the 2022 calendar year. The E-Rig should be ready for use by Swick's drilling division by mid-2023.

This global step change from such a wide range of underground equipment manufacturers highlights the growing demand for underground battery-electric mobile fleets. The next step will not only be the successful manufacture of these machines, but also the right supporting infrastructure and education to facilitate a smooth transition at underground projects.

Mine design and infrastructure

The roadmap to implementation of new technologies within the industrial workplace is naturally a long one, running from initial scoping and workforce engagement through to system selection, education and procedural upgrades.

The dialogue around the initial, underlying value of a battery-electric fleet is a complex one that draws on many parts of the mining cycle. As a consequence, the implementation process requires a fundamental rethink about mine design and mining practices.

While the largest challenges will come from the energy demands of a heavy haulage fleet, any piece of the battery-electric future fleet will require its own unique planning. Miners in many jurisdictions will have a hard time finding the deep knowledge and ability within technical service departments to accomplish this.

Development of innovative ideas and machines requires an element of trust – especially when multiple manufacturers are still in the trial stage

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SANDVIK PAVING THE WAY TO FULL ELECTRIFICATION IN UNDERGROUND MINES

Leading OEM boasts a full suite of underground BEVs, included trucks, loaders and drills

The development in recent years of batteries powerful enough to drive drill rigs, heavy loaders and haul trucks in underground mines has made clear the advantages of battery electric vehicles (BEVs) over their diesel-powered counterparts.

BEVs are emissions free, require less maintenance and can yield increases in productivity and output. Seizing on those advantages, Sandvik Mining and Rock Solutions has become a market leader by developing and introducing an industry-leading suite of BEVs for underground mining applications. Sandvik is the only OEM with a full offering of underground BEVs.

To date, 26 Sandvik battery- electric loaders and trucks have logged hours in hard rock underground mines in Canada, the U.S. and Australia. As for drills, 13 Sandvik units have drilled well over 2.8 million metres at operations in Canada, Sweden and Finland.

Over the past five years, the company has introduced progressively more productive and technologically sophisticated drills, loaders and haul trucks. Last year, Sandvik introduced two new battery electric drill rigs, the DL422iE production drill and the DS412iE rock bolter. As part of its program to convert its entire fleet of drill rigs to battery power, the company will later this year unveil the DD422iE with Dual Controls, which can be used for development drilling, bolting, scaling or meshing.

Now, Sandvik is preparing to raise the bar yet again with the TH665B, a haul truck capable of carrying 65 tonnes of ore per load. The TH665B will be the largest underground electric truck on the market and represents a 30 percent increase in carrying capacity over the company's 50-tonne BEV truck TH550B.

"We're beginning our site acceptance testing at our research facility in California," says Brian Huff, Vice-President, Technology and Product Line, at Sandvik's Mining and Rock Solutions. "We're doing full load tests of the truck on a 20% ramp." The TH665B is scheduled to begin field tests by the end of 2022 in AngloGold Ashanti's Sunrise Dam mine in Western Australia. A preliminary production run is tentatively scheduled for late 2023 and the vehicles should be commercially available by 2024. The advantages of battery electric drills and vehicles have become clear as these new products log more operating hours. Eliminating diesel particulate, as well as the noise and heat generated by diesel-powered vehicles, benefits the health and safety of workers underground.

The mining industry produces some 4% of greenhouse gas emissions and underground hard rock mining accounts for nearly one-fifth of the total. Switching to electric equipment aligns the industry with global initiatives to achieve net-zero emissions by mid-century. The shift also appeals to investors, who are increasingly demanding that mining companies adhere to principles of environmental and social governance.

The economic case for electric over diesel is also becoming clearer with the passage of time, says Huff. Battery electric vehicles are pricier to purchase than diesel vehicles, but the real measure is total cost of ownership. On that basis BEVs are slightly cheaper.

Electricity drawn from power grids is generally less expensive than diesel and that differential will only grow as fuel prices rise over time. Furthermore, eliminating diesel particulates reduces the demand on ventilation systems as well as heating and cooling systems.

BEVs have also been shown to outperform diesel-powered loaders and trucks. "Our BEVs are 10-15% faster than diesel vehicles," says Huff. "That more than compensates for the time spent swapping batteries."

That said, batteries can be swapped in three minutes with Sandvik's unique Auto Connect and Auto Swap technology, which eliminates the need to install cranes or any other overhead infrastructure. The operators of loaders or trucks can swap batteries from the cabs of their vehicles. The vehicles are equipped with arms that lift the batteries and slide them into a charging station. Likewise, the arms are used to lift the replacement from the charging station and lock it into place within the vehicle. "You can charge a battery in less than an hour, but you're putting more strain on the grid," says Huff. "Our system allows you to charge the battery over two to three hours. You charge slowly to match charge time with run time. The battery is ready when you need it, but you've minimised the impact on the grid, minimised the heat generated in the charging process and you've reduced the strain on the battery."

Sandvik has also developed patented charging while drilling technology. Elina Pyykkö, Vice President Product Development and Product Management at Sandvik's Underground Drilling Division, says the charger is built into the drill rig. Once a rig is in position, whether it's a development drill, production drill or rock bolter, it is connected to the electrical grid within the mine. "When you are moving your booms or preparing for drilling, the power is used to charge your battery," says Pyykkö. "When you're drilling, the power is used to drive the drill. Power is shared automatically. It's embedded in the technology itself."

Apart from that groundbreaking innovation, Sandvik's intelligent control systems allow the rigs to perform a drilling cycle autonomously. "You set the drill plan, which includes the number of holes and their positions," says Pyykkö. "The rig positions the booms and drills the holes automatically." The drills can also continue to work without an operator present, which means they don't have to be shut down during a shift change. And, when the work is done in one part of the mine, batteries are fully charged and the rigs can be moved elsewhere.

"You're using existing infrastructure," she says. "You just drive it to the next spot. It's always going to be charged and ready to go."

There in increased interest in the mining market to introduce new BEV technologies and equipment. "We have customers who want to try the technology by replacing diesel units with BEVs in extensions of their mine, or when replacing or expanding their fleets," says Pyykkö.

"The biggest benefit is for developers of greenfield mines." Permitting can be quicker and simpler. Regulators, as well as local communities, tend to look more favorably on all-electric mines because they have a much lower environmental impact. The capital cost of developing the mine can be substantially lower.

"There are huge capital costs to digging and installing ventilation," says Huff. "By reducing the size of the shafts and the size of the fans for ventilation, you can offset and sometimes pay for a large part of you fleet just from the capital savings." There are substantial savings on the operating side as well. "Once you're installed, the rough numbers are you're using half the ventilation from a flow standpoint," Huff adds. "When you decrease the vent flow by half you save dramatically on electricity costs from the operation of the fans."

At the same time, Sandvik has been able to pack more horsepower and carrying capacity in its battery-electric loaders than is possible with diesel loaders of the same size and footprint. As Huff explains: "Your ventilation requirements are driven by the amount of horsepower you install. From a total mine economy standpoint, you want the smallest diesel engine that can get the job done." With battery electrics, there are no emissions and, as a result, no restrictions on installed horsepower. Thus, Sandvik's 10-tonne battery loader is the same size as seven-tonne diesel-powered unit and the company's 18-tonne battery model is the same height and has the same footprint as a 14-tonne diesel.

The company introduced its battery electric products in the U.S. and Canada before introducing them in Europe and Australia. Sandvik is now offering them globally. And why not. "We have the most extensive offering of battery electric equipment on the market," says Pyykkö.

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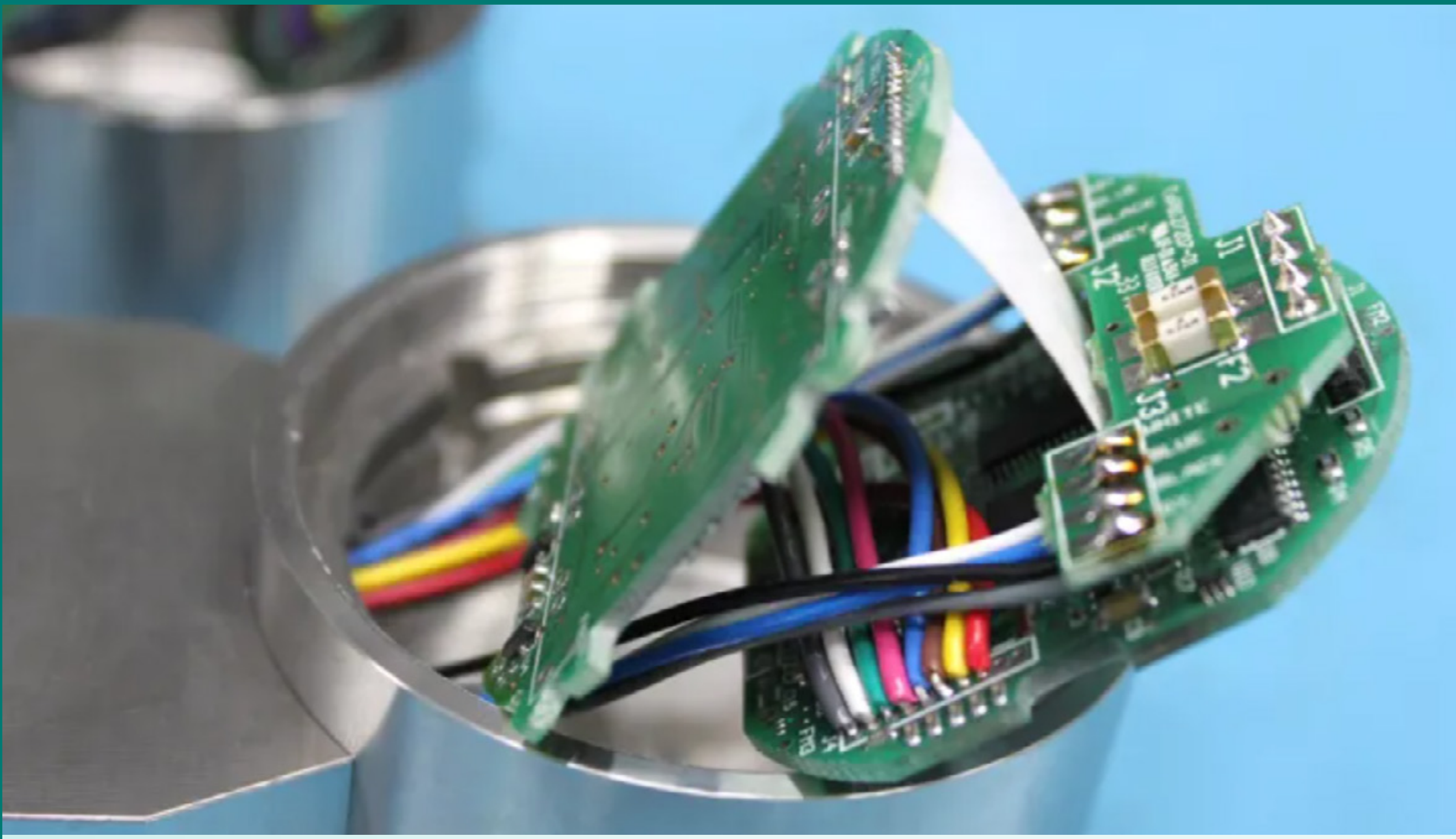

NAUTITECH ENABLING SAFE OPERATION OF BEVS UNDERGROUND

Aussie firm is ahead of the pack on technological solutions for battery-powered mining vehicles for hazardous zones

The shift from diesel to battery-powered vehicles in underground mining has already begun, but a wider roll out is not without challenges – especially from a safety perspective.

Major advantages of using battery-electric vehicles (BEVs) underground include the absence of carcinogenic emissions and a reduced heat signature. While this all but guarantees an improved operating environment, current safety monitoring and shut-down systems are designed for diesel vehicles and therefore must be adapted to fit their battery-powered replacements. Enter Nautitech, a Sydney-based original technology manufacturer (OTM) that has seen the transition to BEVs coming and has been working on harnessing technology to keep miners safe in all underground conditions. Their technical solutions are agnostic of vehicle type; they work with diesel, battery or electric. This allows miners and OEMs to swap the technology across with minimal fuss.

"The revolution doesn't have to be a shock; it can just be a shift. From a technological perspective, the same principles apply to monitoring and shutdown systems on a diesel vs. battery-powered vehicle," said Mac Powolny, Nautitech

CEO. "It's a simple swap of the air solenoid to a relay to make the technology compatible with battery vehicles. What it means is, if the mine site has been using our technology for a while, they don't have to change out everything. Our user interface can facilitate a quick transition," he added.

Nautitech has already supplied its Methane Master shut-down systems to LDO Group, the Australian distributor of Rokion electric vehicles, as well as to the BHP Mitsubishi Alliance in the Bowen Basin of Central Queensland via Canada's Miller Technology. They also work closely with 3ME, an Australian heavy vehicle battery manufacturer.

Powolny believes while the number of vehicles will remain the same regardless of electrification, demand for monitoring systems will increase to ensure there are no hiccups with the nascent technology.

"There is a huge concern in the industry about what may happen if a battery powered machine catches fire underground – it would be an event likened to Fukushima and would send shockwaves through the industry.

"Of course, we don't want that to happen, and being in the electronic space, Nautitech can provide technology to monitor the temperature of EV batteries and send a signal that allows mining companies to take relevant action such as fire suppression," said Powolny.

Nautitech has made a name for itself as an Aussie-owned and operated OTM. It invests 15% of its turnover in R&D, and it does everything in-house with its own team of about 10 engineers who are dedicated exclusively to smart electronic solutions for OEMs and underground mining companies.

Founded just over 20 years ago and focusing exclusively on the soft-rock space, success came first via the company's Methane Master CH4 monitoring and shutdown systems, before its

expansion into technology in the connectivity area. One of the company's main functions now is as a provider of broadband powerline modem (BPLM) technology, allowing operators to control electrical machinery deployed deep underground.

"Some of the networking solutions for underground mining just don't work one kilometre underground - because of challenging infrastructure, confined spaces, the environment, hazardous areas, roof falls, even the amount of steel that is used on the equipment," said Powolny. "With our Spitfire BPLM technology, mines can immediately achieve connectivity with underground mining machinery through the trailing cables.

The technology is pretty neat because you don't have to daisy chain with Wi-Fi access points or rely on fibre connectivity, which is very fragile in the underground mining environment.

Other products Nautitech is focusing on include its CUBEx Intrinsically Safe (I.S.) lighting solutions, which are vital in an environment where an errant spark from a smashed bulb could ignite a flammable gas or dust cloud. The company's developments in this area have become an industry benchmark, offering best in class performance.

"We are being run off our feet trying to keep up with the demand for our CUBEx I.S. lights," said David McCloskey, business development manager at Nautitech.

"They're being fitted on just about every piece of underground mining equipment you can think of. We now have a large OEM that's fitting them as standard equipment on their shuttle cars at their customer's request, so that's a big thrust for us going forward," he added.

Another new product is the Hawkeye Quad 7-inch smart display mounted on machines to visualise what's being picked up by thermal cameras, which are able to see through dust, water sprays and mist as if these conditions are not there.

"It's great for mining vehicles, particularly shuttle cars when they're coming up to the back of a continuous miner and there are clouds of dust causing poor visibility. With the view from a thermal camera via the Hawkeye Quad, you can clearly see if there is anyone in close proximity and if it's safe to drive forward," said McCloskey.

> *"From a technological perspective, the same principles apply to monitoring and shutdown systems on a diesel vs. battery powered vehicle.*
>
> *said Mac Powolny, Nautitech*

The 7-inch display also allows the user to record images it receives, acting as a dash cam that can be recovered in case of an accident, much like a black box in an airplane. As befits any future-facing company, Nautitech is positioning itself as a modern employer and champion of diversity.

"We are ticking all the boxes, not only decarbonisation, but most of the boxes related to the United Nations Sustainability Goals.

We pride ourselves to be a very inclusive company, with 40% of our female staff in management positions, a team that consists of 11 nationalities with 14 spoken languages, and probably about 20 different accents, including mine!" said Powolny. While the company's business is based on organic growth, one of its main strengths, according to Powolny, is agility. We have a quick decision-making process so we can react and pivot when we need to, ultimately benefiting our customers," he said.


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of equipment, as opposed to extended time delivering shift after shift in the relentless and often-punishing conditions of underground mines.

There are several important issues to consider within mining power networks alone.

A study presented by Caterpillar in 2019 found that battery-powered loaders produced only around one-eighth of the heat of equivalent diesel machines. While the need to charge battery-electric units may place substantial charging requirements on underground power grids, this is often more than offset by the need to run energy-intensive underground ventilation fans. Therefore, instead of having to expand the energy infrastructure, implementation of battery-electric fleets may only require a reallocation of existing power networks to deliver electricity to charging stations underground.

The ability to recharge a battery at depth is something else that requires careful consideration. Not only does the power infrastructure, which is typically delivered by a series of substations throughout the mine, need to be repurposed to different areas of the mine, production areas will need to be designed and excavated with battery charging and exchange in mind. This will lead to a potentially radical new design overhaul of how both electrical infrastructure and engineered mine designs are conceptualised and delivered.

While an industry standard for underground battery swapping has yet to emerge, one could foresee the rise of specialised areas, such as existing diesel fuel bays, being used for this purpose. These could be clean, well-lit areas, with suitable barricades and safety devices in case of an emergency.

The Global Mining Guidelines Group (GMG) is currently in the process of finalising the release of the third version of its 'Recommended Practices for Battery Electric Vehicles in Underground Mining'. This document will draw on experiences and learnings from those already on their battery-electric journey and should allow for greater knowledge sharing across the broader industry. For mines to become truly net-zero, they will need to move to clean energy sources such as renewables.

Naturally, closing the energy loop through solar power or other renewable energy sources will require substantial capital investments. Therefore, mine operators will need to take a long-term view about powering supply through to the end of a mine's life. The benefits of this renewable-energy delivery extend beyond the near

THREE ADDITIONAL BENEFITS & RISKS OF USING BATTERY-ELECTRIC EQUIPMENT UNDERGROUND

BENEFITS

1. Improved operator comfort for shift duration, with reduced noise, vibrations, and a diesel-free work environment.
2. Reduction in handling and transfer of diesel to deeper levels of the mine, decreasing potential environmental and fire hazards.
3. Fewer moving parts in electric motors allow for a decrease in scheduled servicing and maintenance requirements.

RISKS

1. Reduced ventilation capacity has an impact on clearance of explosive fumes when firing large underground stopes, potentially delaying re-entries.
2. Electric motors are much quieter than their diesel counterparts, creating a possible collision hazard. Miners use all senses in their dark working environment, most notably hearing around the large load and haul equipment. Additional collision avoidance or hazard warning systems may need to be implemented.
3. Battery fires pose a large potential risk. However, they are thought to be less likely than diesel equivalents. The highly flammable nature of several of modern battery components makes them a potential hazard.

emission-free power source. The reduced requirements of transportation of diesel and/or other possible fossil fuels to projects will dramatically reduce ongoing opex costs across the life of mine.

In 2017, a remote Australian mine site in the Northern Territory had to shut operations for more than 60 days while a heavily flooded roadway prevented it from being able to receive diesel deliveries. This led to a halt in production, at a cost of 8,000 ounces of gold per week, and the need to have 500 personnel remain on standby for site startup.

Given cases like the above, an all-electric fleet powered by renewable energy should deliver a reduction in risk profile for the corporate office, lessening the requirement to purchase fossil fuels and delivering stability to the bottom line. While fossil fuels may still act as a contingency to a blend of renewable sources such as wind or solar farms, over-reliance by mines could be reduced with this approach.

Gold Fields' Agnew mine in Western Australia is a shining example of renewable energy generation within the Australian underground mining sector. The mine, which is located approximately 1,000km from Perth, is in line to deliver 60% of its overall power needs from renewable sources. It has utilised a hybrid electricity power source via a combination of five 110m-tall wind-powered turbines and a 4-megawatt solar farm that consists of almost 11,000 solar panels. The utilisation of a large battery at the project also

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Change management

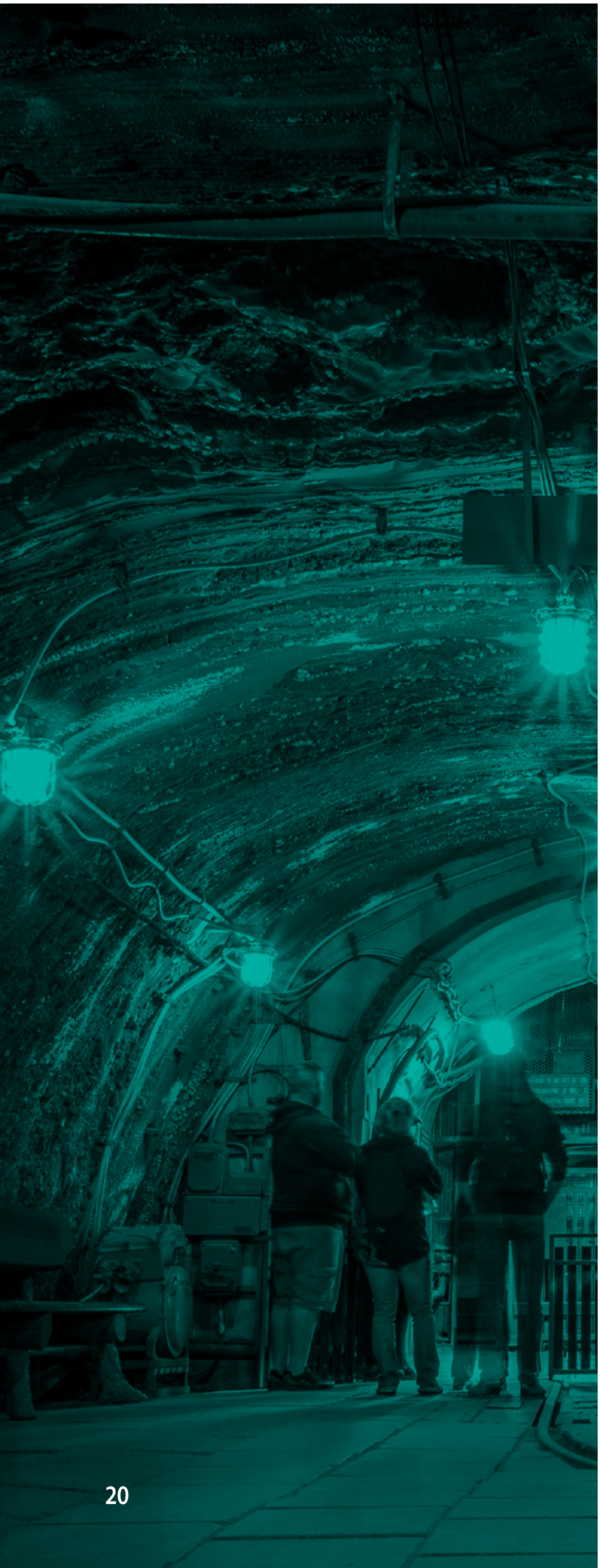
The radical change in working practices coupled with alterations in mine design and infrastructure requirements could be overwhelming for operators and personnel. The extensive background work required to implement even one piece of the battery-electric fleet could be off-putting for others. Fortunately, major OEMs are working with miners to deliver these often-complex solutions.

"When scoping our existing battery-electric projects in Australia, we are often asked to assist with project delivery beyond just fleet delivery," said Alisa Bennett, business manager for Epiroc's underground division in Australia and Mongolia.

This was the reason Epiroc recently acquired JMTEC, a specialist electrical engineering and manufacturing business, "to offer additional value and insights to our underground battery-electric journey", she said. With OEMs looking to offer turnkey solutions beyond their initial business scope, these types of strategic purchases of specialist businesses focusing on the digital mine have become more frequent in the past decade. This consolidation should allow for smoother transitions and simpler integration of what are often very complex systems.

Change management for these systems is regularly delivered at an operational level by either specialist project-engineering teams or external contractors who specialise in technology integration.

Sandvik has an application-engineering team that works with mine operators long before the beginning of the deployment stage, according to Dawson.



"An application study will be completed considering the mine design, the best place to put charging infrastructure and we look at the specific mining cycle."

This approach from OEMs will allow them to share knowledge from across their global business case studies and will instil confidence in these new technologies, he continued.

"Zero emissions and improved safety outcomes are driving lots of interest in our battery-electric systems. There are so many questions we get asked by our customers who are starting to explore the technology. We help them as much as we can and they help us, so we can all reach our common goal."

Emergency situations are also managed with a collaborative approach, he said. "Each mine will have its own constraints and each mining region will have its own legislation and regulation. So we work with our customer emergency response specialists to ensure suitable training, documentation, and procedural change is delivered as part of the implementation."

This collaborative approach will empower positive change within the mining sector, helping not only to deliver a smooth transition to battery-electric fleets, but also to improve knowledge and awareness of equipment capabilities.

This sentiment is echoed by Epiroc's Kenley. "There is so much to consider when implementing EV machines. We must recognise that our industry has been utilising diesel equipment for many years and it becomes second nature to us all regarding maintenance, operational and safety systems," he said.

"Implementing EV technology to existing brown field mines has its challenges, considering infrastructure, battery swapping and charging bays, skilled personnel, etc.

To assist with this change, the acquisitions of various specialised businesses by Epiroc enables

EVseries
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us to work with various partners to innovate, create and integrate our products and services for mines around the world."

Maintenance departments and existing workshop facilities will have to adapt to the new wave of electric-powered mobile fleets. Skilled and trained dual-qualified personnel will be required by miners to deliver both mechanical and electrical fault finding across the operations. Heavy-diesel fitters and auto-electricians will have to learn new systems of work for the new technologies and their requirements in the underground environment.

This could be delivered by OEMs to the crews on-site or via external courses to bring those across the industry up to speed with the requirements for new machines they will be encountering. Planning and scheduling of previously routine tasks can require new ideas and concepts, a topic highlighted by Patrick McKenna, business line manager of underground drills for Sandvik Australia and New Zealand.

"With our drilling fleet we have a chassis fixed battery that is charged while the machine is plugged into the jumbo box at the drill site. This means we can't use AutoSwap (Sandvik's battery-swapping technology) for quick exchange.

The problem we are working through with some customers is long tramming distance.

An example may be on a weekly trip to the surface workshop, where there needs to be a charging point off the decline and time allocated for a recharge to ensure the machine reaches its destination."

This highlights the risk that a battery-electric vehicle may not reach its destination due to lack of power, something which of course is also possible with a diesel-powered machine. However, with continued collaboration and knowledge sharing, these problems will be quickly overcome by the industry.

Digitalisation

The digitalisation of mining operations is slowly changing the expectations of operations on what equipment, personnel, and production rates can be achieved. The continued innovation and ability to harness technologies is allowing for increased interconnectivity and transparency of working systems at the underground face. This allows for data gathering and downstream analysis, which were historically never available to technical services teams.

The battery-electric revolution can play a large part in this digital change, allowing a ground-breaking overhaul of expectations of what future fleets can deliver. New connectivity of hardware and software, together with improved automation-led systems, are popping up across the mining landscape, leading to major improvements in safety and production rates.

A clear example of where this interconnectivity will play a big new role is in assisting electric-powered machines to know where their next charging point is within the mine. Operational management systems deliver real-time information to operators on performance, remaining power, and the best opportunity for recharging. These systems are especially valuable within trucking fleets, where they can optimise the charging and rotation of machines within increasingly long cycles.

Swick, developer of the Gen3 E-rig mentioned earlier, is also working on a remote-control drilling system, or RCD. The technology allows drillers to operate rigs remotely through video-linked controls from the surface effectively and safely for up to 24 hours per day.

"Diamond drilling is a complex work stream and involves drilling, tube handling, core samples

> *"With our drilling fleet we have a chassis fixed battery that is charged while the machine is plugged into the jumbo box at the drill sites.*

handling and rod handling, which is complex and impractical to fully automate," said Kent Swick.

"In addition to the productive time benefit, many locations in deep mines can be difficult for drill crews to tolerate for extended periods generally due to the temperature profile in some areas of complex and deep mines.

By having the drilling process controlled from surface, crews will only have to attend the rig for short periods to take core samples and move

equipment from hole to hole. This highlights that automation and removal of personnel from the "firing line" is paramount to the vision of the future mining fleet. The WiFi networks that have become common in larger underground operations allow for live communication with those tasked with jobs in all corners of the mine.

This visibility and connected future will allow for more automation of repetitive and dangerous tasks, while the battery-electric power source will allow for modulised and consistent power without the need for lengthy daily trams to refuel. This will ultimately increase utilisation across a full working shift, with only marginal downtime due to battery swaps and daily inspections.

"All of our latest jumbo or longhole drills will be part of the 'I series'; what this essentially means is that they are intelligent. [With] full data transfer and connectivity built in from the factory, we have the platform to assist our customers transition to automated or remote operations." said Sandvik's Patrick McKenna.

At this point, it is worth noting Sandvik's recent acquisition of Australia's Deswik, a major manufacturer of mine design and scheduling software. The acquisition will enable Sandvik to completely integrate Deswik's hardware and software within the next generation of machines, building on the existing AutoMine system that is already delivering underground load-and-haul automation for stoping activities.

Future view

If data compiled by *Mining Magazine Intelligence* is any guide, the future has already arrived underground. At least 27 underground mines around the globe have reported using or implementing battery-electric fleets of various types and sizes.

These range from LHDs and haul trucks from the likes of Epiroc and Sandvik-owned Artisan

Vehicles to light vehicles from companies such as ZERO Automotive, Miller Technology and Safescape. Battery-electric fleets are expected to dominate the next wave of equipment deliveries to the mining sector, with Sandvik recently declaring that more than half of its underground mining equipment sales will be electric by 2030, and a number of its competitors expressing similar sentiments.

As Sandvik's Andrew Dawson said, "We have all the equipment an underground mine could want to transform to a battery-electric fleet right now, I just don't know that the whole industry has the appetite or the courage to implement [that] currently."

Regardless of the timeline, the implementation of battery-electric fleets will affect all underground mining personnel, who will have to shift their expectations of what equipment can help them deliver in their daily tasks.

The battery-electric powertrain will also propel significant upskilling in maintenance personnel and both electrical and mining engineers.

These people, in turn, will have to explore and understand the complex trickle-down effects that utilising alternative power sources will have on operations. Delivery of a full battery-electric mining fleet will require considerable change management throughout the lifecycle of underground mines – whether it be at feasibility stage or 10 years into mine life.

Mine design, work cycles and schedules will require substantial overhauls.

The battery-electric revolution will constitute a key component in a network of new technologies delivering environmental, health and operational benefits.

A number of forward-thinking underground mines are already enjoying these benefits, and if the trend is any indication many more will embrace battery-electric technologies in the years to come.

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