The Electric Mine

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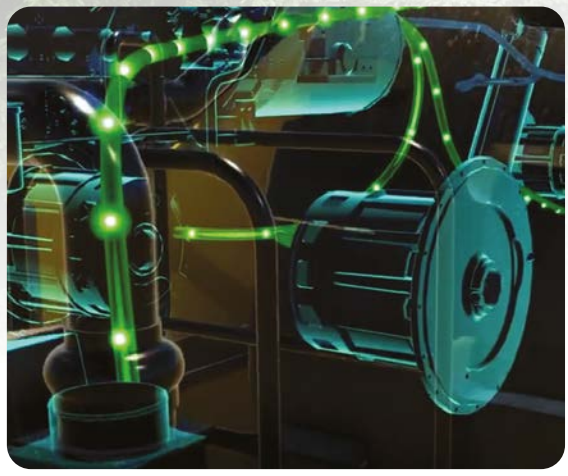

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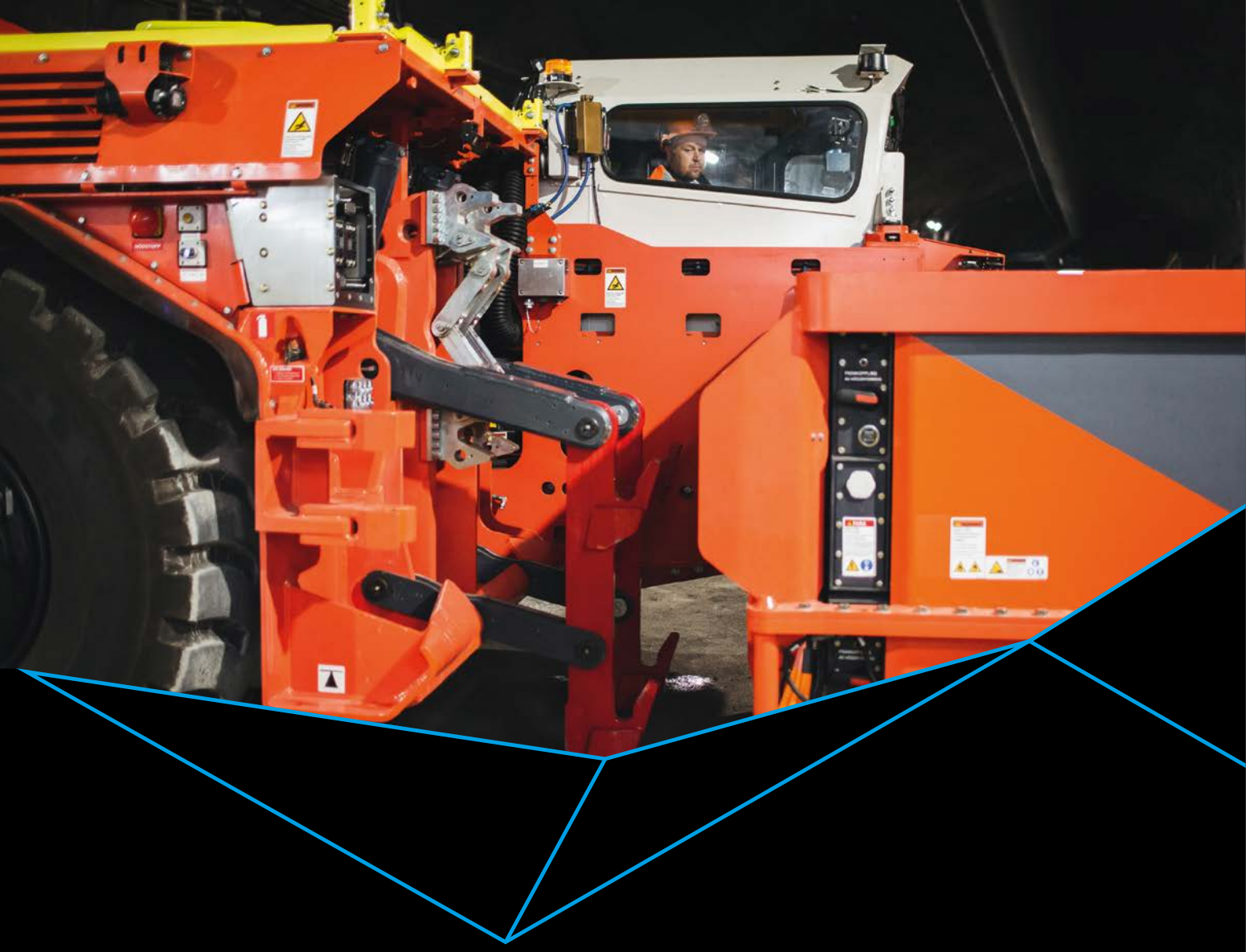
The Electric Mine

Most major mining companies have committed to decarbonising their operations, as seen in the 2021 pledge by the 27 members of the International Council on Mining and Metals to achieve net-zero Scope 1 and 2 emissions by 2050 or sooner.

It is broadly agreed that, to achieve net-zero, miners will need to focus on a transition to low-carbon power generation along with electrification of all mobile equipment.

Swift progress has been made on electrification, with mine operators already deploying or planning to deploy a total of 352 trucks featuring battery or hybrid technologies. But as this report will show, challenges remain – and these are being broken down by advancements in areas such as battery capacity and on-board charging systems along with innovations involving older technologies, such as trolley-assist systems.

This report features expert discussion on the technologies that will enable miners to achieve full electrification. It also includes profiles on three of the world's leading OEMs and technology providers in the field of electrification: ABB, Epiroc, and Liebherr.



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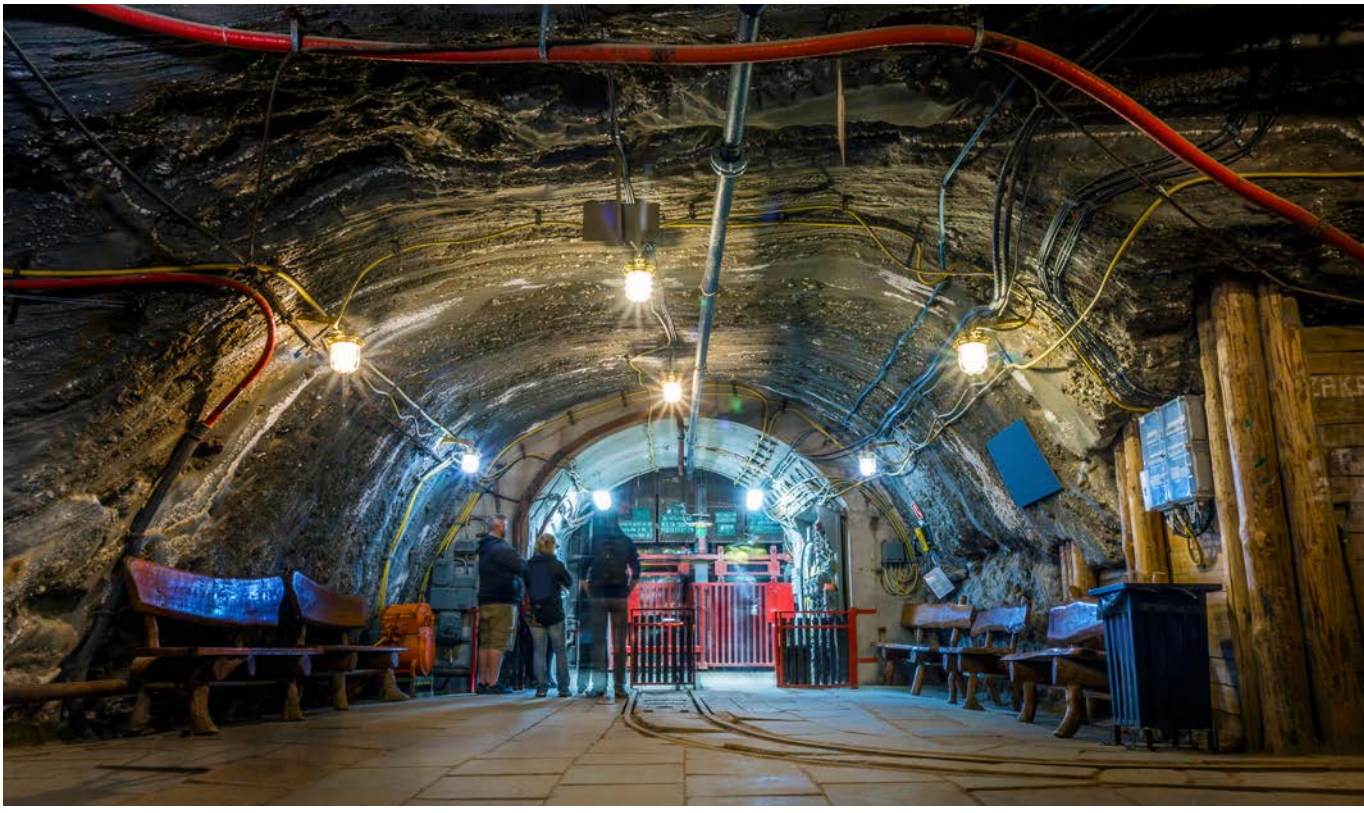
The Electric Mine

Technological gains, net-zero goals have led to rapid progress on electrification



Mining companies are rightly proud of the role that minerals such as copper, nickel, zinc, lithium and cobalt are playing in the green energy transition. But at the same time, they are finding themselves having to reckon with their status as major contributors to greenhouse gas emissions.

Direct emissions from the mining sector, excluding methane emissions from coal mining, currently account for 1% of global greenhouse gas emissions, according to a recent McKinsey study. Diesel-powered mobile equipment contributes 40-50% of these emissions, while non-renewable electricity sources such as coal and natural gas contribute an additional 30-35%.

The October 2021 pledge by the 27 members of the International Council on Mining and Metals to achieve net-zero Scope 1 and 2 emissions by 2050 or sooner marked the point of no return in the mining sector's commitment to reduce emissions. Although a handful of mine operators had previously set their own targets, this was the first time a group of majors – in this case representing about 30 percent of global mine production – had made a joint commitment on climate change.

To achieve net-zero, miners will need to focus their attention on two key areas: transition to low-carbon power generation based on renewables or nuclear; and electrification of all mobile equipment.

Miners have made rapid progress on electrification

Electrification of heavy mobile equipment, namely haul trucks, is arguably the greatest barrier to achieving net-zero due to the high capital costs and infrastructure requirements associated with the existing technologies.

Two main technological categories have emerged as the ideal solutions for heavy mobile equipment: battery-electric vehicles (BEVs) and hydrogen-powered fuel-cell electric vehicles (FCEVs).

BEVs are the better option for lower-weight hauling, typically below 200 tonnes, due to the limitations of lithium-ion energy density, as Richard Horton, partner, Partners in Performance, noted in the *2023 Mining Magazine Intelligence Future Fleets Report*.

FCEVs, on the other hand, have the energy density and flexibility necessary for hauling more than 200t, and provide similar characteristics and refuelling times to diesel engines. However, hydrogen-powered vehicles are currently limited by far higher capital costs and infrastructure requirements than their battery-powered counterparts, as Horton explained.

Despite the challenges, the mining sector has made rapid progress on electrification of haulage solutions in recent years. For decades, trolley systems provided the only feasible way of electrifying haul trucks.

The first feasibility study took place at Kennecott Copper Corporation's Chino mine in New Mexico, in 1967, which involved a truck carrying a payload of 123 tonnes up a 400m ramp at a 7% incline, but the trolley line was not able to sustain a high-enough voltage to justify commercial implementation.

The big breakthrough came with the Kiruna Electric Truck system, which was developed by a joint venture of LKAB, Kiruna Truck and ASEA (now ABB) in Sweden in the early 1980s for the purpose of developing an inclined ore-haulage system for underground mining. The first model, the 50t K1050E, went into commercial operation at Boliden's Zinkgruvan underground mine in 1988. By 1995, when the joint venture introduced the 35t K635E, 16 trucks were in operation at four underground mines: Zinkgruvan, Canada's Hope Brook and Kidd Creek, and Australia's Mount Isa Mines.

It was only in 2013* that Canada's RDH Mining Equipment (later acquired by Scharf OEM) delivered the first commercialised battery-powered truck and LHD – the 20-tonne Haulmaster 800-20EB truck and the 2m³

Muckmaster 300EB – to Kirkland Lake's Macassa underground gold mine in Ontario Canada.

By 2017, a number of OEMs were offering battery-electric trucks and/or loaders, among them Epiroc, Liebherr, Maclean Engineering, and Artisan Vehicles. However, fewer than 10 mines had begun trialling or deploying these machines.

Electrification began to take off on its current trajectory around 2018, when Epiroc launched its second-generation battery fleet following more than one million operational hours of its first generation of equipment. The ascent since then has been rapid, with year-on-year increases in the delivery of electric fleets and the deployment of mines on every continent.

By the end of 2022, mine operators had deployed or were planning to deploy a total of 352 trucks featuring battery or hybrid technologies. Hydrogen technology, despite lagging far behind battery-electric technology, was being trialled by Komatsu at Anglo American's Mogalakwena platinum mine in South Africa and was being considered by a handful of other big players, including Ivanhoe's flagship Kamoa-Kakula project in the Democratic Republic of the Congo.

Net-zero goals have been arguably the biggest factor in the rapid uptake of battery-electric equipment.

According to *Mining Magazine Intelligence*, 51% of operators using battery-electric vehicles have stated that lower emissions were a key driver of their investment.

Furthermore, in a survey around 450 mining executives run in 2021 by the research group State of Play, 60% of respondents named "environment" one of the two key motivating factors in considering electrification.

The second-most popular answer was "cost", given by 48% of respondents. In the context of the survey, "cost" referred to the fact that electrification would reduce the need for diesel, ventilation systems and cooling equipment, which are all costly items. Ventilation alone may contribute 30-50% of the total energy operating costs in underground mines, and more as the mine gets deeper, so reducing the need for ventilation systems can have a substantial impact on total opex.

"We strongly believe in the Key Technical Supplier model. It requires us to work closely with the other technological providers to build best solutions and take care of interfaces"

Mehrzad Ashnagaran, ABB

However, the respondents could just as easily have been referring to the cost of capital, which can be 20-25% higher for miners with the lowest ESG scores, according to the same McKinsey study we reference earlier. In other words, although electrification requires large upfront capital costs, the cost of not embracing electrification could end up being higher.

Breaking down the technology enablers

Rapid technological development – including advancements in battery capacity and on-board charging technology – has been the other key enabler of the upswing in battery-electric deployment seen in the mining sector in recent years.

"Battery development has exceeded expectations. If you had asked us five to 10 years ago, we could not have imagined where we would be today," said Mehrzad Ashnagaran, global product line manager - electrification and composite plant for ABB.

[*] *Data compiled from Mining Magazine Intelligence 2023 Future Fleets Report and data supplied to Mining Magazine by Jake Harris, owner of UGMiningTech.com*

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Epiroc targets conversions as key to fulfilling electrification commitments

Sustainability has emerged as the number one goal for mining equipment manufacturer Epiroc in recent years, as it has for much of the sector as a whole. For both the company itself and the wide range of customers who use its products every day, that commitment to sustainability means, in large part, a shift to electrification.

The Swedish founded business has set itself some bold, ambitious targets to deliver a greener and more sustainable future through electrification. It has pledged to offer a complete range of underground equipment in battery-electric form by 2025, while by 2030 it intends to provide a battery-electric version of every part of its vast portfolio of mining equipment.

"Yes, it's a big task and it's a short time period," admitted Shawn Samuels, business line manager for Rocvolt, an electrification accelerator unit within Epiroc that focuses to drive electrification both internally and with its mining customers who are increasingly embracing the concept of the electric mine.

"I would say there's customer interest, in every offering, is to be electric and sustainable," continued Samuels. "We were a big driver ourselves to start with, when we saw it as the future, but over the last six or seven years I see everyone talking sustainability. The big mining houses want to be sustainable and green, and we do too. We are all in on this, and it's full tilt."

That sense of being all-in is the driving force behind the development of Epiroc's Rocvolt unit which coordinates the wider company's electrification efforts. It is also why Epiroc is engaged in what Samuels described as a "two track" approach to electrifying its products.

"Because of this [short time period] what we've done is develop new equipment Scooptram ST14, Minetruck MT42 and drilling equipment, but at the same time we are converting older equipment from diesel to battery," he explained.

So far, this process has seen Epiroc complete conversion of three models: its Scooptram ST14 and Scooptram ST1030 loaders, and its Minetruck MT42 vehicle. It is currently working on conversions on the Scooptram ST7 loader and Minetruck MT436. The benefit of converting these models to battery power is not only in reduced emissions. Epiroc has found that they use 70% less energy, require 25-30% less preventative maintenance spend, increase productivity by 10% and account for less noise.

The transformational nature of what Epiroc is doing in catering to a mining industry in the process of electrifying operations on a vast scale is about more than just the physical process of converting its longstanding diesel fleet to electric; it is also about skills and knowledge. The manufacturer has to replace

100 years' worth of knowledge on diesel vehicles and plant into a similar level of expertise to cater for the electric future. In short, Epiroc needs to educate an entire workforce to operate and service electric equipment, virtually from scratch.

In part, the process of converting the existing fleet is helping people in the business – and the company itself – to acquire this knowledge. The "two track" approach is an important factor in this, as Samuels explained: "We're making new equipment and new designs and making battery equipment that way, but we're also taking the older models and converting them; so then we are using that knowledge we learned from the conversion process to provide new battery equipment of the same models from our factory."

In addition, to help accelerate the process, Epiroc is engaging with educational institutions as well as developing its own training programmes to educate and train its workforce.

While developing an electrified fleet and converting diesel power to battery will be important in the digital mine of the future, these new tools will be rendered redundant without good infrastructure, both physical and digital.

"Electrical infrastructure is critical to an electric mine as installed electricity, substations, and charging capacity needs to be considered when planning the mine," said Samuels.

"Data capabilities are also critical – so digital infrastructure is important for management of the assets including vehicles, batteries and electrical infrastructure like chargers etc. management of the large electrical mine components can be critical to managing electric costs."

With a view to providing this infrastructure for its customers, Epiroc has brought in significant expertise through acquisition in recent years. The company has made between numerous acquisitions over the last three years, with the focus of the acquisitions being on automation, electrification and digitalisation.

"Infrastructure is critical to the success of the mines," added Samuels. "We started selling the chargers, the batteries and the machines. And then we got we got on line and [customers] would say 'how much power do I need for these machines?' and 'how do I get the power? And we saw opportunities in acquiring more expertise in this field."

Among companies brought into the Epiroc fold in 2022 were Australian electrical infrastructure solutions provider JTMEC and Remote Control Technologies (RCT), another Australian firm that specialises in automation and remote control solutions for mining.

In 2021, Epiroc partnered with Kempower, a Finnish tech start-up that designs and manufacturers direct current fast charging solutions for electric vehicles and machines. That year it also bought Canadian electrification infrastructure provider Meglab, to help service north American mining customers.

Explaining the synergies these acquisitions bring for Epiroc and its clients, Samuels said: "These companies knew infrastructure so now we can bring their knowledge to the table and we can talk substations, we can talk power requirements, we can talk about how much cable you need, the sizing, how much power you need to do these kind of things."

> **"Digital infrastructure is important for management of the assets including vehicles, batteries and electrical infrastructure like chargers"**
>
> Shawn Samuels, Rocvolt

Another important part of the jigsaw for the electric mine is the battery itself. Epiroc has partnered with fellow Swedish company Northvolt since 2018 to provide batteries for its electric machinery, with sustainability at the heart of this partnership too. The partners are currently working on a recycling programme, with Northvolt aiming to have all its batteries use 50% recycled material by 2030.

All of these elements are already coming together for Epiroc, as evidenced by its position as the main mining and haulage equipment supplier for Glencore's Onaping Depth Nickel-Copper project in Ontario, believed to be the world's first all-electric mine, and due to come onstream in 2024. Epiroc will supply the mobile mining battery-electric machines for this project.

It is a major endorsement of Epiroc's commitment to developing the electric mine, but with the way the industry is heading, it is only likely to be the start of the journey.

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Today, small vehicles – such as personnel vehicles, transport vehicles, loaders, and small haul trucks – can be easily retrofitted with battery-packs. This has enabled the likes of Epiroc, a leading producer of loaders, haulers, and dumpers (LHDs) with capacities ranging from 20 to 65 tonnes, to commit to having battery-electric options for all underground equipment by the year 2025 and all surface equipment by 2030.

Today, small vehicles – such as personnel vehicles, transport vehicles, loaders, and small haul trucks – can be easily retrofitted with battery-packs

For larger battery-electric haul trucks, the biggest constraint is in designing a battery that meets the required energy density and can fit inside the limited space available onboard the vehicle. However, OEMs are reporting progress in this area. For example, Williams Advanced Engineering, now owned by Fortescue Metals Group, recently unveiled a prototype battery system designed specifically for use in a Liebherr 240t haul truck. And Caterpillar recently announced a successful demonstration of the first battery-electric version of its 265t 793 mining truck.

On the charging side of the equation, the most-critical bottleneck is the connector and its ability to convey more energy to a vehicle in less time, according to Ashnagaran.

In 2021, ABB launched eMine, a portfolio of advanced electrification, digital and autonomous solutions aimed at helping operators integrate battery-electric vehicles into their operations while maximising energy efficiency and performance.

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Innovation behind **Liebherr's zero emission push**

As one of the world's leading suppliers and manufacturers of heavy machinery, Liebherr was always likely to be at the forefront of the mining industry's move towards electrification.

Since unveiling its Zero Emission Mining Program at MINExpo 2021 in Las Vegas, the German-based multinational has been working hard to meet its ambitious targets on greenhouse gas (GHG) emissions. The company's zero emissions strategy included a pledge to offer low GHG emission solutions for all trucks and excavators by 2022, something that was achieved last year with the offer of electric configuration on these products. It now intends to follow up by offering fossil fuel-free solutions for the majority of its clients' applications by 2030.

Liebherr has committed to exploring a wide range of pathways to meet its zero emission targets. These include conducting investigations into future zero emission technologies, updating its equipment offerings, and partnering with customers and industry experts to develop zero emission solutions for the wider mining industry.

Liebherr has also conducted a feasibility study to investigate the viability of a variety of zero emission technologies that could be used to complement its existing mining equipment portfolio. The study, which was finalised in early 2022, examined four drivetrain technologies that have potential use cases for large mining machines: battery electrification, including trolley solutions and the ability to undertake stationary or dynamic charging; ammonia internal combustion engines; methanol internal combustion engines; and fuel cell electrification, either via a hydrogen fuel cell-battery hybrid in a truck running on a trolley line or through other ways of dynamic charging.

As part of the feasibility study, simulations were run on these technologies in a number of different scenarios, including looking at how each would work in different locations and in a range of haul

profiles. The simulations also factored in fuel pricing predictions for 2030 to assess the viability of the proposed solutions.

A commitment to innovative solutions

Liebherr offers equipment and zero emission technology solutions for its customers that are modular. This allows the company to offer upgrades and retrofits to future energy solutions on existing equipment, easing their client's transition to low or zero emissions and futureproofing their existing assets.

Dr Isabelle Ays, head of Zero Emissions for Liebherr Mining, said: "We know that zero-emission mining solutions increase complexity in the mine. We are continuously expanding our expertise so that we can assist our customers to manage the increasing complexity in their business, including but not limited to professional consultancy for the most appropriate zero emission mining solution.

"We are also working hard on the modularity of our trucks so that our customers have the option to retrofit or upgrade their trucks to any powertrain and fuel source of the future. This is already possible with our excavators, with the option to convert them from diesel to electric.

"Further, we understand that the key to the success of our Liebherr solution is to bring the energy into the machine. That's why we are continuously expanding our expertise in dynamic and stationary charging."

Liebherr's application engineers use specialised simulation software to determine the optimal combination of stationary charging and dynamic charging solutions for each customer. All elements – such as possible locations for trolley line hardware, line length, ramp design and other key elements – are considered to optimise costs, maximise production, and minimise overall emissions.

Trolley solutions

Liebherr has offered trolley solutions for its range of mining trucks since 2016 through its Trolley Assist System. This system allows customers to power diesel-electric trucks by connecting them to overhead electric powerlines.

> **"Dynamic charging with trolley overhead lines offers an optimal way to use electricity without interrupting the mining process"**
>
> Dr Isabelle Ays, Liebherr Mining

"We have recognised that in the future electricity will continue to be the cheapest alternative to today's diesel," Ays explained. "For this reason, every mine should try to use electricity whenever possible.

"Dynamic charging with trolley overhead lines offers an optimal way to use electricity without interrupting the mining process. Also, future Liebherr trucks with zero emission drives will have this Trolley Assist option so that our customers can keep their energy costs as low as possible."

The existing global fleet of Liebherr trucks with the Trolley Assist System consists of 50 363t T284 trucks across two sites, and seven 100t T236 trucks in Austria.

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Mining

Liebherr is a leader in proven low emission solutions, utilising grid electrification. By 2030, fossil fuel free solutions will be established.

Liebherr strives for long-term sustainable solutions, providing different modular options centred on environmental sustainability, safety, cost, flexibility, and maintainability including:

- 30 years experience in electric drive mining excavators with all machine models available ranging from 150 t to 800 t class
- Trolley Assist option available on all Liebherr mining trucks
- Liebherr combustion engine compliant with Hydrogenated Vegetable Oil (HVO) fuel
- Tier 4 Final certified engine available on trucks, excavators, and dozers
- Liebherr AC drive system on all truck models providing a modular platform for future powertrain technologies

Liebherr‘s roadmap includes batteries, combustion engines using green fuels, and hybrids.

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Cable management solutions for electric excavators

Liebherr has worked with electric excavator technology for over 30 years, and has now introduced the Liebherr cable reeler option for its entire range of mining excavators from R9150 to R9800 in both face shovel and backhoe configurations. The cable reeler enables management of the excavator's electric cable during operation. This provides better mobility of the machine, optimises safety, and reduces the number of crew required for cable handling.

The cable reeler is an automated, hydraulically-driven solution, with a reach of up to 300m. The heavy-duty installation integrated into the undercarriage structure is designed so that the excavator ground clearance is not reduced. This way the system is durable even in hard operating conditions with the lowest impact on the mobility of the machine.

D98 engine

Liebherr's D98 engine series is designed specifically for mining applications. With its modular design, this engine can be used in equipment produced by Liebherr and by other OEMs.

Despite being originally designed as a diesel engine, the D98 series can also work with certain alternative fuels. Due to the engine's larger volume displacement, the D98 series can use synthetic renewable fuels such as hydrotreated vegetable oil (HVO) and up to 10% biodiesel. The D98 series is also being used as the basis for developing internal combustion engines that can operate using other kinds of alternative fuels.

Hydrogen and ammonia engines

At the Bauma 2022 exhibition, Liebherr demonstrated its expertise in hydrogen engines by winning the Bauma Innovation Award in the climate protection category for its first hydrogen-powered excavator, powered by its H966 hydrogen engine. Liebherr began developing hydrogen combustion engines in 2019 and now, following the H966 engine's success, is further exploring the capabilities of these engines to run with ammonia. Testing this fuel source in an internal combustion engine is expected in early 2023.

FMG partnership

As part of its Zero Emission Mining Program, Liebherr has formed a partnership with Fortescue Metals Group (FMG) for the development and supply of mining haul trucks, integrating zero emission power system technologies into the Liebherr T264. The phased supply of haul trucks will commence following a two-year joint validation period which has already begun.

To engineer, manufacture and supply the new trucks in accordance with Fortescue's delivery requirements, Liebherr will use its vast OEM expertise in the design and manufacturing of machinery and machinery core technology such as electric drive systems, hydraulics, and electronics.

Partnerships such as this are important in accelerating technical development, field testing, and implementation of practical and relevant solutions for clients. They support Liebherr's commitment to the zero emission agenda and to a sustainable future for the mining industry.

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The electrification solution comprises charging systems and trolley lines. Whether operators choose one, the other, or both of these technologies requires mapping of the mine constraints, including:

- The location of loading and dumping areas;
- Resources needed to perform loading and dumping;
- Power availability throughout the mine area; and
- Other operational limitations imposed by the mine design.

The eMine portfolio includes a fast offboard charging system for smaller haul trucks used in almost-continuous operations with limited idle time. These offboard systems are essentially charging stations installed at fixed points throughout the mining area. Depending on battery size (which typically ranges from 100-400 kWh for smaller haul trucks), it takes 6-24 minutes to get from a 30% charge to 90% and 10-40 minutes to get from 0% to 100%.

Trolley-assist systems, whose commercial implementation predated that of battery-electric trucks by a quarter-century, are making a comeback

Trolley-assist systems, whose commercial implementation predated that of battery-electric trucks by a quarter-century, are making a comeback as an intermediate solution for mine operators looking to reduce emissions associated with existing diesel fleets. A trolley system takes a hybrid diesel-electric truck (a truck with an electrical motor and diesel generator) and feeds power into the truck, eliminating the need for diesel along the entire length of the trolley line. Each vehicle is equipped with a pantograph, which collects power through contact with the overhead lines, much like an electric train, tram, or electric bus. Other essential infrastructure includes poles, an overhead line system, substation, and rectifier station that converts normal AC power to DC power at about 1,500 to 3,000 volts.

ABB has successfully implemented this system at Boliden's Aitik open-pit copper mine in Sweden, where four large diesel-haul trucks connect to a 700m trolley line, and at Copper Mountain's flagship mine in British Columbia, Canada, where seven diesel-electric haul trucks connect to a 1km-long trolley line. In both cases, the system has helped to substantially reduce diesel usage, saving the operators money and minimising greenhouse gas emissions.

In a unique approach to the problem of charging larger haul trucks, ABB is also developing a combined solution that uses trolley-assist to provide in-motion charging along fixed-distance routes.

With this system, "the battery is charged while the truck is connected to the trolley system," Ashnagaran said.

The challenges associated with mine electrification have led the sector to embrace collaboration, as seen in the creation of a Global Mining Guidelines Group

"It's too early to say, but we see this is as (potentially) being the better solution for larger trucks, while the smaller-sized trucks can operate as full battery-equipped vehicles with the offboard charging system."

Adopting a collaborative approach

The challenges associated with mine electrification have led the sector to embrace collaboration, as seen in the creation of a Global Mining Guidelines Group (GMG) made up of representatives from mining companies, OEMs, technology providers, research organisations, consultants, regulators, and industry associations.

In July 2022, the GMG published a 121-page "Recommended practices for battery-electric vehicles in underground mining." This guideline comprises sections on mine design and operations, battery-electric vehicle design, energy storage systems, charging systems and methods, charging and connection interfaces, and performance standards.

The push for collaboration has been driven partly by mine operators, who expect standardisation on charging infrastructure so that they can retain the flexibility of working with multiple OEMs, according to Shawn Samuels, business line manager for Epiroc's Rocvolt zero-emission technology division.

Samuels gave the example of the Onaping Depth underground copper-nickel project in Ontario, where Glencore is aiming to become one of the world's first fully-electric mines when it commences production around 2024. Onaping Depth has confirmed orders from three OEMs: Epiroc will supply 23 battery-electric machines, including 40t Minetruck haulers, 14t Scooptram loaders, and drilling and bolting equipment, while MacLean Engineering and Kovatera will provide additional support units.

"Glencore said that if they're going to build an electric mine, we need to provide standardised charging," Samuels said.

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ABB advances fully electric mine

When ABB launched its eMine portfolio of integrated electrification and automation solutions in 2021, it did so as the industry was ramping up the shift away from diesel-powered equipment.

The drivers for doing so are hard to argue with. The mining industry needs to reduce its hefty contribution to climate change – which is up to 7% of all greenhouse gas emissions – while still extracting the raw materials required for the green-technology revolution.

It's also incumbent to reduce the health impacts and costs associated with fossil fuels, especially for increasingly remote mine sites that do not have local grid access.

Electrification and renewable energy sources are the answer. But while this is clear, how to build the electric mine is less so. This is where ABB sees an opportunity to share its expertise.

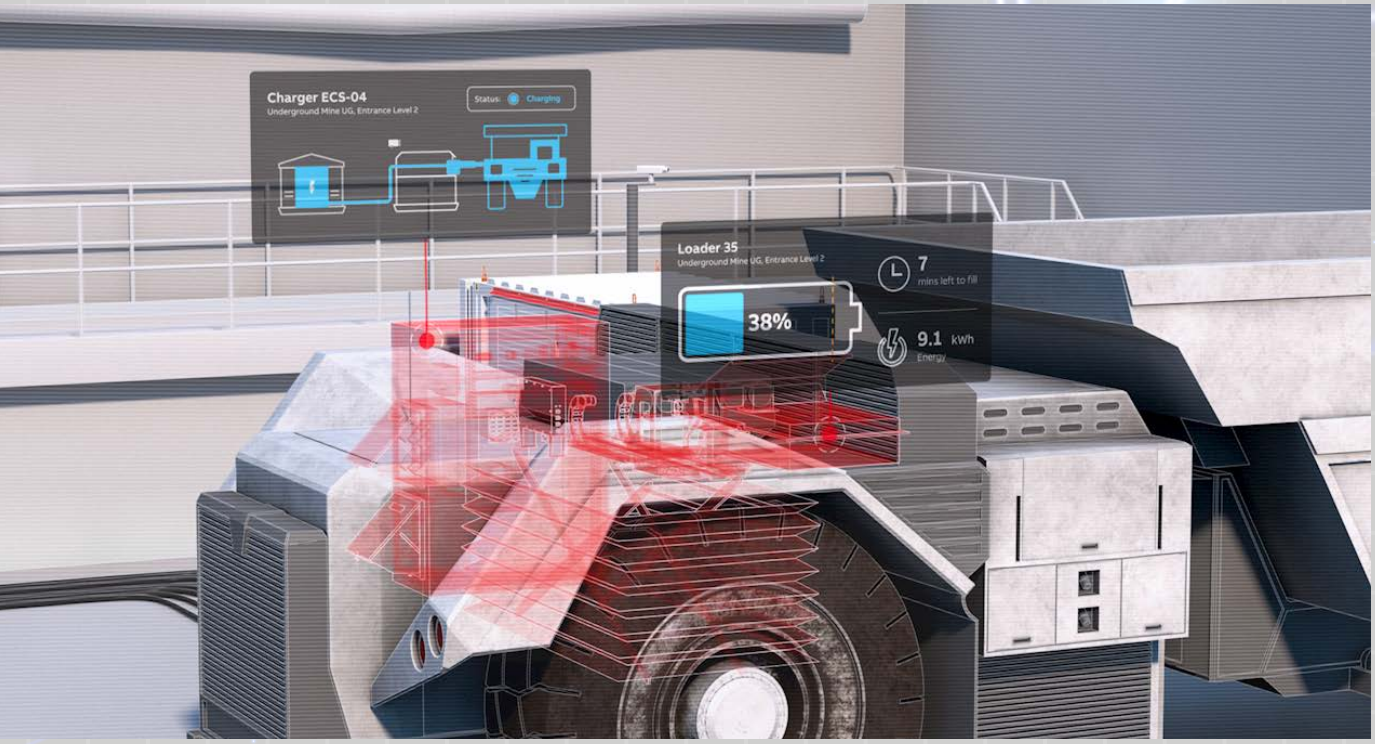
Building fit-for-purpose solutions

The eMine portfolio draws upon ABB's extensive, decades-long experience in electrification and automation, offering 'fit for purpose' solutions, using proven methods and a holistic approach , according to the company.

The eMine vision encompasses full integration of electrification and automation from 'pit to port' to help the industry decarbonise not only its fleet, but the entire ecosystem.

"These are all elements we have used before in the mineral process area and have now extended to the mine, which is the last piece of the puzzle," said Mehrzad Ashnagaran, ABB global product line manager – electrification and composite plant.

It is also part of ABB's wider ambition to partner with its customers to reduce their annual CO_2 emissions



by 100 megatons by 2030. This is equivalent to the annual emissions of 30 million internal combustion engine cars. It also plans to achieve carbon neutrality in its own operations by the same date.

And according to ABB, the eMine portfolio solutions are also proven to significantly reduce an operation's emissions while minimising capex and optimising opex.

These solutions include the eMine trolley system, in which haulage trucks transporting ores are converted to electric-diesel hybrids, cutting diesel usage by up to 90%, according to the company, thereby reducing emissions and saving money on fuel costs. The system, which includes an overhead catenary system and a rectifier substation, will eventually move to battery-trolley hybrids.

The trucks alone can have a huge impact on lowering a mine's carbon emissions, given that ABB estimates that electrifying a single one eliminates the same amount of CO_2 emissions per year that it would take 46,000 trees to absorb.

As well as reducing costs and emissions, the trolley assist operation gives dump trucks under load an additional boost so they can cover gradients on the hauling route faster, according to the company.

Ensuring trucks and equipment can charge when and where needed is integral to keeping an all-electric mine operation running for 24 hours a day.

With this in mind, Ashnagaran said the eMine trolley system can't be separated from another element of the eMine portfolio – the pilot ABB eMine FastCharge system – which was unveiled in 2021.

"More and more customers are asking for such a combined solution – they are eager to understand how the trolley system works with the battery-equipped vehicle," he said.

ABB's pilot eMine FastCharge is the world's fastest and only fully automated charging system for mining trucks, offering up to 600kW of power, according to the company. The technology can be installed anywhere and can charge any truck without the need for human intervention. Additionally, once digitally connected, the system infrastructure can be monitored and controlled to optimise the charging process and energy usage in real time.

> **"Interoperability for us is extremely important. If a mine is running various types of fleets, it shouldn't need different chargers and connectors"**
>
> Mehrzad Ashnagaran, ABB

According to the company, charging points can be strategically placed throughout the mine so trucks remain charged for longer and so their use can be further optimised, boosting overall productivity, and avoiding the need for additional tramming routes and vehicles.

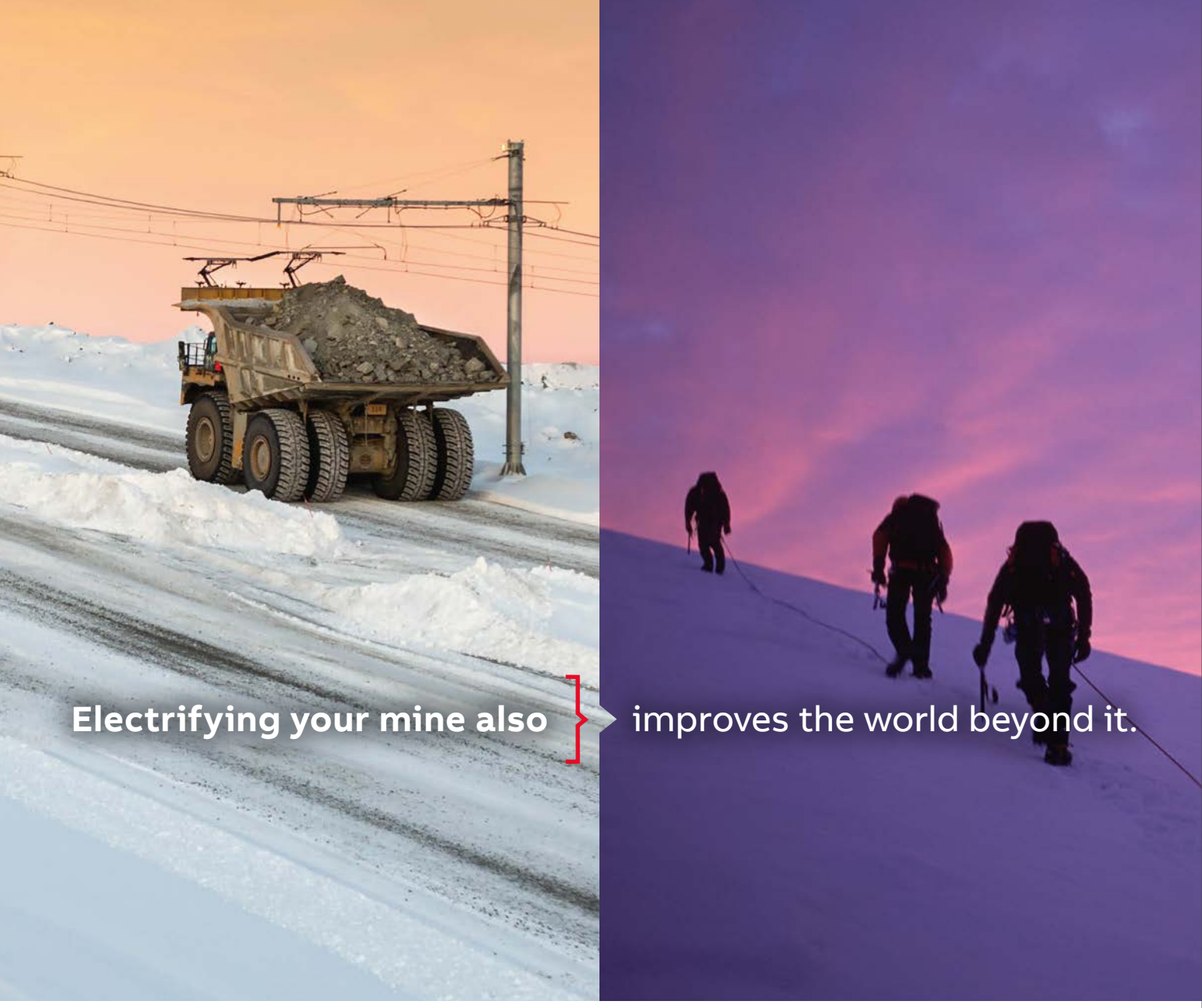
Tailoring solutions with automation, integration and interoperability

Ashnagaran was keen to stress that when ABB was developing the eMine approach of methods and solutions, the thought that no two mines are ever the same was very much front and centre in its approach. This is why being able to tailor the solutions to individual operations, specifically to match up to their unique challenges, was paramount. And, as such, so was ensuring interoperability and integration.

"Interoperability for us is extremely important," Ashnagaran said. "If a mine is running various types of fleets, it shouldn't need different chargers and connectors. Similarly, it was important that the connector convey the higher kilowatts of energy in a shorter time to vehicle. This is why a big focus for us is working with different OEMs, including the technology provider active on the connector system."

The FastCharge system, for example, follows open standards to remain vendor-agnostic, meaning it can be used across all vehicle types and OEMs. This allows the customer to make a one-off investment and maximise the uptime, productivity and return on investment of every piece of charging equipment, Ashnagaran notes.

For these purposes, ABB has a global agreement with Hitachi, Liebherr, and Hitachi Construction Machinery, as well as actively working with other OEMs.



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In fact, Ashnagaran said that collaboration was one of the first steps ABB took when developing the portfolio and this approach was key to bringing the right solution to the market.

"We strongly believe in the Key Technical Supplier model, which is part of the DNA of ABB. We have not applied this concept only on eMine, but also previously in the mineral process area. It requires us to work closely with the other technological providers to build best solutions and take care of interfaces and other things," he explained.

It's also important for the next piece of the 'pit to port' portfolio puzzle – automation. "One of the most important components in the electric mine is the automation system; without that we cannot do it," he explained. "This needs to be integrated into the whole system to create a full overview of what is happening through the operation; the customer needs to monitor and control and get data from the system to then fine tune their operations, and, at the same time, to understand what's required to do this."

For this, ABB has developed the Ability MineOptimize concept, a framework that integrates individual solutions and brings together the electrification, automation and digital elements to optimise capex, and maximise productivity, sustainability and safety throughout the whole 'pit to port' process.

Optimising the mine of the future

ABB's eMine trolley system has already been successfully used in at least two mines: Copper Mountain in Canada and Boliden Aitik in Sweden.

At Copper Mountain, a conventional open pit, truck and shovel operation which produces approximately 100Mlb (45,000t) of copper equivalent per year, the haul truck trolley assist infrastructure was able to cut carbon emissions by 90% on the trolley segment. The operator has also reported that trucks are now running 80% more quickly overall.

At Aitik, Sweden's largest open-pit copper mine, located 100km above the Arctic Circle, the operator said the eMine trolley system is expected to save 830cu.m of fuel across two trucks running under a 700m trolley, resulting in an 80% reduction of greenhouse gas emission.

Despite these advances, Ashnagaran was keen to

stress that there is no silver bullet for building an electric mine. It is a process – one which, due to the technological complexities, still faces some challenges.

For example, one of the limitations ABB is working to overcome is managing the variability of renewable energy so that it can eventually support the mine through its 24/7 work cycle. Currently the variability of renewables and the uneconomic viability of most storage solutions present limitations. It's also looking to overcome challenges around the size of batteries and their energy density in trucks which have limited space. The future mine will most likely have pure battery pack vehicles, noted Ashnagaran.

But while the fully electric mine cannot be achieved overnight, the process can begin today. And on this point, Ashnagaran said, because they are technologically different to traditional mines, the earlier in the journey after mine conception that the process can begin the easier implementation will be. And here ABB is keen to deploy its expertise.

"Before we did not physically exist in the mine fleets , but now we are here to electrify the fleet, to make the pit to port vision happen and we have a system that can cover the entire process with full implementation and integration between electrification and automation systems," Ashnagaran concluded.

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In this case, Epiroc and the other equipment manufacturers will supply CCS-Type 1 charging systems, one of the two widely-used charging systems recommended in the GMG guidelines.

Rocvolt takes Epiroc beyond its traditional role as an OEM, offering a suite of solutions to support customers in their electrification journey. These include batteries, chargers, substation and power components, and digital solutions. But at the same time, it remains mindful of its customers' need to be able to pick and choose solutions from different providers.

"Mine operations are moving more towards control towers, like the production and plant areas did a long time ago. These control towers use digitalisation, telemetry and all this other software to monitor, track and put out tasks to equipment to the machines and personnel in the mine area. They (the mine operators) don't want to have one form of communications to look at one piece of equipment and another form of communications to look at another," Samuels said.

"Mine operations are moving more towards control towers, which use digitalisation and telemetry to monitor, track and put out tasks to equipment to the machines and personnel in the mine area"

Shawn Samuels, Epiroc

As a result, "these digital solutions can't be an Epiroc solution or a MacLean solution, they need to be agnostic. That's really important for the mine operators."

ABB has been a vocal proponent of collaboration between OEMs and technology, arguing that combined solutions are critical to meeting the industry's goals of reducing CO2 emissions and supporting a sustainable society. It has signed memoranda of understanding

with two major OEMs, Hitachi Construction Machinery and Liebherr Mining Equipment, to work together on electrification, as well as an informal collaboration with Komatsu.

In the case of the Hitachi MoU, the partners will explore possibilities to apply ABB's electrification, automation and digital solutions to mining trucks and excavators provided by Hitachi as part of wider efforts with mine operators to electrify all processes from pit to port.

The combination of electrification, automation and digital solutions is by design, according to ABB's Ashnagaran.

"Customers need to monitor, control, and get enough data on what is happening with electrified systems to be able to finetune the operation, and to be able to understand the requirements needed to optimise the operation," he said.

"Customers want us to offer a full solution – a grid-to-wheel solution. We are the grid side, the OEM is the wheel side because they know what is happening in the truck," ABB's Ashnagaran said.

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These partnerships include a focus on integrating OEM equipment with ABB's trolley support. But they also go beyond that, reaching into the spheres of automation and digitalisation.

"Integration of electrification with automation and digital systems is crucial," Ashnagaran said.

"We are set up to plan, monitor and optimise the operation and energy usage from grid to wheel. And we nee to effectively manage the process and power control simultaneously. That is why we have to deliver a highly standardised, configurable, automation solution for continuous production, which is connected to the power control and to advanced integration, and which also considers interoperability (between machines from different OEMs)," he explained.

"We must also manage cycle loads efficiently, and increase productivity while also reducing costs and emissions. That is why we need power and energy management. On the other side, we must have full visibility over the complete value chain from mine to port, including the health conditions of multiple types of assets. This is to ensure that the highest productivity is actually achieved and that maintenance requirements are reduced, increasing uptime. That is why we need asset performance management.

"We must also efficiently manage the allocation of people and assets connected to the energy requirement in a way to improve the productivity, while also, like the other models, reduce the cost, reduce the environmental impact. This is why we need mine operation management systems."

In other words, he said, "automation is the glue that bring everything together, enabling electrification."

Conclusion

Electrification won't happen overnight, but miners will get there

If the current trend is any indication, then it's easy to imagine fully electric mines becoming commonplace in the near future.

With that said, electrification is not a one-size-fits-all-solution. While it could make sense for a large greenfield project or brownfield expansion with a long mine life to implement full electrification, existing operations may only consider converting some of the fleet to electric if at all.

Brownfield operations should weigh up whether electrification will deliver sufficient reductions in carbon emissions and operational costs to justify the capex, according to Ashnagaran. Greenfield operations "make our job easier," he said, as electrification can be integrated into mine planning and designing.

But, ultimately, ABB recommends a phased integration of battery-electric equipment into a mine operation rather than transitioning from diesel to electric in one fell swoop.

"An electric mine looks different from a traditional mine. We are working with miners to break down this long-term roadmap into short-term actionable projects, piece by piece, to gradually transform their operations," Ashnagaran said.

"A phased approach enables mines to immediately lower carbon footprints with a limited up-front capital investment, while simultaneously advancing progressively as technology becomes more mature, scalable and cost effective."

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Published by Aspermont Media, 1 Poultry, London, EC2R 8EJ, UK.
Printed by Stephens & George Magazines, Merthyr Tydfil, UK.
Subscription records are maintained at Aspermont Media Ltd, 21 Southampton Row, London, WC1B 5HA

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