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MINING & QUARRY WORLD

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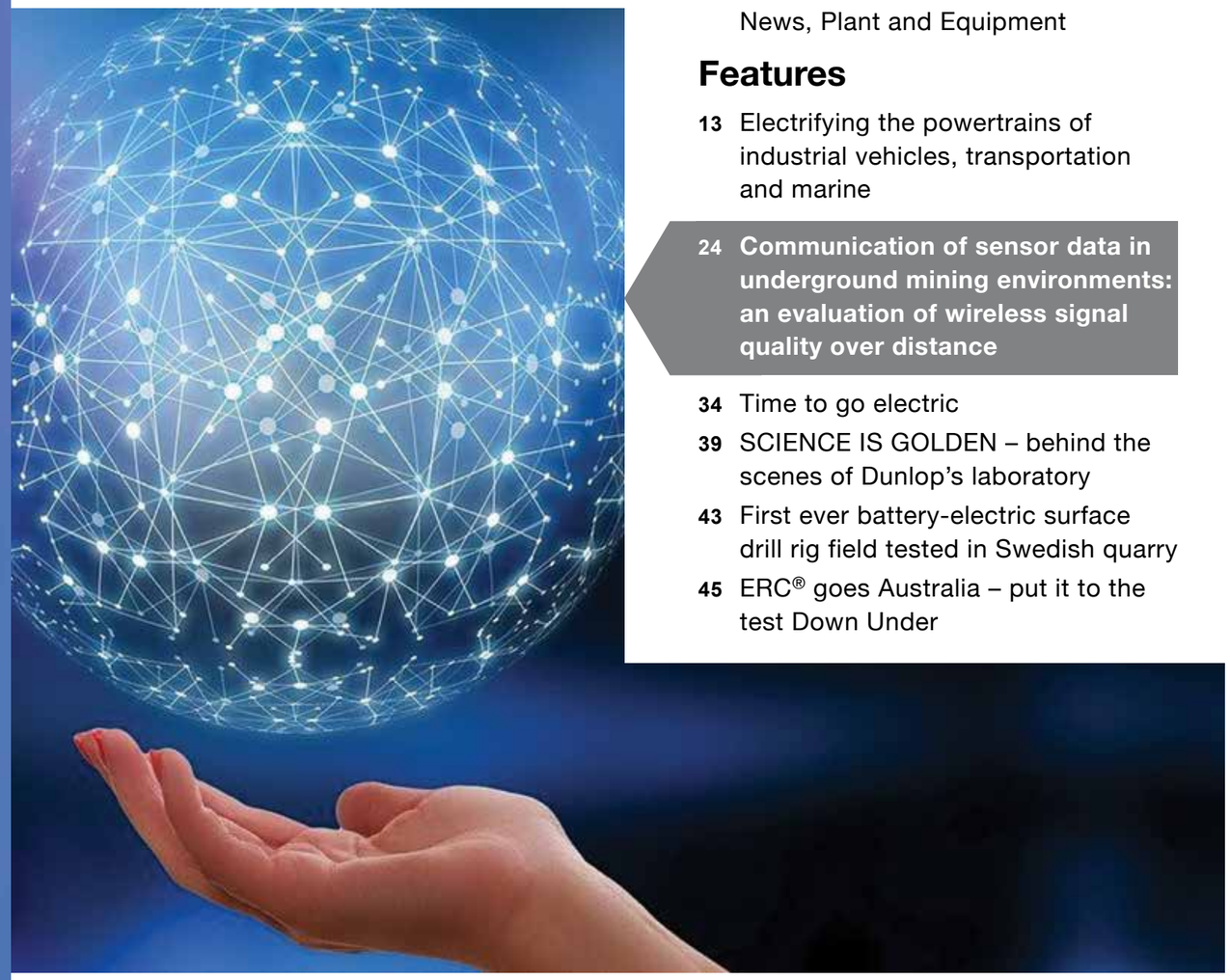

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World premiere of the new 280 SM(i) surface miner

The Wirtgen 280 SM(i) is a high-performance surface miner for reliable, selective extraction of primary resources by direct loading, sidecasting or cut-to-ground.

100% mining – environmentally friendly, efficient and safe extraction of primary resources in a single operation

With the new 280 SM(i) surface miner, Wirtgen has developed another efficient and practice-oriented solution for the extraction of primary resources. Its innovative technologies enable high machine utilisation rates and maximum productivity.

Cutting, crushing and loading of rock in a single operation

The 280 SM(i) is a high-performance surface miner designed for the reliable and selective extraction of primary resources by direct loading, sidecasting or cut-to-ground. Raw materials are extracted and crushed in situ in purest quality in a single operation – without drilling and blasting, and with minimal environmental impact.
The 280 SM(i) is driven by four steerable and height-adjustable crawler units. The machine is highly manoeuvrable and can be quickly turned at the end of a cut. The LEVEL PRO ACTIVE automatic levelling system maintains the specified cutting depth with consistently high precision and without further aids.

Efficient cutting technology

The 280 SM(i) is an all-rounder for all rock hardnesses and applications. The 2,750 mm cutting drum unit with a cutting depth of up to 650 mm is precisely adaptable to each specific application and achieves outstanding cutting performance with minimal pick wear. Wear-resistant toolholder systems ensure optimal pick utilisation and minimal downtimes. The soft rock cutting drum unit is designed especially for high material flows in soft rocks. In contrast, the hard rock cutting drum unit ensures maximum durability and long life in hard rocks.

With the 280 SM(i) surface miner, primary resources are extracted in purest quality and crushed in situ in a single operation – without drilling and blasting, and with minimal environmental impact.

Maximum utilisation rates for maximum productivity

In the extraction of primary resources by open cast mining, the key priority is always a combination of highest possible productivity, maximum purity of the material mined and the reduction of impact on people and the environment to a minimum. Aside from performance, the productivity of mining equipment depends primarily on constant operational readiness and optimum machine utilisation. Only a reliable and maintenance-friendly machine assures high utilisation rates. The innovative operator's cabin contributes to the operator's ability to exploit the full potential of the machine and maximise productivity. The 280 SM(i) surface miner is therefore the tool of choice for cost-efficient mining processes in the 120-ton class.

High-performance belt conveyor unit with high material flow

The high-performance, hydraulically height-adjustable, rear discharge conveyor with a movable counterweight can be slewed to the right and left by 90° and enables the loading of mining trucks with payloads of up to 100 tons. What's more, the operator can continuously vary the speed of the belt independent of the engine speed to reduce belt wear dependent on the material volume and the piece-size of the mined material.

The Wirtgen 280 SM(i) is a high-performance surface miner for reliable, selective extraction of primary resources by direct loading, sidecasting or cut-to-ground.

With the 280 SM(i) surface miner, primary resources are extracted in purest quality and crushed in situ in a single operation – without drilling and blasting, and with minimal environmental impact.

The 280 SM(i) surface miner's air-conditioned and soundproofed operator's cabin with all-round glazing is swivel-mounted on the front chassis column and provides a productive working environment with a low risk of fatigue.

Outstanding operator comfort

Entirely new standards are set by the dust-sealed and air-conditioned positive-pressure cabin with fresh air filtration, which effectively prevents the ingress of dust into the operator's workplace. Mounted on the front left chassis column, the operator's cabin with all-round glazing is decoupled from the machine body and can be rotated by 90° in both directions. Up to six cameras can also be installed to provide even better all-round vision. Various automatic functions also contribute to the operator's comfort, reduce the risk of fatigue, assist the operator in the achievement of high productivity rates and make the overall process more efficient.

The 280 SM(i) surface miner's air-conditioned and soundproofed operator's cabin with all-round glazing is swivel-mounted on the front chassis column and provides a productive working environment with a low risk of fatigue.

Conservation of resources and environmental awareness

These days, the reduction of carbon emissions, noise, dust and vibration while maintaining consistently high extraction rates and productivity is more important than ever before. With the new surface miner, Wirtgen offers innovative technologies that minimise impact on the environment and conserve valuable natural resources. Thanks to the reduction of carbon emissions by low specific fuel consumption, an efficient water management system and effective solutions for the minimisation of dust pollution, the 280 SM(i) shows that ecological and economic considerations are actually compatible and closely interconnected.

Akobo Minerals reaches agreement with experienced underground mining contractor

Akobo Minerals the Scandinavian-based Ethiopian gold exploration and boutique mining company, announced that it has reached an agreement with the South African company IW Mining (Pty) Ltd to operate the underground mine at Segele.

IW mining is a highly experienced mining contractor with years of hard-won underground mining experience in the tough South African mining arena. This fundamental agreement secures Akobo Minerals access to personnel and competence for mining of the Segele gold ore according to the following timeline;

- Mining to be underway in October 2022
- First gold extraction to begin in Q1 2023
- Full production expected to begin by end of Q2 2023

In line with the company's ESG guidelines, IW Mining will recruit and train a significant number of Ethiopian personnel who will work with the Segele mine.

Already a lot of planning and preparation have been undertaken together with IW Mining for the last few months ahead of the signing of the agreement. Sourcing of mining equipment has already begun and first shipments to be dispatched imminently. IW Mining will mobilize an experienced mining team from South Africa that will travel to Segele within weeks.

Jørgen Evjen, CEO of Akobo Minerals, stated: "Getting IW Mining on board was the last piece of the puzzle. Together with Solo Resources for the plant production we have now secured all necessary expertise to start mining. With Ian and Willem guiding us through the next phase of development I am sure we will succeed with our plans. Our companies share the same values and philosophy, delivering responsible and world class projects. "

Ian Lowers, CEO of IW Mining Services, stated: "Our aim has always been to provide a level of service that exceeds the normal contractual Scope of Work. For IW Mining Services this contract in Ethiopia with Akobo Minerals is an important milestone in line with our growth strategy. IW Mining Services has committed itself fully to ensuring the success of this unique project by being a responsible partner in mining innovation. Our belief is that this mining project is the beginning of a strategic multi party partnership in Ethiopia between Akobo Minerals and IW Mining Services."

Akobo Minerals is now ramping up activities in all areas for preparation of mining operations. With the newly secured Convertible loan and signing of Solo Resources on plant design and production in May all tasks are on track. Solo Resources has already completed design work and the process plant is now under fabrication and deliveries of the parts will begin shortly. The final project funding is also moving forward with several positive dialogues ongoing.

Is the mining sector ready and able to deliver net zero?

The chief of the International Council on Mining and Metals (ICMM), the joint sustainability initiative backed by the world's biggest miners, is confident Europe's drive to shore up mineral security and deliver on climate goals could result in a cleaner and greener future for the global mining industry.

"I think we are on the brink of a sustainable mining renaissance in Europe," says Ro Dhawan, arguing that projects in Europe have most of the three essential ingredients required for a successful modern-day mining project: resource availability, ESG credentials, and a favourable legislative and geopolitical environment. "Numbers two and three are really favourable in Europe," he adds. "And where there are resources, numbers two and three will help companies extract them well."

Dhawan was speaking recently to mark the 20th anniversary of the ICMM, which was set up by more than two dozen major miners in 2001 to help establish best environmental practices for the mining sector. He says the group's mission is more crucial now than ever before, given the extractive industries' critical role in providing the minerals and metals required for the technologies that enable a low carbon economy. "The mining industry is an enormous enabler of economic growth that is sustainable, that is environmentally positive," he contends.

It is a characterisation many campaigners would reject, given the mining sector's notoriously mixed environmental and human rights record and massive emissions footprint. A McKinsey report from 2020 calculated the sector is responsible for four to seven% of global greenhouse gas emissions across its operations and power use. This figure soars to roughly 28% once emissions generated by the minerals it extracts – most notably, the burning of coal for power production and steelmaking – are accounted for. There will be many commentators who argue the mining sector will struggle to expand in Europe because its social license to operate is in tatters after centuries of environmental negligence and scandals, such as the 2019 dam failure in Brumandinho, Brazil, which killed 270 people.

But at the same time, Dhawan's take on the centrality of the mining sector to the net zero transition is demonstrably true. The net zero transition depends on copious amounts of graphite, lithium, cobalt, and other materials that provide the building blocks for energy efficient buildings, electricity transmission infrastructure, solar panels, electric vehicles, energy storage, wind turbines, and myriad other technologies. There is potential to create a more circular economy that ensures these crucial raw materials are re-used multiple times, but there is no credible path to net zero emissions that does not require a significant increase in demand for multiple mining commodities, even as demand for fossil fuels plummets.

The World Economic Forum estimates that production of certain minerals could increase by 500% by 2050 to meet demand for clean energy technologies. Leading research and consulting firm Wood Mackenzie predicts demand for lithium could increase nine-fold between 2022 and 2050 under a decarbonisation scenario compatible with 1.5C of warming. Mining majors are set to play an outsized role in building the foundations of the clean energy economy – and are gearing up for a clean energy materials boom.

Such projections have naturally prompted concerns about an increase in unsustainable mining practices that could undermine the net zero transition and thwart progress towards a greener future. But Dhawan says the ICMM is on a mission to make the mining sector, governments and civil society understand that mining can be done sustainability.

Really high standards of environmental performance are now in place at mines around the world, he stresses. "And if one company can do it, then we can learn from that, and make that the way that everybody operates," he argues. "Our objective – and this is where I think the world's relationship with mining will change – is when the whole industry continues to perform better and better, not just one or two companies."

Dhawan details how there are already major miners operating on 100% renewable power across entire continents; mining companies operating the world's largest clean energy micro-grids; mines that are able to operate with no fresh water; and mining firms that are on track to be 'nature positive' by 2030. "That's what gives me immense confidence that it is absolutely possible for the industry to meet this demand for critical minerals for the energy transition and do it in a way that minimises the harm that mining may have traditionally caused," he says.

The ICMM works to share information and guidance about sustainable practices across its 35 members and the broader industry with a view to making them the norm. It is also helping to bring nascent clean mining technologies to market – for instance electric or hydrogen trucks that can replace diesel vehicles – by connecting 'first mover' coalitions of companies that are looking to fast-track development of zero emission technologies with equipment manufacturers.

And Europe could be a place where the mining sector really proves both its sustainability credentials and its value to the net zero economy, Dhawan argues.

Once an important driver of economic growth and employer, mining exploration activity has shrunk significantly across the continent over last 50 years, with the majority of raw materials used in European products imported from countries where labour and infrastructure costs are cheaper and planning and permitting regulations less stringent. But governments across Europe are now plotting ways to open the continent up to more battery materials extraction, as they attempt to reduce their dependence on other countries for raw materials and claw back control of battery supply chains from China.

A raw materials action plan published by the European Commission in 2020 called for the "sustainable and responsible domestic sourcing and processing of raw materials in the EU", alongside a drive to ramp up materials recycling and reuse, and an effort to diversify supplies from third countries. Mining legislation is now being drafted by the Commission which officials have suggested will go further than the 2020 action plan in a bid to spur sustainable mining activity in Europe, prompting concerns from environmental campaigners.

In the UK, the government published a strategy late last month that set out its plans for bolstering the resilience of critical mineral supply chains, enhancing recycling capability across the country, while boosting jobs in minerals and manufacturing across the UK. The document sets out a vision for establishing the UK as a "centre for responsible international mining".

The various policy plans come amidst an upswing in European exploration activity, from both large miners and start-ups. For example, various small-scale lithium extraction projects are underway in Cornwall and the Scottish Highlands. In Germany, Renault, Volkswagen, Stellantis, and LG Energy Solutions have signed offtake deals for lithium scheduled to be extracted from geothermal waters under the Upper Rhine Valley in 2024. The exploration company behind the mine, Vulcan Energy Resources, has partnered with energy giant Enel to extract lithium alongside geothermal energy at a site near Rome. And in Finland, a hard rock lithium operation poised for construction has received the backing of a number of international investors, as well as company backed by the Finnish state.

But for these various mining projects to get the green light, the sector must prove the European mining industry of the future will be very different from the coal projects that have historically dominated activity on the continent, Dhawan stresses. "People in Europe will remember the mining of old days that used to take place in Europe which had significant environmental challenges associated with it," he says. "So, I can understand people's reticence with opening up Europe to more mining. But the mining that happened 30 to 40 years ago is not the same mining of today. We have much higher collective standards of performance that can ensure mining is done responsibly, [and in a way] that meets Europe's needs."

To date, the sector still faces a significant challenge winning over officials and communities fearful of the environmental damage and destruction caused by mineral extraction. A number of mining projects planned for mainland Europe have been derailed or delayed recently after facing significant public pushback.

Earlier this year, the world's largest greenfield lithium project was rejected by Serbian regulators after the Rio Tinto backed scheme faced significant opposition from locals. Meanwhile, plans for western Europe's largest lithium mine in Portugal have been subjected to a lengthy permitting processing and local resistance, with the CEO of the UK-based mining firm Savannah Resources

Rohitesh Dhawan: President and Chief Executive Officer of ICMM.

recently stepping down after it was slapped with additional environmental licensing rounds. And in western Spain, miner Infinity Lithium has recast its plans for an open-pit hard rock mine as an underground operation which would produce less waste and leave no visible impacts on the landscape in order to try and secure support from communities and regulators.

Dhawan is under no illusions the challenges miners have in getting projects off the ground, reflecting it is not an issue particular to Europe. "[Battery materials] are seeing a massive increase in demand because of the coming energy transition, at the very same time that it is arguably the toughest time to start a new mining project," he says. The many thousands of permitting obligations new mines are subjected are "really important and critical", he acknowledges, but they must be processed more quickly if clean technologies are to be deployed at the pace and scale needed to slash emissions. "We have to find ways to allow responsible mining projects to grow and expand, to provide the metals and minerals that are needed for the transition, and to provide the stock of metals and minerals that can then be used in a circular economy," he says. "There is no circular economy if you don't have enough materials to go around."

But the mining sector clearly has a long way to go to convince investors, campaigners, and the public it can deliver on its sustainability and emissions reduction commitments. ICMM companies have collectively pledged to achieve net zero across their Scope 1 and Scope 2 greenhouse gas emissions by 2050 or sooner, but few have announced net zero targets that account for their value chain or Scope 3 emissions, despite these making up as much as 95% of a company's total footprint. A 2020 report from Transition Pathway Initiative investor group noted that none of the 10 largest mining companies was aligned with a 1.5C pathway, with just two firms – Freeport and Grupo Mexico – aligned with limiting climate change to a 2C scenario.

Dhawan says the group is working with the Science-Based Targets initiative (SBTi) to create a Scope 3 emissions accounting framework for the sector, which would enable its members to meet a commitment to set a detailed, transparent Scope 3 target by 2023. But he notes ICMM will not be pushing for members to achieve any particular level of emission reduction across their Scope 3 emissions once the framework is established. "We don't see it as our role to police individual company's targets, we see it as our role to set the framework so that every company sets robust, credible, transparent targets, and it's up to their stakeholders to then judge whether those are sufficient in line with the Paris Agreement," he says.

ICMM is also working with the investment community to create convergence around the sustainability disclosures that are requested of mining firms "What we've found is that there's been a huge increase in the number of information requests from investors for companies on decarbonisation," he says. "And that's a good thing. But at the same time, the fact that there are so many different ones creates a huge burden, and also creates confusion about how best to report the information."

And then there is the elephant in the mine. While the mining industry is investing heavily in the extracting the minerals that underpin the clean tech boom, many of the same companies are continuing to extract the world's most polluting fuel: coal. Moreover, campaigners maintain that few if any leading mining companies have a credible plan for shuttering coal mines, as they transition towards extracting clean tech minerals.

Does Dhawan see an inherent contradiction between ICMM's mission as an initiative committed to making mining sustainable and the extensive coal extraction activities of some of its members? He insists not, stressing that ICMM's focus has always been on the process of mining, not the afterlife of its products. "We do not currently have an intention to have a policy about companies not producing coal, because there are different ways in which the world can decarbonise and reduce its coal consumption, and we're not taking a position on which one is right," he argues.

Across the sector, companies are taking varied approaches to winding down their coal assets. BHP and Anglo American, for instance, have sold off their thermal coal production assets to other companies following investor pressure, whereas Glencore has argued it is more "environmentally responsible" for it to slowly wind down production of its most carbon intensive assets over time rather than sell them to a firm that operates with higher carbon emissions. Although critics will note that it is unclear how the firm's announcement in mid-July that it was expanding coal production at its Hail Creek Mine – which scientists have warned is a methane hotspot – squares with this stated objective.

Dhawan says the Ukraine crisis has highlighted the dangers of energy insecurity and argues that while miners "need to do everything they can" to reduce emissions, governments, investors, and companies must work together to find ways to shrink demand for polluting minerals in a sustained fashion. "The world is once again consuming large amounts of fossil fuels because we have no alternative at present, because we haven't sufficiently decarbonised demand," he reflects. "And in mining, it's a similar story."

The answer, as is so often the case with the net zero transition, is likely to lie with emerging technologies. "Once we have steelmaking technology that doesn't require metallurgical coal in the same quantities, or at all, then that solves the issue," Dhawan says. "That's how we've been thinking about the coal debate. But as long as coal is being produced, whether its metallurgical or thermal, then it's our top priority that that ICMM members do it as responsibly as possible."

It remains to be seen whether Dhawan's vision of a 'green' mining boom in Europe materialises. But it is clear the transition to a truly green economy depends on the mining sector engineering a net zero commodities boom, and doing it in a way that is as sustainable as possible.

Zimbabwe will raise taxes on platinum

Zimbabwe plans to increase royalty rates on platinum producers and introduce one for lithium miners from Jan. 1 as part of efforts to boost its coffers that have come under strain from weakening economic conditions.

The rate for platinum miners will double to 5% and a new rate of the same amount will apply to lithium producers, Finance Minister Mthuli Ncube said in his mid-term budget review presented to lawmakers in the capital, Harare, on Thursday.

"Mindful of the fact that the tax regime is the main instrument for sharing benefits from finite minerals and also provides an important source of government revenue, it is necessary to maximize revenue to the fiscus," he said.

An accelerating shift to electric vehicles and soaring lithium prices have drawn investor interest to Zimbabwe. Chengxin Lithium Group Co. and Sinomine Resource Group Co. are setting up a joint venture to explore for the metal and Zhejiang Huayou Cobalt Ltd. plans to invest $300 million to develop its Arcadia lithium mine.

The southern African nation has the world's third-largest known platinum reserves, after Russia and South Africa. Platinum producers in the country include units of Zimplats Holdings Ltd. and Anglo American Platinum Ltd.

Ncube announced the measures as he cut the nation's economic growth forecast for this year to 4.6% from 5.5% at the end of last year, citing the global economic slowdown. Growth is being crimped by Russia's war with Ukraine, the escalation of sanctions on Russia, a sharper-than-anticipated slowdown in China, and soaring inflation and a depreciating currency.

Zimbabwe's annual inflation rate jumped to 192% in June, the highest level in more than a year.

Managing and disposing of processing waste safely and effectively

Implementing a Dry Stack Tailings (DST) solution provides a safe and sustainable alternative to the storage of tailings in impoundments.

The recent commissioning of a Dry Stack Tailings (DST) system supplied by TAKRAF to a Brazilian mine highlights the advanced expertise and unique positioning of the company to offer a complete end-to-end solution for safe and environmentally friendly mine waste management.

While the dry stacking concept is not new, with references as early as 1909 in Australia, technological advances have made DST an increasingly important alternative to conventional methods for handling mine waste, enabling mining companies to significantly decrease their risk profile.

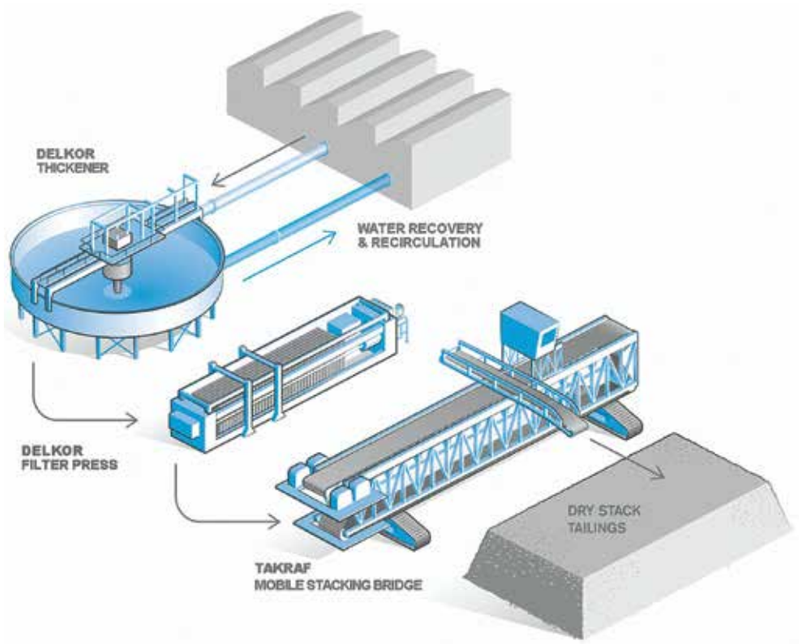
Currently, the most widely utilised method of disposing tailings (waste material from the mineral extraction process) is to pump the tailings slurry to a dedicated impoundment area (pond or dam) to allow sedimentation to occur and solids to settle out. Part of the water is then recovered and re-used in the process. However, the risks and challenges associated with this method, combined with evolving mining conditions, mean that the safe and effective handling and deposit of tailings, whilst also considering the environment, is of ever-greater importance. Challenges include the considerable space requirement when storing tailings in impoundments, while the catastrophic tailings dam failures, which have occurred, resulting in significant loss of life and environmental damage, are a stark reminder of the risks.

Exacerbating the situation are current mining conditions, which utilise advanced mineral processing technologies to allow lower grade ores to be processed. This results in a much larger quantity of tailings that need to be safely stored. This ever-increasing tonnage of generated tailings makes a conventional deposit in dams an increasingly significant burden curtailing the expansion and development of mine operations and further highlights the potential of DST as a viable and beneficial alternative.

Advantages of DST

With DST, the moisture content in the tailings is reduced by a mechanised and controlled process to the point that it can be safely transported, deposited, and stacked as solid cake-form tailings. This yields several advantages over other surface-tailings storage options, including:

- Significant safety improvement with the risk of catastrophic dam failure and tailings run-out being eliminated.
- Transformation of tailings into a stable landform, and facilitation of rehabilitation and eventual closure.
- Smaller tailings footprint and can be employed in undulating or steep terrain.
- Suitability to areas of high seismic activity and areas where there is limited construction material to develop a conventional retention impoundment.
- Reduced requirements for make-up water in plants, principally achieved by recycling process water, and near elimination of water losses through seepage and/or evaporation.



A “typical” flowsheet showing an example of TAKRAF’s complete DST solution.
Source: TAKRAF

As tailings processing is complex, a detailed understanding of and expertise in the different steps specific to the commodity and project location are required. All equipment needs to be designed and/or adapted to specific project requirements and to be integrated seamlessly into the overall system. As a result, TAKRAF adopts a comprehensive and holistic approach to the design of its DST systems, combining its proven expertise in dewatering (DELKOR) and materials handling (TAKRAF) with a dedicated team of mining, materials handling, and processing specialists. This two-fold approach – *bottom-up*, equipment supply, and *top-down*, planning a long-term sustainable system – enables TAKRAF to develop solutions that best suit a client’s specific requirements, as well providing the client with a single point of responsibility during implementation. This approach has resulted in clients not only procuring equipment for tailings treatment, but also in contracting TAKRAF to carry out conceptual studies and economic trade-offs for DST systems. All this culminated in a recent DST system order being placed in January 2019.

DST system designed for Brazilian Mining Company

The order, placed by Mineração Usiminas, one of the Usiminas companies, and one of the largest steel producers in the Americas, comprised basic and detailed engineering, manufacturing, supply, transportation, and site assembly supervision of equipment to process iron ore tailings.

The system is designed as a fully integrated dewatering process via thickening and filtration and includes the following main equipment:

- 1 x flocculant plant
- 1 x coagulant plant
- 1 x DELKOR high-rate thickener: 35 m-diameter, 680 t/h (nominal); 748 t/h (design)
- 1 x 300 m2 slurry tank with agitator
- 4 x double stage centrifugal slurry pumps
- 4 x DELKOR filter press overhead beam (FP OH): 2 m x 2 m plates, each 170 t/h (nominal) and 187 t/h (design), capacity for 215 chambers
- 4 x compressors with tanks (process and instrument air)
- 4 x TAKRAF belt feeders: 2.0 m width, 31 m length with transfer chutes

Mineração Usiminas implemented the DST system to enable the filtering and stacking of tailings as the deposit area of the existing tailings dam reached full capacity. The process dewaters the tailings slurry in a single stream – a two-stage process using a DELKOR high-rate thickener followed by the filtration of thickener underflow using DELKOR overhead filter presses. The next process step allows further water recovery through the filter press, designed to achieve a moisture content level of about 14% (dry basis). Particular attention has been given to the redressing of the slurry using reagents to improve maximum recovery. The result is a dry filter cake that can be effectively handled and deposited.

In line with TAKRAF’s approach to supply site-specific solutions, the tailings material was extensively tested prior to the selection of the equipment. For example, the DELKOR filter presses, designed with a collaboration partner as an overhead beam type, are best suited for the operational conditions. The design of such machines enables them to process large volumes of material, yet are robust and maintenance-friendly, since they provide easy access to the filter plates and filter cloths.

“Sustainable water management, together with safety, are increasingly important topics for mining operations and all stakeholders around the world; especially in areas where water conservation is critical and/or tailings failure risks are significant as has unfortunately been the case in Brazil. The Mineração Usiminas project is testimony that implementing a full DST solution, in line with the overall mine development plan, is the most environmentally-friendly and beneficial approach for all stakeholders,” noted Thiago Machado, Head of DELKOR products at TAKRAF Brazil.

DST system under construction for the safe and effective handling of iron ore process tailings recently supplied by TAKRAF Brazil to Mineração Usiminas.
Source: TAKRAF

Electrifying the powertrains of industrial vehicles, transportation and marine

THE IMMEDIATE NEED TO IMPROVE ENERGY EFFICIENCY AND REDUCE EMISSIONS

Transportation of people, goods and raw materials accounts for over 25% of the world's total energy consumption and almost 30% of carbon dioxide (CO_2) emissions worldwide[1,2]. While the emissions from vehicles like passenger cars are often the first consideration given their high volume, non-rail transport of either people or goods like busses, ferries and industrial vehicles also have a significant impact. For example, in the EU, although trucks, busses and coaches account for less than 5% of traffic they account for about 25% of vehicle CO_2 emissions[3]. In addition, diesel engines emit significant amounts of particulate air pollution, which can be harmful to people's health.

Given the urgency to reduce the impact on our planet, in addition to ongoing price and supply volatility of fuel, it is critically important for companies to transition to a sustainable transport approach to reduce both their emissions and energy consumption. To prevent irreversible climate change, the Intergovernmental Panel on Climate Change (IPCC) calculates that we must reduce the current level of carbon emissions by 43% by 2030[4]. And to improve air quality, The World Health Organization (WHO) suggests steps that governments must now take, including implementing stricter vehicle emissions standards and modernizing public transport.

The electrification of public transport vehicles like busses has already proven to be effective in reducing emissions, and the technology is already mature and growing in popularity. In this white paper we take a look at the impact that continued use of fossil fuels will have on society and how the transition to electrification of powertrains in industrial vehicles, transportation and marine vessels can provide viable solutions.

ENERGY USE AND EMISSIONS BY INDUSTRIAL VEHICLES

It is estimated that diesel-powered construction vehicles such as excavators, cranes and dozers collectively emit around 400 Mt of CO_2 per year. That amount accounts for approximately 1.1% of global CO_2 emissions. Of these construction vehicles, excavators over 10-tonnes in weight are responsible for close to a staggering 46% of those emissions[5]. In addition to CO_2 emissions, diesel-powered vehicles also emit other harmful gasses and particulates. For example, in the US, it's been estimated

that construction machines contribute to about 32% of mobile source NOx emissions, which can form smog and exacerbate asthma and other health conditions[6]. While in the construction industry in the UK, around 8% of occupational cancer cases are thought to be directly related to diesel engine exhaust emissions[7].

Meanwhile, in underground mining, vehicles typically work in tight and enclosed spaces where a build up of exhaust gasses like CO_2 and NOx can lead to hazardous situations for workers very quickly. As a result, underground mines that operate diesel-powered vehicles require extensive ventilation systems to extract the diesel exhaust fumes and make the air in working areas safe and breathable. And, although these ventilation systems are electrically powered, they still add to the overall energy consumption of the mine.

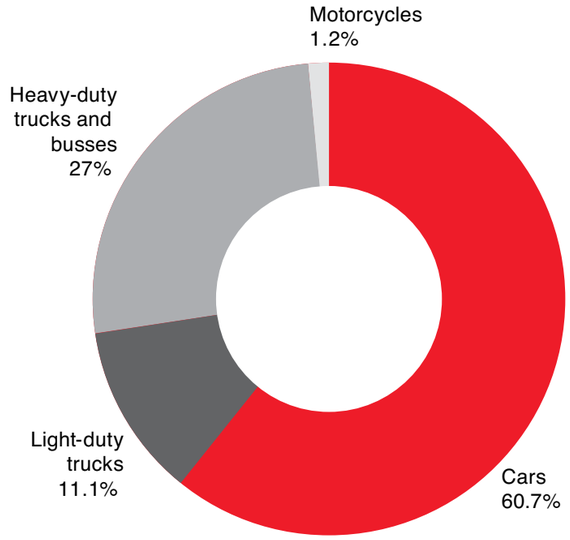
Given these environmental and health concerns, there is already a major effort across many industries to reduce emissions from vehicles including marine, materials handling and mining. Part of this effort in mining is being led by the International Council on Mining and Metals (ICMM) that has committed to achieving the goal of net zero greenhouse gas (GHG) emissions by 2050 or sooner[8]. A major contributor to achieving this goal will be electrification. And, although the electrification of operational vehicles is relatively new in many industries, it can be an effective and realistic solution which is discussed later in this whitepaper.

Energy use and emissions in transportation by road, rail and marine The transportation of people and goods accounts for about 25% of the world's energy consumption[9]. Over-land transport is provided mostly through road and rail vehicles, but we are also concerned with small-to-medium marine vessels such as ferries. This white paper does not cover aviation.

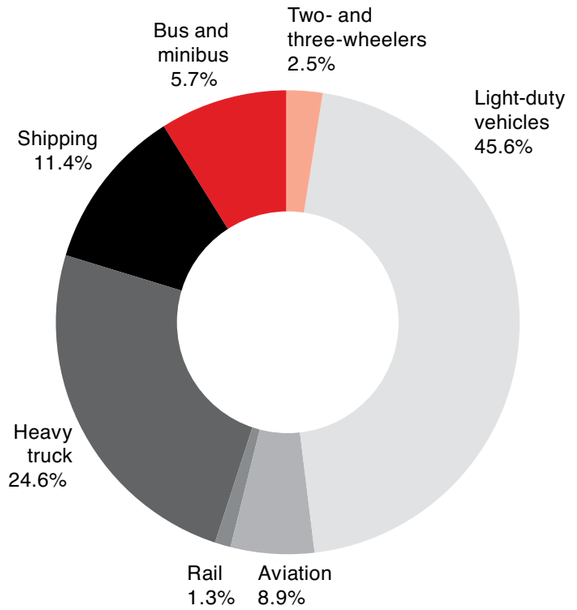
ROAD TRANSPORT

While cars account for the majority of road transport emissions, busses and heavy-duty trucks also account for a significant proportion. For example, in the EU, heavy-duty trucks and busses account for 27% of emissions[10]. As with industrial vehicles and machinery, diesel emissions

Mining has committed to achieving the goal of net zero greenhouse gas emissions by 2050 or sooner.



CO_2 emissions from road transport in the EU (2019)[10].



Global CO_2 emissions from transport by subsector (2020)[14].

from transportation vehicles have negative impacts on the climate, as well as on health. According to the WHO, air quality globally is at unsatisfactory levels and around 99% of the global population currently breathes air that exceeds the organization's recommended limits[11].

Since the majority of public transport routes operate in busy urban areas with dense populations, the effect of diesel emissions on air quality and public health is also a notable problem in many cities. In addition, diesel engines also generate a significant amount of noise and vibration, which also impacts health and wellbeing, and can lead to issues like cardiovascular disease and sleeping difficulties[12].

RAIL TRANSPORT

Rail transport is significantly more efficient than road transport. While railways account for 9% of the world's passenger transport and 7% of freight transport, they only account for 3% of transport energy use[13]. Even when trains are powered by fossil fuels – usually diesel – they are, on average, nearly 12 times more energy efficient than cars per passenger kilometer and 8 times more efficient than trucks per tonne of freight[15]. Nonetheless, many routes in the world are still served by diesel locomotives due to the difficulties in providing electrical infrastructure in remote locations.

MARINE TRANSPORT

The transportation of people and goods by sea is also a significant source of greenhouse gas emissions and energy consumption. International and domestic shipping in the EU accounts for about 3.6% of total transport emissions, and has seen an increase in emissions of 32% over the past 20 years, representing the fastest growth in the transport sector (along with aviation). Emissions from shipping are projected to increase by 2050 to between 50% and 250%, resulting in a potential responsibility for 17% of global greenhouse gas emissions[16,17]. This is mainly due to the diesel engines that are ubiquitous among these vessels. Due to this expected growth, increasing the energy efficiency and sustainability of marine operations is of paramount importance.

However, transporting goods by sea is still more efficient than transporting goods by road or air and generates lower CO_2 emissions. And although 85% of international freight is carried by ship, it accounts for only 2-3% of global CO_2 emissions. In comparison, road transport produces over 50% of all trade-related freight emissions[18,19].

Now that the inefficiencies and risks associated with diesel emissions are more widely known, there is increasing pressure to find more efficient, more sustainable alternatives. There are already many initiatives underway that promote the decarbonization of transport, including the European Commission's Sustainable and Smart Mobility Strategy, which aims for 90% lower transport sector emissions by 2050[20].

For land-based vehicles, electric powertrains offer an effective and proven way to both reduce emissions and to improve efficiency of transport. In the marine industry, fully electric propulsion systems can also improve efficiency and they are already available for small to mid-sized vessels.

For larger vessels, full electrification is more difficult. However new and more sustainable fuels are being researched. For example, biofuels like bioethanol, as well as e-fuels synthetic hydrocarbons produced using renewable feedstocks and renewable energy. In addition, companies like ABB offer technology to improve efficiency and reduce fuel consumption. For example, the ABB Azipod® propulsion system can reduce fuel consumption by up to 20% compared to a traditional shaft line setup[21,22].

Supplying power to electric vehicles

Electrically-powered vehicles are those that use electricity as their primary source of energy rather than liquid fuels or gas, for example. To operate electrically-powered vehicles requires an infrastructure to support them, either to supply power directly or for recharging onboard batteries.

While the infrastructure for rail-based transport is already well developed, the infrastructure for road transport and marine applications is still under development, although this is proceeding quickly. The industrial situation is much more fragmented. In some industries, companies have already started to adopt electrically-powered heavy working machines and the associated infrastructure, whilst in others the concept is still in its relative infancy.

There are several different ways that industrial vehicles, transportation, and marine vessels can be powered with electricity, including via overhead catenaries, using rechargeable batteries, and using a combination of both catenaries and batteries, as well as with hybrid diesel-electric power.

CATENARY POWER/ELECTRICAL TROLLEY SYSTEMS

Catenaries are overhead power lines which supply electricity to a vehicle traveling directly underneath them. The vehicle connects to the lines using a device on the roof called a pantograph. Although the range of this type of electric vehicle is limited to routes covered by overhead power lines, catenary-powered vehicles like trains and trolley busses are well proven in the public and goods transportation sector.

For example, trains powered by catenaries are a familiar sight in many countries – they have been in use for well over 100 years – and they can haul large loads very efficiently.

One big advantage of catenaries is that they can provide the large amounts of power needed to operate very heavy vehicles, like locomotives, or even mining trucks. In recent years, catenaries have been trialed in open-cast mining sites to power heavy trucks.

Note: the term catenary is used for rail vehicles, trams, trolley-busses and busses, while for heavy working vehicles the term electrical trolley system is usually used.

BATTERY POWER

Transport vehicles that use rechargeable batteries have become more common in recent years in a number of cities as the recharging infrastructure and technology is advancing rapidly. However, it is important to note that the batteries required for industrial and transport vehicles and marine applications are different from the types of batteries used in electric and hybrid passenger cars. The batteries used for those larger vehicles need to supply much more power (electricity), as well as enduring continuous use and withstanding many more charging cycles. For example, the average public transport vehicle such as a bus is in use for 16 to 18 hours a day, while the average passenger car is used for less than a 2 or 3 hours per day. Energy storage systems, which use powerful new lithium-ion battery technology, like the ABB BORDLINE® Energy Storage System (ESS), have been developed to meet the needs of heavy vehicles.

ABB applied its eMine™ purposeful framework of methods and integrated solutions to design and install an effective electrical infrastructure to power several mine trucks at Boliden AB's Aitik mine in Sweden. The lane is ~700 meters and Boliden is expected to save ~830 m^3 diesel per year and reduce its greenhouse gas emissions from transportation by up to 80% along those routes where the technology can be implemented.

Battery-powered vehicles require their own infrastructure to enable recharging. Several different types of battery charging technology are already in use, including plug-in charging posts, catenary charging stations, catenary recharging while driving and using the electricity generated by the diesel engine in a hybrid system. Some vehicles also use removable batteries which can be swapped and recharged in a maintenance depot.

COMBINED CATENARY-BATTERY POWER

Trains, trams and trolley-buses which can operate with both catenaries and batteries are also becoming more common. These vehicles use catenary power on routes with overhead power lines and switch to battery power on other routes. The ability to use both types of power source enables transport networks to extend the range of their fleet beyond the limits of the overhead lines. It also enables city bus routes to be expanded to cater for growing urban populations, making electric busses an option over cars where there is no rail network in place.

Modern systems, like ABB's Bordline® ESS system for trolley busses, use catenary power to recharge the batteries as the vehicle drives. On average, 1 km of catenary-powered driving enables 1 km of catenary-free driving, extending the vehicles' catenary-free range by 50%[23].

HYBRID DIESEL-ELECTRIC POWER

Hybrid diesel-electric vehicles can operate using both diesel engines and electric motors. Depending on the type of vehicle, the electric power may be provided by catenaries or batteries, or from electricity generated by the diesel engine.

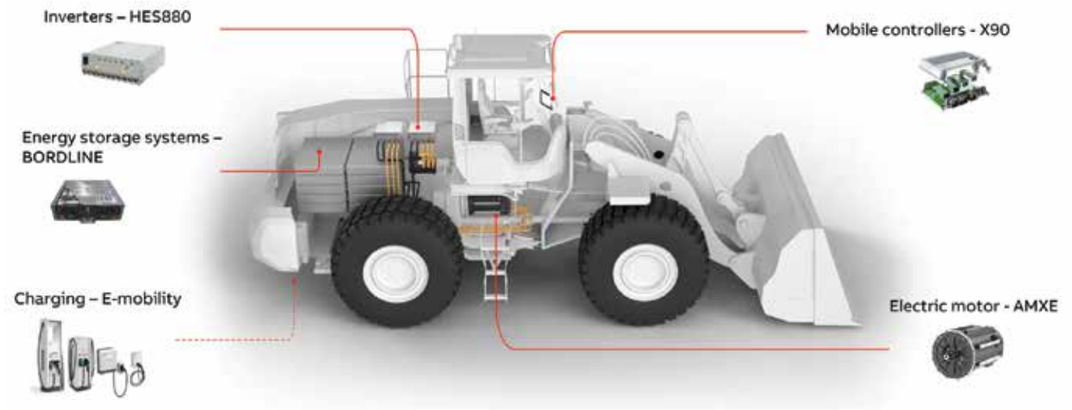
Hybrid diesel-electric power is particularly important for rail transport because a significant proportion of trains and still rely on diesel engines in areas where there is no catenary network available. For example, in the EU, although almost 100% of urban rail networks are electrified, only 60% of the mainline networks are[24]. This is because many long-distance transport routes carry a low density of traffic, which makes electrifying them economically unviable. Hybrid diesel-electric power also enables commuter trains to operate electrically in urban areas, while reverting to diesel power outside city limits.

Hybrid power systems are also an attractive option for marine vessels. For small and mid-sized vessels, diesel-electric drivetrains are already in use, while for larger vessels new types of hybrid systems are being developed. For example, super capacitors, as well as several different types of fuel cells are being researched that can be used together with electric propulsion systems. These include alkaline fuel cells, proton exchange membrane fuels cells, as well as hydrogen fuel cells[25].

Trolley-buses which can operate with both catenaries and batteries are becoming more common.

An overview of electric powertrains

Electric powertrains include several key components including an electric motor, which turn electrical power into motion, and a traction converter/inverter which regulates the voltage and frequency of the electricity that is supplied to the motor. Depending on the power source, other components will be needed. Batteries and charging outlets are required for battery powered vehicles, while DC/DC converters are required for catenary powered vehicles.



The components in a battery-powered electric wheel loader.

ELECTRIC MOTORS

The electric motors for both industrial and transportation vehicles need to be robust, more powerful and have a longer working life than the smaller motors used in vehicles like passenger cars. Typically, they will be moving vehicles of 10 tonnes or more in weight and operate continuously over long working hours. This means they must be able to deliver high torque and perform efficiently at a wide range of loads. In addition, they must be designed to withstand all kinds of weather, a wide range of ambient temperatures, extreme working conditions, and shocks and vibrations. They are expected to have a long and productive working life.

ABB AMXE® motor for heavy vehicles.

These kinds of heavy duty motors have long been in use in rail transport, so the technology required is mature and proven, and it can be easily and effectively applied to industrial vehicles as well. For example, the ABB AMXE® motors range are compact, permanent magnet synchronous motors for high efficiency propulsion and auxiliary usage, allowing configuration with specific lengths, windings and voltages to achieve the required performance.

TRACTION INVERTERS

A traction inverter converts the electrical supply from the power source into a variable voltage and variable frequency output to match the needs of the vehicle. Because this process affects all other components in the powertrain, it is important to choose a traction converter which operates efficiently.

For example, for transport vehicles like trolley-busses and trains, ABB's BORDLINE® Compact Converters are among the most efficient on the market. They allow total optimization of the traction transformer and motors, significantly reducing losses in the traction chain. In practice, this means that a typical commuter train can reduce its energy consumption and costs by up to 20%.26

As another example, the ABB HES880 Mobile Drive provides similar efficiency benefits for heavy working machines, while also being built to withstand harsh working conditions and heavy operation.

REGENERATIVE BRAKING SYSTEMS

Although electric motors are usually used to turn electric power into motion, when combined with the appropriate type of traction converter/inverter, they can also be used in regenerative braking systems to generate electricity. These systems recover the kinetic energy of the vehicle during braking.

A moving vehicle has kinetic energy, and for the same velocity, the heavier the vehicle, the more energy it will have. The heavier the vehicle, the more kinetic energy it has. To drive an electric vehicle, energy in the form of electricity is sent to the motors, which then rotate and move the wheels. In regenerative braking, the system works in reverse: the motion of the wheels is used to rotate the motors, which then generate electricity. The recovered electricity can then be stored either in an onboard battery or, if the vehicle is catenary powered, fed back into the network power supply for storage or use by other vehicles.

Note that regenerative braking uses the magnetic field in the motors to provide resistance and slow the vehicle down and to generate useful electrical energy. In contrast, mechanical braking relies on the friction created by brake disks or pads, which then lose and waste the energy as heat. This is why regenerative braking can make vehicles more energy efficient.

Regenerative systems are already used widely in both road and rail vehicles, where they can reduce energy consumption and costs. They are also becoming more common in electric industrial vehicles.

An electric bus equipped with ABB powertrain technologies in Zurich, Switzerland.

The drivers to transition towards building a sustainable transport fleet

When businesses set out to reduce their energy consumption and costs, a good starting point is to look at their operations overall, to identify inefficiencies at all phases of usage, including transport, idling, logistics and on-site work. This will help them identify which vehicles, vessels and machines would be the best fit to operate with an electric powertrain or other method. Companies like ABB have the expertise to advise companies on implementing electrification projects – whether that is starting with one operational vehicle or a whole fleet.

It is also worth noting that sometimes energy efficiency can be improved using relatively simple means, like training operators how to complete tasks efficiently and how to operate machines economically. This approach applies as much to operators in the works site as it does to directors in the board room – companies have to choose to be energy efficient.

Modern electric powertrains help make this choice easier. Using electricity instead of fossil fuels to power vehicles can significantly improve energy efficiency and drastically reduce emissions. For example, when operating in the optimum load range, diesel and petrol engines can reach efficiencies of 45% and 33%, respectively. In contrast, electric motors can typically reach about 95% efficiency[27,28]. Traction converters/inverters can also control the speed and torque of an electric motor directly, rather than the clutches and gears required by internal combustion engines, which lose energy through friction and heat. And, in addition to gains in efficiency, electrification offers additional benefits to businesses, operators and the environment.

BETTER ENERGY EFFICIENCY

The energy savings and efficiency gains for an electrically-powered vehicle or vessel vary depending on the technologies in use and on the application. However, the improvements can be substantial for industrial vehicles, transportation, and marine vessels, whether or not the vehicle is fully electric.

For example, when regenerative braking is used with a hybrid diesel-electric compaction roller, equipped with an onboard battery, the energy from braking is captured and stored. This energy can then be used by the electric motor to level out peaks in power demand, which in turn means that a smaller diesel engine is required, reducing fuel consumption by up to 30%[29].

Training operators in efficient machine use can result in fuel savings of up to 30%[30].

Alternatively, if the diesel engine is used to generate electricity, it can be operated in a steady state in its most efficient range, while the converter/inverter and electric motor handle variable loads. For large construction machines with this kind of system, fuel savings of up to 20% have been identified. And, if an electrical drivetrain is used in the same type of machine, instead of a mechanical one, together with an onboard energy storage system, it's been calculated that fuel savings of up to 30% could be reached[31].

For heavy working vehicles with hydraulic systems, electric pumps can be used to power zonal hydraulics. Zonal hydraulic systems separate the areas of hydraulics into different working zones, for example, the hydraulics for drive systems, boom and buckets. This means that that the pumps do not need to provide power to all the systems all of the time, which results in energy savings, because the hydraulic pumps do less work.

Meanwhile, for fully electric transport vehicles, like catenary powered trolley-busses, if a modern onboard energy storage system like the ABB BORDLINE® ESS is added it can improve the efficiency of regenerative braking, enabling energy savings of 15% compared to systems that feed energy back into the grid[32].

Diesel and petrol engines can reach efficiencies of 45% and 33%, respectively. In contrast, electric motors can typically reach about 95% efficiency[27,28].

REDUCED OPERATING AND OWNERSHIP COSTS

On average, electric vehicles have 40% to 60% lower operating costs than equivalent vehicles powered by an internal combustion engine. This is mainly due to the improved tank-to-wheel efficiency and reduced fuel consumption, as well as the reduced maintenance needs. Although the initial investment price may be higher for an electric vehicle, the total cost of ownership over its working life is likely to be lower. For example, calculations indicate that total cost of ownership of battery powered electric heavy vehicles may be about 20% lower than for internal combustion engine powered equipment[33].

Electric vehicles can lower operating costs by **40-60%**[33].

REDUCED EMISSIONS

When powered by renewable sources of electricity such as solar or wind, electric vehicles produce no CO_2, NOx or other emissions, nor do they emit any particulate pollution. Even when they use electricity supplied by fossil fuel-fired power stations, they still generate lower emissions overall, and no emissions or pollution in the area around the vehicle.

For example, if the diesel engine in a 24-tonne excavator is replaced by an ABB electric powertrain, which uses battery power together with an AMXE motor and HES880 drive, it can eliminate 48 tonnes of CO_2 emissions per year[34].

HIGHER PRODUCTIVITY

Electric vehicles can increase the productivity of some applications. This is because electric motors are more efficient and deliver more power to the wheels. This is especially beneficial when heavy vehicles, like mine trucks, are hauling loads up hills – each unit of energy does more useful work per tonne, and the vehicle can drive faster but equally as safe. If the vehicles also have regenerative braking systems, they can recover significant amounts of energy on the journey back down the hill further reducing the energy consumption per tonne.

EASIER AND SAFER TO OPERATE

Electrically powered systems can also give operators better control of heavy machinery. This is because electric systems respond instantly to operator input, giving them more accurate control and more feel for what the machine is doing, which makes them easier to operate. In contrast, traditional combustion engine powered hydraulic systems always have a small amount of lag, which makes operating them more demanding and slightly less precise.

Many different types of mining vehicles can be electrified.

REDUCED VENTILATION AND COOLING NEEDS

All internal combustion engines generate fumes and heat. On a working machine such as a ferry, the fumes are emitted through the exhaust pipe and the heat from the engine is managed and dissipated using radiators and fans. However, in an enclosed environment, like an underground mine, both the fumes and the heat have to be removed from the work area as well, using ventilation and cooling systems. As a result, as much as 40% of an underground mine's energy costs come from powering this type of ventilation system[35].

In contrast, electric vehicles emit no fumes and generate much less heat than diesel engines. This means that they can reduce cooling and ventilation requirements, and reduce energy consumption and the associated costs. It also means that fewer ventilation shafts are needed, which, in turn, reduces construction costs.

REDUCED NOISE AND VIBRATION

Large diesel engines create a lot of noise and vibration. The noise means that workers often have to wear ear protection and the vibration can lead to fatigue. In addition, the noise and vibration are disturbing to bystanders and, in built-up areas, working hours may be tightly regulated to minimise disruption to the public. Electric motors are much quieter and generate much less vibration, which makes them much less fatiguing to operate. And, because they create much less disturbance, electrically powered machines can often be quiet enough to operate at night, even in densely populated areas. This also extends their productive working hours.

Success Stories

Nasta electrifies heavy construction machinery with ABB motors and drives

Nasta AS in Norway distributes, redesigns and rebuilds Hitachi diesel-driven construction machinery. It converts vehicles like excavators for operation using battery power or direct cable connection. The conversion procedure includes fitting ABB powertrain components such as electric motors and drives, together with an energy management system, battery and charging solution, along with a power connection.

Electrification of heavy vehicles provides clear environmental benefits. A diesel-driven 24-tonne excavator typically uses about 18,000 liters of fuel per year, which produces an annual total of around 48 tonnes of carbon dioxide emissions. After the upgrade, these CO2 emissions are eliminated, as are sulfur oxide (SOx) emissions, and the machines produce much less noise. These factors improve the environment, both for workers on the construction site and for people who live or work nearby. In addition, operators have told Nasta that the electrified machines are much more responsive when excavating.

ABB technologies help buses in Zurich become more sustainable

Energy-efficient drive solutions and energy storage systems from ABB are helping municipal public transport companies approach the goal of emission-free mobility.

Electric buses equipped with ABB powertrain technologies are significantly more sustainable than conventional diesel-powered vehicles. These are already on the road in cities across Europe, specifically line 83 of the Zurich public transport company (VBZ), which has been operating exclusively with electricity.

The buses operate through a combination existing catenaries and battery power. The energy storage system installed on the roof of the vehicle is recharged when the bus travels on existing sections equipped with catenaries. The dynamic recharging of the energy accumulator in particular guarantees great flexibility for cities with an extensive catenary infrastructure when it comes to expanding their network.

CONCLUSION

Although diesel is still used to power the majority of industrial vehicles and transportation, as well as marine vessels, solutions for electrification are advancing rapidly. Electric powertrains that rely on catenary and battery power, as well as diesel-electric hybrids, have already proven their worth and demonstrated clear efficiency and cost benefits in heavy vehicles like electric busses, trolley-busses and trains. Now the technology and know-how gained from these fields is increasingly being applied to industrial vehicles, transportation and marine. Thanks to progress in electrification, more efficient, lower emission industrial vehicles are now within reach.

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ABB Electric Powertrain Solutions for Mining Vehicles

Reduced emissions, high efficiency and lower operating costs

198,000 tons

Amount reduced **per day** if every truck in every mine were electrified.

95% vs 45%

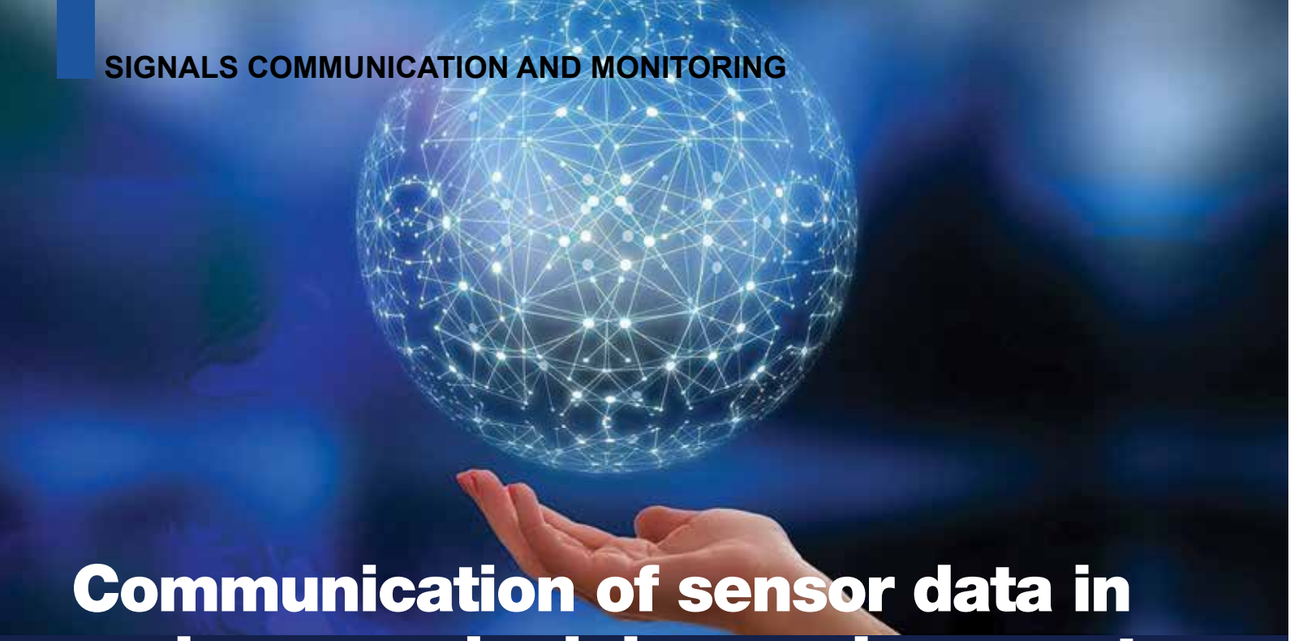
Electric motors **efficiency** versus typical diesel engines.

40% - 60%

The amount that electric vehicles can **lower Total Cost of Ownership**.

Given the urgency to become more energy efficient and achieve lower emissions targets, mining equipment manufacturers can change to sustainable transport with solutions from ABB.

Learn more



Communication of sensor data in underground mining environments: an evaluation of wireless signal quality over distance

The technologies of the fourth industrial revolution have the potential to make zero harm possible for the first time in the history of mining. In the journey toward zero harm, rock stress monitoring systems are important for the risk management process. Although communication systems for underground mining have improved significantly over the past two decades, it remains difficult to achieve reliable-all-the-time wireless communication in ultra-deep level underground mines. The aim of this study is to explore and test a smart phone network for communicating sensor data from the underground production environment to the surface. In this paper, the evaluation and performance over distance of a wireless communication system is performed in underground mining environments. The wireless system transmits the data collected from a sensor installed in a narrow reef stope, horizontal tunnel, and vertical shaft area of a mock underground mine. The evaluation was performed using the received signal strength of a mobile receiver over distance. The path loss coefficients of the underground mining environment were then derived for the measurement areas. The results show that a communication speed of 80 Mbps was achieved in a 60 m range, thus, indicating the potential for the support of applications requiring higher data rates.

The advances in mobile computing and hardware designs have enabled the deployment of more efficient functionalities on mobile devices while these devices have become smaller and compact. In underground mining environments, the low rate of mobile device usage is mainly caused by strict safety regulations. Currently, several wired[1,2] and wireless communication technologies are available that satisfy the minimum required criteria for the data broadcast speed and range to support remote mining operations and advanced monitoring systems.

The main advantage of wireless communications is mobility within a closed space. In underground mines, wireless technologies can be used to support the mobility of humans and machines in dangerous working areas. In those areas, conventional cable communication can be easily damaged by heavy machinery and may not advance quickly enough with the required expansion of working areas.

As a result, wireless sensor networks (WSNs) have become useful for measuring and monitoring important data, such as in situ stress and strain, air quality, and data from machines in underground mines. Long term in situ stress and strain monitoring systems are necessary to observe the rock conditions in mining excavations. While numerical modelling methods can provide a faster approach, actual measurements from sensors installed around the areas of interest can provide more accurate stress and strain measurements of the surrounding rock.

These measurements can be more valuable if an efficient communication system is present at the working areas and can deliver the data over long distances to important decision making locations, such as the central processing office, which is usually located at the surface. Before communication technologies can be deployed in situ in underground mining environments, extensive measurement campaigns in safe test-bed environments are necessary to estimate the performance of such technology under harsh conditions.

The measured data have shown to be useful in applications such as optimised network design, file download efficiency, user and machine localisation, and positioning. In order to successfully develop these algorithms, the path loss properties of the wireless signals, such as the received signal strength indicator (RSSI), are collected from test environments and used to train the algorithms offline. The trained models can then be used for actual navigation and the determination of the users' positions in realistic scenarios using existing algorithms, such as the k-nearest neighbour (KNN) or triangulation.

Such methods can also be adopted in underground mining environments and will require extensive RSSI measurements in order to understand the effects of different geometries on direct WiFi signals. In scenarios where the data are required to be transferred over long distances, such as to a surface office for further processing, the effect of deep fading is mitigated by simply re-transmitting the signal over a distance where the signal can be received, decoded, and re-transmitted reliably. Hence, adequate knowledge of the propagation properties, such as the received signal strength (RSS) can inform the placement and deployment of transmitter-receiver pairs in the mine in order to achieve reliable data hops to the destination.

In this paper, the practical integration of a multi-sensor, cell monitoring system with a low-complexity WiFi communication system is evaluated in a narrow tunnel, narrow-reef stope, and vertical shaft of an underground mining environment. The data from the sensor is transmitted directly to a mobile phone receiver that is in the transmitter's line-of-sight (LOS) and non line-of-sight (NLOS). The RSSI as well as throughput performances are evaluated with respect to the distance and geometry of the environments. Using the RSSI data, the path loss propagation properties of the different measurement areas of the mine are also derived. By conducting physical experiments to measure the performance of WSNs, we evaluate the performance in underground mining environments. The results have the potential to inform the transfer speed and signal quality that can be achieved in real severe environments.

This paper is organised as follows: in the introduction, the concept of a wireless monitoring system and path loss model is discussed, Section 3 introduces the proposed in situ stress monitoring system. In Sections 4 and 5, the principle of the experiment, the RSSI Model for WiFi Direct, and the setup of the experiment are described. Sections 6 and 7 conclude the paper, discussing the results and proposing further steps for expanding the experiment.

RELATED WORK

Wireless Sensor Networks

The efficient monitoring of natural events that pose a safety risk to humans in underground mining environments can assist with improving the health and safety conditions in the environment. Such risks can emanate from rock movement due to stress, imbalances in temperature and ventilation, and smoke and air quality issues[3]. Generally, *in situ* stresses increase with depth as, in shallow coal mines, the rate of increase in horizontal stresses as the depth increases is greater than the rate of increase of vertical stress.

On the other hand, with increasing depth, the rate of increase in horizontal stresses decreases. Therefore, a considerable scatter in the in situ stress test data may be due to distinct differences in both the strength and deformation moduli of strata located in different geological environments and coal districts[4].

In monitoring rock masses in deep underground environments, an extra-deep, multiplepoint borehole extensometer was investigated in an iron-ore mine in eastern Jinshandian. The extensometer was demonstrated to be applicable for up to 300 m depth. The in situ monitoring results collected over eight years were analysed[5].

WSNs in underground environments can assist with measuring events that include, but are not limited to, temperature, dust, smoke, air pressure, air quality, humidity, rock stress, and movements. In[6], a review of WSN applications was performed in which the impact of wireless technology, such as ZigBee, was discussed and evaluated for mine collapse monitoring, the tracking of miners in underground environments, and the support of robots for the collection and delivery of data from areas that are inaccessible to humans.

A direct application to gas monitoring was performed in[7] and fire detection was conducted in[8], where the authors evaluated the fire detection speed in a Bord-and-Pillar coal mine using WSN. Using simulations, the authors proposed a prevention system capable of detecting the location of fire breakouts in seconds as well as the direction of the fire as it spreads.

While the data from sensors in an underground environment can be collected and analysed locally, the work in[9] further discussed the potential of integrating an Internet of Things (IoT) system with the data collected from sensors in underground environments.

Trust models of WSNs security have flourished due to the day-to-day attack challenges, which are most popular for the IoT[10]. Designing a robust IoT network imposes some challenges, such as data trustworthiness (DT) and power management. In[11], a repeated game model was used to enhance clustered WSN-based IoT security and DT against a selective forwarding (SF) attack. However, WSN trust models are not considered in this paper, and more details can be found in[10,12].

Using the IP protocol, the data collected from the sensing layer can be available in real-time and remotely through cloud storage. Security challenges, however, exist in the sensing layer, suggesting the need for robust security

protocols to safeguard the end-to-end delivery of the data. The transmission of the collected data to the remote cloud can suffer from high latency when using current communication technology. By bringing the server relatively closer to the miner, mobile edge computing (MEC) is a promising distributed computation architecture to seize the opportunity of enabling low-cost, and low-latency data collection. These issues are covered in detail in[13,14].

In the event of a mine disaster, traditional communication networks can potentially be damaged and disrupted, affecting the ability of mine to understand the underground environment's conditions. This influences the quality and speed of decisions due to the disruption of real-time information required for mitigating the effect of any problems that may occur underground. Therefore, ZigBee and geographic information systems (GIS) technologies have been suggested to provide more effective communication systems[15,16].

Moridi *et al*. investigated various sensor node arrangements of ZigBee networks for underground space monitoring and communication systems[17]. The proposed system integration considering WSNs enables GIS to better monitor and control underground mining applications from the surface office.

Based on the capabilities of WSNs in the study, the ZigBee network was considered applicable for near real-time monitoring, ventilation system control, and emergency communication in an underground mine. The outcomes of such application provide promising, suitable network performance in such environments. Moreover, experimental measurements of ZigBee radio waves attenuation were validated by simulation results[18] for underground mines.

The outcome of this work shows that WSN can be reliable in deploying low data rate applications in underground mine environments, such as ventilation fan remote control, text messaging, and temperature and humidity readings and settings. The system functions of the model were tested and verified in an underground mine in Western Australia[19].

An overview of wired and wireless communication technologies, such as ZigBee, radio frequency (RF), and very low and very high frequency communication in underground mining and tunnel environments, was reviewed in[20]. In particular, the different modelling techniques of RF in underground mines show the different path loss propagation properties of the wireless signals, such as roughness, refraction, and sidewall tilt loss.

From the derived models, it is evident that signal propagation in underground mines is heavily influenced by the topology of the environment, such as the corners in tunnels, the unevenness, and tilting of the walls. Such channel knowledge was shown to be important in the deployment and implementation of underground mine applications for tracking and transceiver designs. An integration of a WSN with optic fibres in[21] was used to deliver the data collected from sensors installed in an underground coal mine to a monitoring centre at the mine surface.

Here, Zhang *et al*. attempted to address the need for safety by proposing a generic, integrated ambient-assisted living system architecture. A mesh network architecture was demonstrated in the WSN such that a cluster head, in the form of a routing node administers connected sensors, played the role of cluster members in the network[21].

Such architecture ensures that a broken sensor or broken link to the cluster head does not break down the entire system, while the cluster head manages dual communication with the surface control center. WSN was also integrated with WiFi in[22]. Here, Tao and Xiaoyang's system showed that WSN-WiFi applications can be used to extend the reach of the WSN system in low to high data rate applications, such as gas monitoring and video surveillance.

Applications of the Path Loss Model

The path loss model[23] for wireless signals can assist with evaluating the RSS of WiFi signals over distance. Other properties describing the fading nature of the signal in the environment, such as shadowing or path loss coefficients, can be determined by direct measurements. These properties not only provide understanding of the effect of the environment on wireless signals but also assist with offline analysis and simulations.

Mobile devices are equipped with RSS functionality. Hence, applications, such as user indoor positioning and navigation[24-31] and battery resource management[32], have emerged. In[24], the localisation accuracy based on RSS was improved by using a priori information obtained from measurements. Introducing the local environment parameters to wireless signal networks enabled better calibration of the WSN.

Aside from the RSSI-based method for fingerprinting and position location, the fine timing measurement (FTM), introduced in IEEE 802.11-2016, uses the properties of the received signal between mobile phone sensors, such as the arrival time and delay, for positioning. Hence, in[25], a comparison of the FTM technology with RSSI-based indoor positioning over a 2.4 GHz wireless system under realistic scenarios was performed.

The IEEE 802.11-2016 introduced FTM, which uses received signal properties, such as the arrival time and delay, for positioning with mobile phone sensors. Using the least squares (LS) method in a given radius, the position of the user in an indoor environment, transmitting over a 2.4 GHz channel is estimated, with the results showing that FTM improves the positioning when compared with the RSSI method. The statistical processing of RSSI measurements can also be used to process RSSI fingerprint data in order to improve the accuracy and reduce the complexity by reducing the amount of data required during offline processing.

In[27], a comparison of the accuracy of machine learning algorithms, such as KNN, singular value decomposition (SVM), and decision tree models, was used to classify finger-printing data used for indoor positioning. The classification enabled offline localisation using predictive measures during offline processing.

In[28], a hybrid of a KNN algorithm and particle filtering algorithm[29] was adopted to improve the positioning accuracy of a robot in an indoor environment. The effect of Bluetooth interference with the wireless signals on the positioning accuracy was also investigated in[30]. This was performed by comparing the statistical approaches, such as the Weibull distribution and the probability of occurrence of an observed RSSI measurement.

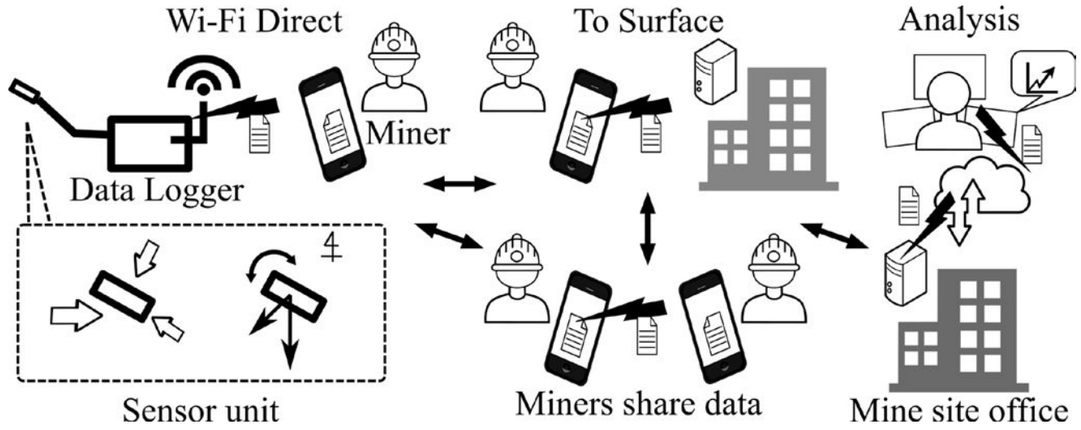


Figure 1: The data transmission monitoring system design.

Studies investigating the propagation of wireless signals in the underground tunnel coal mines go as far back as the work in[33] done in 1975. In this work, the effect of the geometry of the walls and corners were evaluated over high frequency radio waves in the MHz range. Since then, several works have studied the propagation models of wireless signals over higher frequencies.

The propagation properties of 900 MHz radio signals were measured in[34] for longwall underground coal mines. In[35], the delay, impulse response, and power profiles of signals received over 2.4 and 5.8 GHz frequencies were reported for an underground mining environment.

The measurements for LOS and NLOS scenarios show the fading characteristics as Rice and Rayleigh distributions, respectively. In underground environments, an adaptive fingerprinting technique, using RSSI data obtained from measurements, was used to improve the localisation of users in[26].

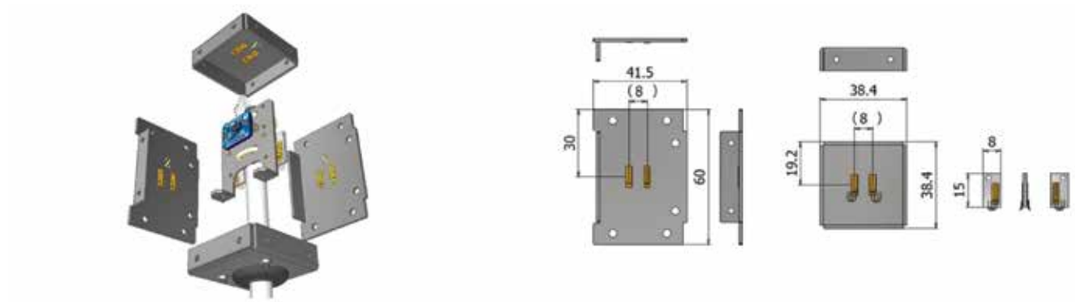
IN SITU STRESS MONITORING SYSTEM

In this study, in situ stress is used as input data. The input data will be sent to the surface and data centre via the proposed communication system, which will be further available in the cloud. The proposed data transfer system design is shown in **Figure 1**.

A data logger installed inside an underground mine senses in situ stress, enabling it to be transferred to a mobile device owned by a nearby miner[36]. Such data can then be sent to another miner's mobile phone using WiFi Direct. In order to develop a differential in situ stress or strain monitoring system, it is necessary to find a suitable device in the market or to develop a measurement unit (sensing), fulfilling the needs of the experiment, in addition to the communication unit.

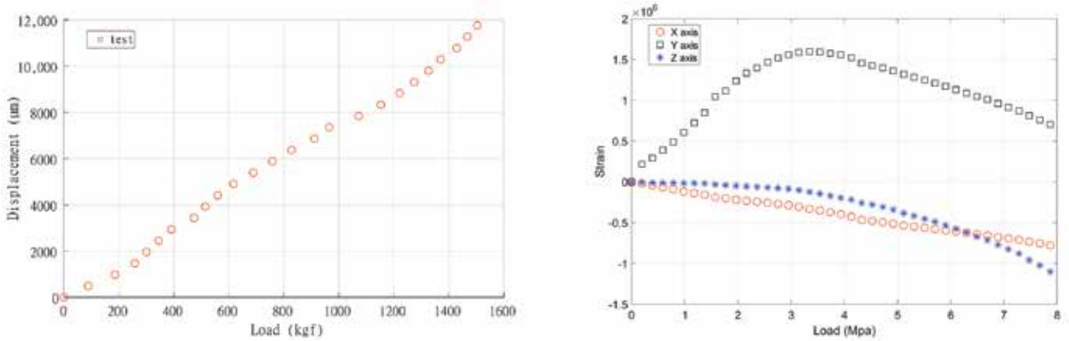
The sensor unit, developed by[37] can be installed by drilling a hole into the support system of an underground mine with a 60 φ drill-bit. The computer-aided diagram of the sensor unit is shown in **Figure 2**. In **Figure 2a,b** the blue-coloured unit, installed close to the centre of the device, is the sensing unit. In addition to a pair of strain gauges attached on the X, Y and Z surface, a nine-axis sensor (LSM9DS1) is installed to detect the orientation of the sensor unit during installation.

Within the sensor unit, each sensor has its advantages and disadvantages. Each sensor's disadvantages are mutually complemented by its advantages to improve the accuracy of three-dimensional (3D) orientation estimation. Since the stresses measured by the strain gauges are relative to the



(a) The x, y, and z strain gauges with a nine-axis unit. (b) Cross-sectional diagram.

Figure 2: Sensor unit.



(a) Displacement vs. load. (b) Strain gauge vs. load.

Figure 3:. Sensor unit load experiments.

rock surface, the magnitude and direction of the stresses inside the rock mass are clarified by combining the results of the attitude detection.

The strain gauges are placed according to the 3D coordinate system (X, Y, Z). The relationship between the strain and stress is determined from the load and displacement of the sensor unit (in situ stress). This can be determined by material testing and the values of the strain gauges. In addition, the in situ differential stress is obtained from the strain applied to the sensor unit in the underground mine.

A load response test was conducted, using Marui's manual uniaxial compression testing machine (the rated capacity of the load cell is 20 tf) to apply a load to the sensor unit. The load was varied in increments of 50 kgf, and the load-displacement curve (between elastic deformation), the strain, acceleration, angular velocity, and geomagnetism of the sensor unit were collected as the measurement data. The displacements from different load values and strain in the experiments are shown in **Figure 3**.

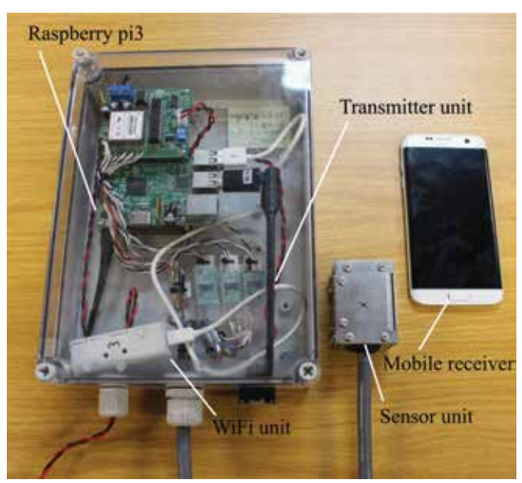


Figure 4: Sensor unit with a WiFi transmitter unit and mobile phone receiver.

The sampling frequency was set to 1 Hz, and the data were transmitted to the receiver via ad hoc communication (WiFi Direct). In the material test, the load was applied up to 5 MPa in terms of stress. By following the steps above, the possibility of the in situ stress measurement in underground mine via WSN is shown. In situ stress and displacement in the underground mine requires attitude and stress detection of the sensor unit. This enables us to identify the direction and the degree of stress in the underground mine. In **Figure 4**, a complete system with integrated the wireless transmitter with the data logger is shown.

RECEIVED SIGNAL STRENGTH INDICATOR MODEL FOR WIFI DIRECT

Tunnels in underground mines typically have rough and irregular wall surfaces. The irregularities of the walls influence the scattering, fading, and delay properties of a 2.4 GHz WiFi signal's propagation. Consider a setup in which a mobile phone is placed at w meters (m) from a datalogger, placed at a reference position w0. The path loss, which follows the normal distribution, is expressed as

Equation 1

$$\mathrm{PL}_{\mathrm{dB}}(w) = \bar{\mathrm{PL}}_{\mathrm{dB}}(w_0) + 10\eta \log_{10}\left(\frac{w}{w_0}\right) + N,$$

in decibels (dB) is used, assuming the antennas used at the transmitter and receiver have unity gain. The average path loss $\bar{P}$LdB(w0) is measured at the reference position w0, η is a constant that describes the path loss exponent, and N is modelled as Gaussian noise samples having a zero mean and a standard deviation σN. From the measured values of PLdB(w), the values of η and N can be approximately obtained using the LS regression method for curve-fitting.

EXPERIMENTAL SETUP

The data collected by the sensor unit is transmitted over a WRH-300WH3-S WiFi module through a Raspberry Pi 3 module. The WRH-300WH3-S unit implements the IEEE 802.11n standard, with a power consumption of 2.4 W. The WiFi receiver is an android operating system mobile device. Measurements are then carried out in a model underground mock mine.

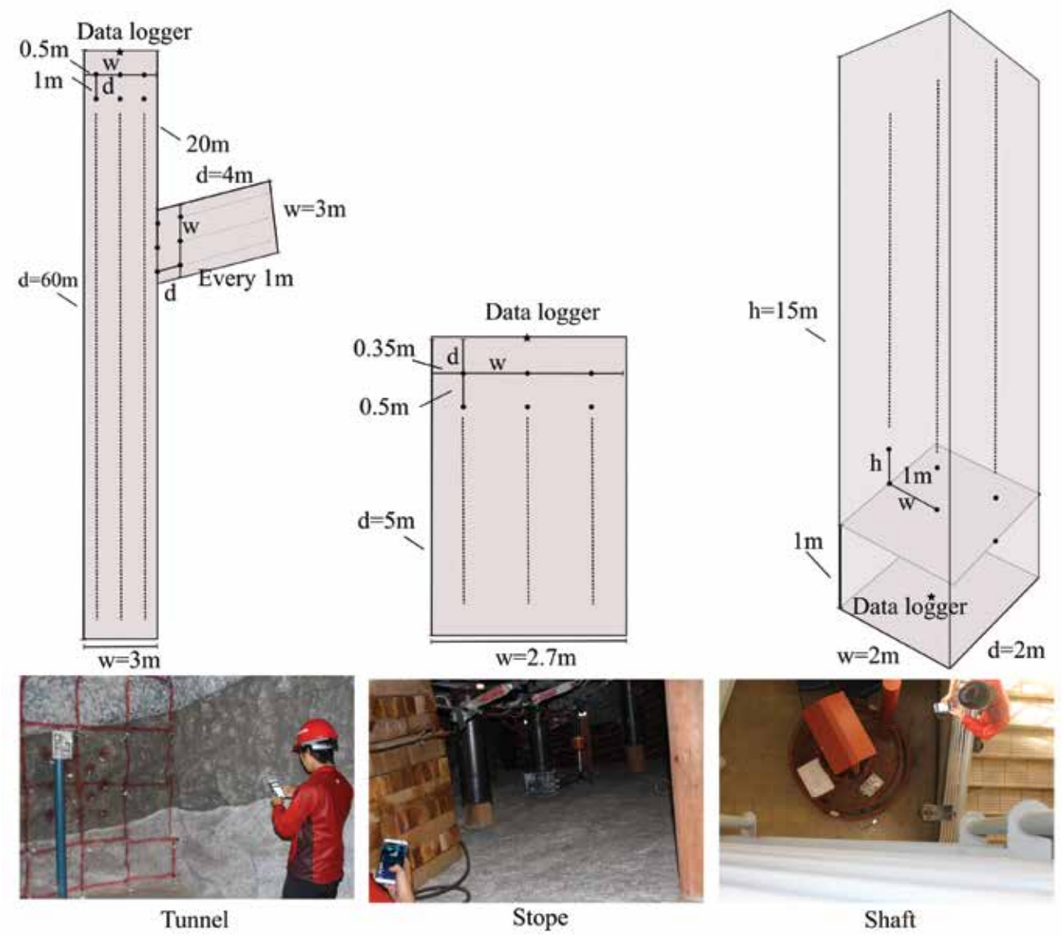


Figure 5: Cross-sectional diagram of the tunnel, stope, and shaft.

The mine contains a part representing a vertical shaft, tunnel, and narrow-reef stope with the corresponding cross-sections shown in **Figure 5**. The dimensions of the measurement areas are defined as (w, b, h), where w is the width, b is the length, and h is the height in meters (m). The position of an object in the measurement areas is described as (x, y, z) in meters, where x is the horizontal position of the object along the width w, y is the horizontal position along the length b, and z is the vertical position of the object along the height h. The dimensions of the tunnel, stope, and shaft are given in **Table 1**.

In the tunnel that has a height of 3 m, the sensor along with the transmitter are mounted on a pole and positioned at three different positions, namely (0.5, 0, 1), (1.5, 0, 1), and (2.5, 0, 1). The RSSI is then measured by centering the mobile receiver at position (1.5, y, 1), where y = 1, 2, 3, ... , 60 m along the tunnel. In the stope, which is 1 m high, the transmitter is positioned at positions (0.35, 0, 0.5), (1.35, 0, 0.5), and (2.35, 0, 0.5), while the transmitter is placed at the floor of the shaft in positions (0, 1, 0), (1, 1, 0), and (2, 1, 0). The receiver is placed at positions (1.35, y, 0.5), y = 0.5, 1.0, 1.5, ... , 5 m and (1, 1, z), z = 1, 2, 3, ... , 15 m, respectively.

Table 1: Dimensions of the experimental environments.

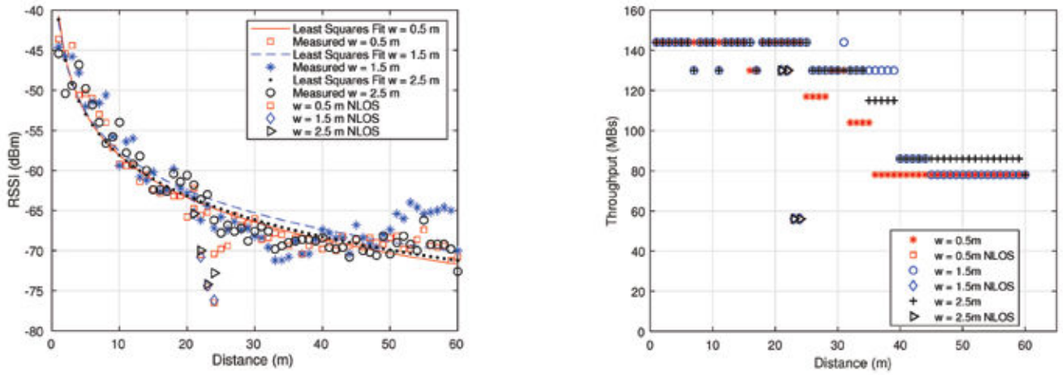
	Tunnel (m)	Stope (m)	Shaft (m)
w	3	2.7	2
b	60	5	2
h	3	1	15

RESULTS AND DISCUSSIONS

Measurements are retrieved in the tunnel, stope and shaft of the mock-up mine testbed in order to evaluate the RSSI and throughput performance in terms of speed of the WiFi signals over distance. The throughput is the ratio between a size (in megabytes) of a transmitted file and the amount of time (in seconds) that it takes the receiver to download the file. Using the measurements and (1), **Table 2** shows the path loss coefficients as well as the corresponding variance σN of N. The path loss coefficients of the tunnel and shaft are lower than the free space path loss of η = 2. However, the path loss coefficient of the stope is higher. The stope is narrower and also attenuates signals faster when compared to the tunnel and shaft, according to the **Figures 6a, 7a** and **8a**.

Table 2: Dimensions of experimental environments.

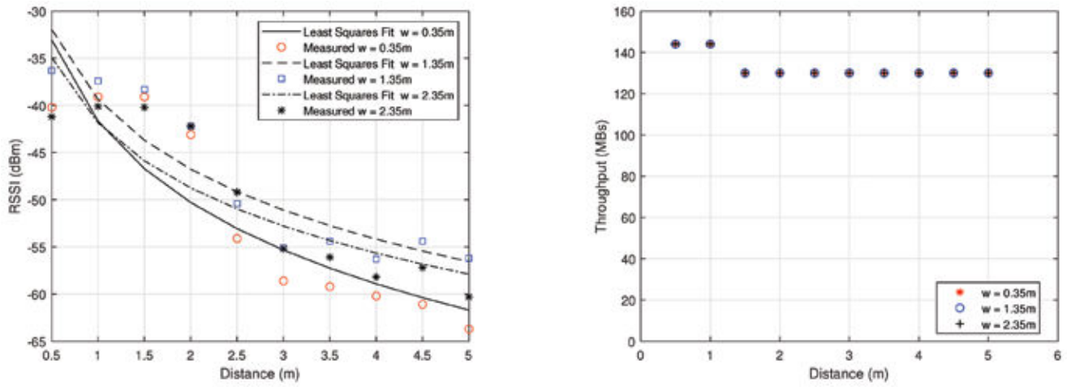
	Path Loss Coefficient (η)			Variance (σN)		
	ω1	ω2	ω3	ω1	ω2	ω3
Tunnel	1.745	1.618	1.692	2.5597	3.9103	2.6163
Stope	2.865	2.461	2.295	7.7357	5.5932	6.7104
Shaft	1.669	1.776	1.463	3.9315	3.4931	4.4972



(a) RSSI vs. distance in the tunnel

(b) Throughput vs. distance in the tunnel

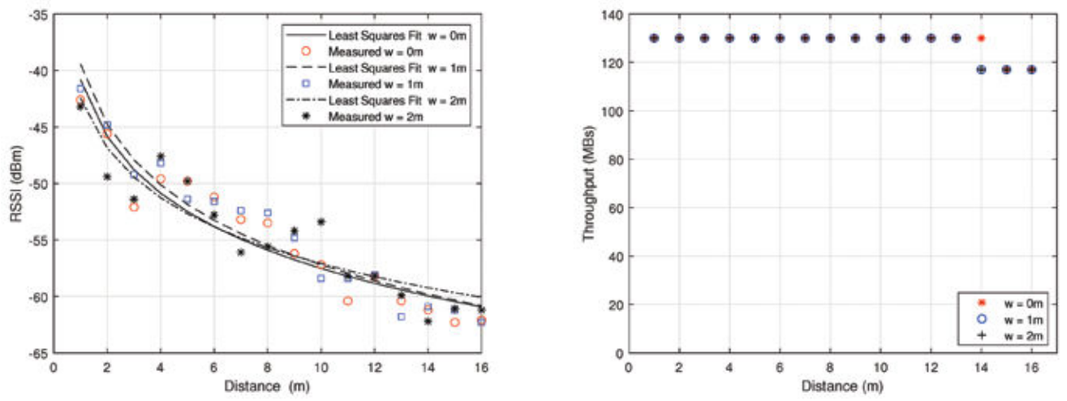
Figure 6: RSSI and throughput obtained at distance points in the tunnel.



(a) RSSI vs. distance in the stope.

(b) Throughput vs. distance in the stope.

Figure 7: RSSI and throughput obtained at distance points in the stope.



(a) RSSI vs. distance in the shaft.

(b) Throughput vs. distance in the shaft.

Figure 8: RSSI and throughput obtained at distance points in the shaft.

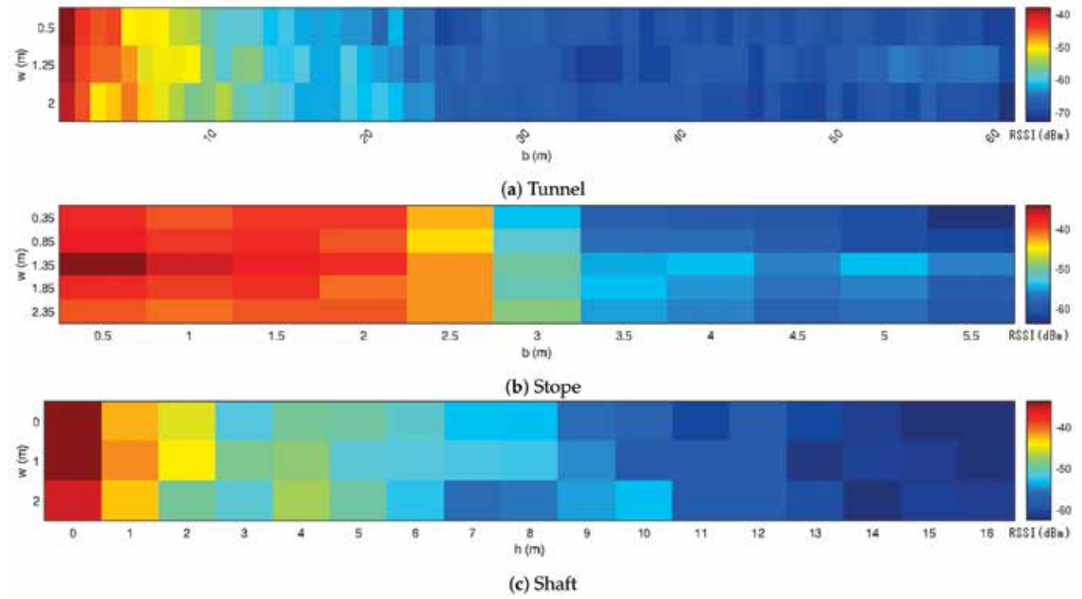


Figure 9: Heat maps visualisation of the RSSI values.

The RSSI over distance is also visualised using heat maps. The colours range from dark blue to dark red, which depicts weak signal strength to strong signal strength, respectively.

It is presumed that there is no other radio-emitting equipment in the measurement areas while measurements were taken.

The graph in **Figure 7a** shows the sharp decrease in the RSSI values in the stope as compared to the RSSI values in the tunnel and shaft. The stope, however, has stronger RSSI values closer to the transmitter, which can be attributed to constructive reflections due to the more confined area. The tunnel and stope showed different RSSI values at the same distance, and the difference can be attributed to the horizontal measurement of signal propagation in the tunnel and vertical measurements in the shaft.

As observed in **Figure 9a,b**, the RSSI values of the transmitter positioned at the edges of the measurement areas show stronger received signal power as the receiver moves away from the transmitter. This is in comparison with the transmitter positioned at the centre of the measurement areas. Furthermore, some regions, such as 54-59 m in the tunnel, show stronger RSSI values compared with the 30-40 m shorter distance. Since the 54-59 m region is closer to the end of the tunnel, which contains steel gates, higher RSSI values in this region may be attributed to multipath reflections in that region.

The heat maps in **Figure 9a-c** show more detailed RSSI distributions across the width of the measurement areas. The transmitter was placed in the centre of the width w of the measurement area, and the RSSI values are obtained along the w axis every 0.5 m in the tunnel, 1 m in the shaft and 0.35 m in the stope. The throughput was measured in terms of bits transmitted per second or bits per second (bps).

In **Figures 6b**, **7b** and **8b**, the throughput drops gradually with distance in most regions, although a sharp drop was observed in some regions in the tunnel. The same throughput of 130 Mbps was observed in all the measurement points in the stope.

Figure 7b showed that high throughput was achievable at lower RSSI values in the stope due to the small area, while the throughput dropped to about half from 63 dBm in the tunnel. Therefore, reliable speed was guaranteed in stope environments to transmit data out of the stope to the next available communication link. Overall, an Mbps communication speed over 60 m was sufficient to communicate important sensor data in real-time. The RSSI values remained above the recommended limit of 80 dBm in all the measurement areas considered.

CONCLUSIONS

In the near future, underground mines will become deeper and more complex in structure. This necessitates the continuous improvement of worker safety and productivity. One area in which improvements can be made is in communication systems, which are crucial for the safe operation of underground mines, preventing potential accidents and losses from occurring.

Reliable communication is also an important pre-requirement for mechanisation and enabler for automation. There is a significant recent body of research on WSN because of its added-value to safety, worker health, improving infrastructure and general efficiency in mining.

In this study, the practical communication of critical sensor data in three underground mining environments was demonstrated and analysed using the RSS. According to the experimental results, a communication speed of Mbps at a distance of 60 m was sufficient for real-time communication of important sensor data. In addition, the recommended RSSI value to maintain was 80 dBm in all

measurement areas. The statistical properties of the path loss associated with the measurement environments were derived. In addition, this communication system does not require a central access point.

Communication is, therefore, possible, not only from the base unit to the mobile terminal but also from the mobile terminal to other mobile terminals. Hence, the signal strength information can influence the placements of the signal repeaters for longer distance transmissions. Furthermore, the communication speed observed from the measurements indicates that high data rate applications can be supported. More than 70 Mbps is possible in LOS environments, while the speed drops to over 50 Mbps in NLOS environments.

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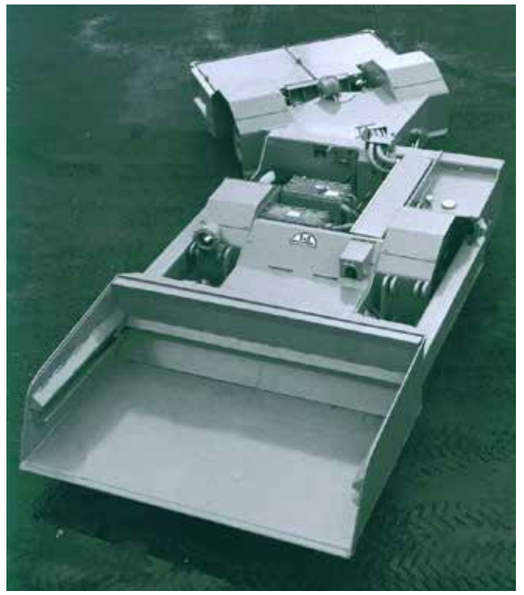
Time to go electric

A Vision for a Sustainable Battery Value Chain in 2030, a report announced recently by the World Economic Forum's Global Battery Alliance highlighted its implications for the mining sector. By 2030, the report found, batteries can bring down emissions by 30% in the transport and power sectors; create 10 million jobs and add $150bn to the global economy and; provide electricity to 600m people.

In order for that potential to be achieved, the metals and mining sector has a prominent role to play, be that through the responsible provision of key materials, the creation of safe and sustainable jobs and measures taken to benefit the environment and eliminate child and forced labour.
Commenting on the publication of the announcement, Benedikt Sobotka, CEO of Eurasian Resources Group and co-chair of the World Economic Forum's Global Battery Alliance, said: "The vast potential of the global battery sector transcends boundaries across economies, industries and geographies. Harnessed appropriately, it may help meet the 2°C goal of Paris Agreement and create millions of safe jobs but also alleviate poverty and tackle ethical issues in the most vulnerable communities. This opportunity should be seized upon but, as this landmark report highlights, it is only through coordinated, collaborative action that we can achieve our collective global sustainability ambitions."

MINING INDUSTRY PLAYING ITS PART

In the wake of the mining downturn, the industry seems to have now recovered to re-affirm its place as a major driver of some of the world's largest economies. The coming years will reinforce this position as hundreds of projects or expansions develop into the next generation of mines. Now global industries demand for fully battery-powered vehicles for underground mining applications is very highly anticipated in the coming years as mining organisations are working towards environmentally friendly and efficient machinery in their workplace. A lot of equipment used in the coal industry lends itself to future innovative battery operations as is being witnessed now in room and pillar operations.



S&S First Battery Powered Scoop.

IN THE PAST

The year was 1968, and USA company S & S Machinery Co. was in its infancy. It was that year that S & S introduced its first battery-powered scoop. The product would change immensely over the next 25 years, but S & S's dominance in battery-powered equipment would not. With as high as 80% of the market share in battery-powered mining equipment, S & S became one of the most successful companies the mining industry has ever seen. With immensely popular battery tractor, scoop, and hauler models, the Simmons name became synonymous with battery-powered equipment throughout the coalfields, and even the world.

Battery powered mining vehicles have continued to evolve, but it is only in recent years that large-scale adoption of the technology is either being considered or has already been adopted. Recent reports would indicate that the market for underground mining machines is still in the beginning stages of a paradigm shift that will ultimately see battery-powered equipment make its diesel competition obsolete. The tipping point where everyone has decided that, in future, they will use battery-driven zero emissions equipment has not yet been reached. Most major mining companies will currently only purchase zero-emission equipment for underground operations, however, as new technology evolves a shift to surface operations also seems imminent.

Battery technology is ideally suited for underground mining and the speed of adoption will be driven by the mines' comfort level with the technology and the OEMs' ability to deliver a solid product that will operate for a full shift [As previously stated battery electric vehicles (BEV) are not some new phenomena and the use in coal mines worldwide were developed back in the 1960s. Room and Pillar operations in the USA, South Africa and Australia in particular have been utilising the use of BEV's for many years. Most projects found that not only were they cleaner, they outperformed the equivalent diesel vehicle both in hill-climbing and top speed capability.

Today the initiative to create battery operated equipment has been driven by new innovative developments in battery technology. This has made it possible to create powerful and productive equipment with zero emissions. The difference being is the latest innovations in battery technology has reached new heights as can be witnessed by the now large-scale production of electric cars worldwide and the ongoing development of Lithium resources with Australia being the current world leader in lithium production. Australia has the Greenbushes, which is the world's largest known single lithium reserve. Companies are also looking at restarting lithium production at Mt. Cattlin in Western Australia. Unlike the second largest producer Chile whose lithium is found in brines below the surface of salt flats, Australia extracts lithium from traditional hard-rock mines and exports a proportion of it to China and other Asian countries. The majority of China's lithium comes from the Chang Tang plain in western Tibet. China has to fully ramp up its lithium extraction as the need for the metal rises. The Atacama salt flat is Chile's most significant source of lithium production. Chilean mines feature the largest confirmed lithium reserves in the world. By some estimates, the country hosts five times more lithium than Australia.

Lithium is abundant; it hasn't been mined in large quantities until lithium-ion batteries grew in demand. Studies in geology prove that there is no alarming shortage of lithium at the level of the Earth's crust. Indeed, almost three quarters of total lithium supply has come from brine (salt lakes) and is now described as white gold by many countries, add new future hardrock mines into the equation and the future for Lithium mines certainly looks rosy.

Overview and location of Greenbushers Operations.

Managing Editor Trevor Barratt takes a look at such developments that continues to show how battery powered equipment is becoming more innovative. A lot of equipment used in the industry lends itself to future battery operations and it seems the sky is the limit. Companies nowadays are developing and offering complete lines of battery-powered scoops, diesel-powered scoops and tractors, multipurpose vehicles, longwall shield haulers, roof bolters, maintenance vehicles and continuous miners and haulage systems. As the future of mining goes, some companies are taking the bull by the horns and integrating new innovations to help mining companies in the most productive, most efficient, and safest way possible. Battery-powered equipment could be just what the doctor ordered.

CAPITAL INVESTMENT

One of the biggest problems with switching from diesel-driven equipment to a new electric fleet is the significant capital investment required. In the typical cyclic nature of the industry an economy dealing with lowered commodity prices places pressure on new purchases. While most mines slow down on their spending, the long-term benefits of investing in a clean, green and modern range of electrically driven underground equipment may outweigh the short-term cash outlay. Directly driven mine machinery (ie. power from an AC feed) has advantages, but there is a serious disadvantage in areas where mobility is required. It is these areas specifically where battery driven, and hybrid units come to the fore.

With the cost of batteries and other storage systems being driven down by other sectors, the cost of converting to BEVs in underground mines is reducing. In addition, the electric vehicle market is developing and producing batteries with increased energy density and of the size and shape suitable for low profile mining traction units. The cost of batteries specifically designed for transport is decreasing rapidly, and charging regimes have been developed which allow rapid recharge of batteries. A further development is the use of hybrid mining propulsion units, which can be adapted to a wide variety of underground operations.

Traditionally, underground mobile equipment in the mining sector has relied on diesel engines which release emissions, and therefore must be ventilated via costly systems. While there are already electric scoops and trucks in underground mines consuming around 80% of diesel fuel underground, some of these units have to be tethered via an electric cable, limiting their limited range and creating other operating challenges.

As major manufactures of underground diesel and electric loaders continue to introduce and indeed showcase their latest innovations at major exhibitions worldwide the emphasis has now definitely shifted to the design of underground loaders, and their battery power capability, being driven by new developments .All the obvious benefits with battery power add up to something that might not be as obvious, like a reduced environmental footprint, higher worker satisfaction, and a better standing in the greener community's mindset. Additionally, as diesel engines are replaced with battery electric solutions, underground mines will produce less heat, noise and exhaust gases, including diesel particulate matter. Thus, the innovative technology will result in decreased mine ventilation needs, which are currently a significant cost factor in deep and complex underground mines.

Of course, when implementing a new technology there is always a lot of questions and concerns from the customers and end users. How safe is a battery machine and will it perform? What's the business case for implementing battery machines instead of diesel machines? The aim within any project is to clarify all these issues and convince the customers that this is the future and the technology is now available now to implement.

Arial photo of Borden Lake.

The newly arrived Scooptram ST14 Battery and Minetruck MT42 Battery at Agnico Eagle's Kittilä mine.

Although some coal mining companies have installed various BEV's at some stage, they are yet to follow in the footsteps of Newmont Goldcorp, which presented its Borden Lake gold project as the world's first all-electric underground mine in northern Ontario, Canada. The company's project is a key part of Goldcorp's plan to increase production by 20 percent by 2021

To help realise its plan of building Canada's first all-electric 'mine of the future', Goldcorp teamed up with technology leaders Sandvik Mining and MacLean Engineering to provide a suite of new innovative technologies that will power all aspects of the mine's operation. These range from battery-powered underground vehicles, drilling and blasting equipment, to electric bolters and personnel carriers.

A 40 metric tonne battery-powered haul truck, which will eliminate all greenhouse gases (GHG) associated with the movement of ore and waste rock, is nearing commercial production. The company predicts that this will translate into a 50% reduction in the estimated GHG emissions associated with these activities (equivalent to 5,000 tonnes of CO_2 per year) in a mine of a similar size.

TAKING ADVANTAGE

Leading equipment manufacturers are certainly taking advantage of the demand for battery electric mining equipment for example less than a year after Swedish company Epiroc's launch of its new generation equipment, the company has won orders for those machines from customers in several countries including Finland, Australia and Canada.

In Finland, Agnico Eagle Mines Limited ordered in the third quarter 2019 the Boltec E Battery rig for use at the Kittilä gold mine. Several orders from other companies have been booked in previous quarters for battery electric versions of the Boltec rock bolting rig, Boomer face drilling rig, Scooptram loader and Minetruck hauler.

In addition, Agnico Eagle Mines is already testing several Epiroc battery-powered machines at Kittilä as part of the Sustainable Intelligent Mining Systems (SIMS) project. SIMS, where Epiroc is serving as coordinator, is part of Horizon 2020, the European Union's most extensive research and innovation program ever. A Boomer E2 Battery has been operating for some months at Kittilä, and in August a Minetruck MT42 Battery and a Scooptram ST14 Battery also arrived at the mine as part of the SIMS project.

"*We see very strong customer interest for our new battery electric mining machines*," said Helena Hedblom, Epiroc's Senior Executive Vice President Mining and Infrastructure. "*The technology is now well established, and more and more mining companies are realizing the significant benefits that come with using electric machines instead of diesel. We are proud to spearhead the mining industry's drive toward a fossil-free future*."

The benefits include improved health and safety, lower total cost of operation and higher productivity. The advantage is especially significant for underground operations where mining companies traditionally must invest heavily in ventilation to air out the diesel fumes.

"*The Boomer E2 Battery has been performing very well and a diesel engine has not been missed*," said Jari Kolehmainen, Production Manager at Agnico Eagle Mines. "*Operator feedback has been positive, and we are looking forward to expand our fleet with more electrically powered equipment in the near future. Therefore, we are also very excited to be testing the battery powered mine truck and loader. These tests are giving us the confidence to be a successful early adopter of this new and exciting technology*."

Epiroc launched its first battery electric machines in 2016. In November 2018, the company unveiled its new generation consisting of 14 and 18-ton loaders, a 42-ton truck and a mid-sized drilling family including face drilling, production drilling and rock reinforcement rigs. Epiroc aims to be able to offer its complete fleet of underground mining equipment as battery electric versions by 2025.

SCIENCE IS GOLDEN – behind the scenes of Dunlop's laboratory

Conveyor belts play a hugely important role throughout the mining and quarry industry. Although many might think that conveyor belts are not much more than thick black rubber bands, in reality nothing could be further from the truth. Industrial conveyor belts are actually complex components and science plays a surprisingly integral role. Here, Dr. Michiel Eijpe, Innovation & Sustainability Director of Netherlands-based Dunlop Conveyor Belting, provides an eye-opening insight into what happens in the company's laboratory and how their work directly influences the performance and quality of the finished product.

CONTROLLING THE QUALITY

The laboratory, situated in our Drachten plant, lies at the very heart of just about everything we do. It consists of two primary functions – one that is responsible for process and product technology and another that is dedicated to research & development and rubber compounding. At Dunlop, our market strategy is entirely based on providing quality and longevity rather than trying to compete at the lower grade, so-called 'economy' end of the market and the laboratory plays a pivotal role in the quality control process. For example, unlike most of our competitors, we make our own rubber rather than using outside sources. The big advantage that gives us is that we are in total control of the whole process.

Every single batch of rubber compound is checked and thoroughly tested in the laboratory. Unless the specific batch of rubber has received the 'seal of approval' from

Every batch of rubber is tested and approved by the laboratory before it can be used.

Dunlop's 'Jack the Ripper' rip test in action.

the lab technicians then under no circumstances can it be released for use. This is key to achieving consistency of quality and performance.

NOT A PAPER EXERCISE

What seems to surprise many people is that despite our obvious focus on quality, as a company we are not currently ISO 9001 accredited. We used to have the accreditation but we do not anymore and there is a very good reason for that. Some years ago, it became clear that we could make much better use of the considerable amount of time and resources needed for re-certification by developing and maintaining a 'custom-made' quality control program of our own. Rather than a paper-based 'tick box' approach, the Dunlop quality program is entirely based on applicable international EN ISO test methods and standards that are specific to conveyor belting and the continuous improvement of our products. In some cases, we use test methods that we believe are more suitable or expand existing test procedures in order to raise the standard. For example, we carry out heat resistance testing according to ISO 4195 at 175°C, which is 25°C higher than the maximum testing temperature for that standard.

Samples of Dunlop belt are routinely tested to the limit.

NO ESCAPE

On the rare occasion that a test method for an important characteristic or property does not exist, we are happy to invent our own. A great example of this is rip resistance. Despite its significance as a key performance indicator, there are currently no internationally accepted test methods or standards for testing rip resistance. However, because a belt's rip resistance is such an important KPI, especially for mines and quarries, we created a test method of our own. What we do is pull sections of belt through a right-angled piece of metal under extreme force and carefully measure and record the level of force exerted. The technicians have nicknamed the specially designed equipment they use for this harsh but very informative treatment 'Jack the Ripper'.

TESTED TO THE LIMITS

Every single square meter of belt passes through a quality control checkpoint and is thoroughly examined and approved before it leaves the production line. However, that is still not the end of the quality control process. Samples of newly manufactured belt are taken at random and subjected to a wide range of tests such as testing the cover rubber for abrasion resistance and for its resistance against the damaging effects of ozone and ultra violet light.

The carcass also undergoes rigid testing of its mechanical properties including longitudinal and transverse tensile strength, tear strength, adhesion, longitudinal and transverse elongation at break and elongation at 10% tensile strength. Sample sections of belt are literally pulled and ripped apart because we believe if you want to make something to perfection then you have to test it to destruction.

MAKING USE OF TEST DATA

All responsible manufacturers, service companies and traders should, as a matter of course, provide a technical datasheet (TDS) for the specific version of the belt that they are proposing to supply because this is where the customer should be able to find much of the selection

Testing competitor's products helps us to keep ahead of the rest.

criteria data. Alongside each part of the criteria on the datasheet should be details of any applicable test methods and international standards. When assessing quality credentials it is essential to differentiate between what is simply an approved *method* of conducting a particular test (the test method standard itself) and the actual quality or performance standards *attained* during that test. In itself, the fact that a belt has been tested in accordance with a certain method actually means very little. What is truly important is the actual level of performance achieved compared against the minimum acceptable level of performance dictated by the test standard. In other words, was the performance standard achieved?

In Dunlop, the data produced by the incessant testing of our own belts is constantly updated and clearly shown on our technical datasheets for most applicable values. Unless specifically stated otherwise, our competitors usually only show generic information such as the applicable test method or the *minimum* standard of achievement demanded by the test. Some may show a few 'actuals' but it is extremely rare. The data therefore does NOT reflect the actual performance achieved during the test or even a level of performance that the buyer might reasonably expect. This even applies to the dimensional measurements and acceptable tolerances such as the actual thickness of the top and bottom covers.

COMPARISON TESTING

Testing samples of belt made by our competitors is also a routine part of the work carried out in the Dunlop lab in Drachten. This kind of testing provides factual, scientific evidence that helps us keep ahead of our competitors. As a company, we need to know the strengths and advantages of our belts and the weaknesses of the competition. It is not enough to simply say that Dunlop belts are better quality and provide lowest lifetime cost because such claims must be supported by factual evidence to have any genuine credibility. Staying ahead of the rest also involves constant research & development. We are always seeking to improve existing products and looking for new innovations. The Dunlop track record for innovation speaks for itself with several breakthroughs including UsFlex, BV GT, Ultra X and Optima Heat Xtreme.

Especially because of the current global problems concerning supply and demand, the Dunlop purchasing team are constantly searching for alternative suppliers. The laboratory team therefore need to thoroughly test, check and approve every potential alternative raw material or component for suitability and compliance before being considered for use. The lab technicians have the ultimate responsibility for making absolutely sure that safety, quality and performance will not be compromised in any way.

SETTING NEW STANDARDS

Different working environments and industries require rubber belts that can withstand the specific demands placed on them. The list is quite long but the most common resistance classifications are abrasive wear, oil, heat and fire with resistance to other factors such as ripping and tearing and ozone & ultra violet light thrown into the equation. A key role of the Dunlop laboratory team is to improve existing products and create new ones that set new, higher standards of performance, especially in terms of safety and longevity. Rubber compounds and belt constructions that can better cope with ripping, tearing and impact are a case in point.

Over the years, our R & D team have developed rubber compounds and new belt constructions that are widely considered as the benchmark for toughness and durability. In fact their efforts in this field are a great example of how levels of performance can be attained that were previously thought impossible. In the case of rip and tear resistance for example, UsFlex was developed some years ago and remains a best-seller for heavy-duty applications. More recently, Ultra X with its unique ground breaking single ply carcass is steadily taking the market by storm. Both belts have a resistance to tearing and ripping that is several times higher than conventional multi-ply belting.

SAFETY – PEOPLE AND THE ENVIRONMENT

The laboratory team are also responsible for ensuring that all of our products are safe for both humans and the environment by complying with EU REACH regulations regarding the use of hazardous chemicals and other safety regulations such as the use of Persistent Organic Pollutants (POPs). REACH was established by members of the EU with the specific aim to improve the protection of

Belts like Dunlop UsFlex and Ultra X have set new standards for durability and longevity.

Complying with EU regulations concerning hazardous chemicals and Persistent Organic Pollutants (POPs) is especially important for maintenance personnel and vulcanizers.

the use of listed chemical substances and staying within specific limits applicable to each substance. However, Article 31 of REACH (requirements for safety datasheets) now demands that if the combined weight of SVHC is more than 0.1% of the gross weight of the finished product then the manufacturer is compelled to both register its use with the European Chemicals Agency and provide their customer with a safety datasheet.

I must confess that accurately calculating the total proportion of weight relating to SVHC for an individual product is quite a painstaking task but there is no doubt in my mind that it is entirely necessary. At Dunlop, we review and calculate the weight of SVHC in all of the materials that we use in each individual product. This includes materials that we buy from outside sources such as resin for example. Thanks to the professionalism and watchfulness of our lab team, we are entirely confident that our belts are the safest anywhere in our industry.

The combined weight of SVHC should not exceed 0.1% of the actual product weight.

human health and the environment through the better and earlier identification of the intrinsic properties of chemical substances.

This is especially important for all those who regularly come into contact with rubber conveyor belts such as maintenance personnel and vulcanizers for example. Sadly, some European manufacturers have chosen to ignore these legal requirements because of the impact on production costs. Manufacturers located outside of EU member states and the UK are not subject to such regulations. As far as I am aware, we at Dunlop were the first to achieve REACH compliance and we have been proud to be the leading advocates within the conveyor belt industry ever since.

REACH regulation regarding SVHC (substances of very high concern) has become increasingly stringent and demanding, particularly since 2018. Previous REACH compliance was largely based on declaring (registering)

CONTINUOUS EVOLUTION

Anything to do with science is a process of continuous evolution and it is for this reason that our laboratory not only lies at the heart of what we do today but also at the very heart of what we will be doing in the future. For us, science really is golden.

ABOUT THE AUTHOR

Dr. Michiel Eijpe is technical director of Dunlop Conveyor Belting in the Netherlands. A former university lecturer, he has worked in the conveyor belt industry for over 25 years. He has a Phd in fibre reinforced polymer composites and is a leading light in the development of high-performance conveyor belting and conveyor belt manufacturing technology.

First ever battery-electric surface drill rig field tested in Swedish quarry

Johan Eliasson, Project Manager Skanska Industrial Solutions AB and Peter Beckman, Business Line Manager Epiroc Sweden in front of the SmartROC T35 E.

Epiroc has entered an agreement with Skanska Industrial Solutions AB to trial the first ever tophammer battery-electric rig in Sweden. This trial marks a significant milestone in the journey towards zero emissions drilling in surface mines and quarries all over the world.

"*This is a proud day. For many years we have been leading the development in lowering fuel consumption within tophammer drilling. With this new solution we are taking a giant leap in the low emissions field – we are practically removing emissions from the actual drilling process*," says Ulf Gyllander, Product Manager tophammer drill rigs, Epiroc Surface division.

The design of the rig is based on the well-proven SmartROC T35 surface drill rig. In combination with invaluable experience gained from the development of Epiroc underground battery rigs, this SmartROC T35 E is designed to enhance the environmental standards of quarries and larger construction sites. Besides the low emissions, this rig comes with a range of smart features, options and enhanced automation solutions for high safety, reliability, and performance.

"*With this achievement we show that the innovations of Epiroc will play a significant role in the shift to low-carbon operations within quarries and large construction applications*," says Jose M. Sanchez, President Epiroc Surface division. "As our sustainability agenda goes hand in hand with those of our customers, we are very pleased to be collaborating with Skanska Industrial Solutions AB in the trials of this important solution."

The tests will commence in September 2022 in one of Skanska Industrial Solution's quarries in the Stockholm area:

Ulf Gyllander, Product Manager tophammer drill rigs, Epiroc Surface division.

"*A milestone has been reached and a new opportunity has come to reduce our climate impact. I am very happy about the long collaboration between Epiroc and Skanska, and it is exciting to be able to do this project together. Both companies have set bold environmental goals – this project really takes a great step towards Skanska´s goal of being completely climate neutral by 2045, which is an important part of our promise to build a better society*", says Johan Eliasson, Project Manager, Skanska Industrial Solutions AB.

Jose M. Sanchez, President Epiroc Surface division.

Peter Beckman, Business Line Manager, Epiroc Customer Center Sweden comments: *"Skanska is a perfect partner for this trial as they have their own quarries which are fitted with the infrastructure required to handle the operation of this new technology. I am looking forward to following this exciting project during the coming months."*

The SmartROC T35 E rig is equipped with both a battery and an electric cable, which improves flexibility considerably. You can choose to drill with the most suitable alternative for the location and occasion. It also allows for quick and smooth transportation in and between sites.

The surface drill rig is fitted with the same type of well-proven batteries and subcomponents as in the Epiroc underground battery solutions. This streamlines spare parts handling and service for customers with several different operations.

ERC® goes Australia – put it to the test Down Under

One of the most valuable assets of a major Australian gold producer is an underground block caving mine in New South Wales. This customer has been operating thyssenkrupp jaw gyratory crushers for over a decade and currently has four of these crushers in operation. Over the years, the jaw gyratory crushers have undergone a continuous improvement process that has resulted in higher throughput, lower power consumption, and longer wear part life. Apart from the excellent operational record of the jaw gyratory crusher technology, the client was interested in using the new developed thyssenkrupp ERC® (Eccentric Roll Crusher) in an industrial test plant to prove its potential for their further expansion projects.

The ERC® 25-25 Industrial Test Plant in New South Wales (Australia).

Potentially better performance in terms of product fineness and throughput were identified as key value drivers. In addition, the significantly smaller footprint and installation height of the ERC® could possibly lead to an installation in a smaller excavation closer to the underground ore body.

Consequently, the purpose of the on-site trial was to evaluate the operational performance of the machine against the above value drivers.

The test facility consisted of a stationary crushing plant with feed hopper, apron feeder, ERC® 25-25, discharge/ stockpile conveyor, electric equipment and auxiliaries. The plant was fed by means of heavy duty front loaders.

The trial was conducted in 4 phases over a six-month period of operation in 2021:

- ***Pre-trial*** with various feed material particle size distributions (PSD) (fine, intermediate, coarse) but constant large crusher gap and low eccentric shaft speed
- ***Main trial*** with various settings – feed material PSD's (fine, medium, coarse), various Closed Side Settings (CSS) and various eccentric shaft speeds.
- ***Continuous operation trial*** with ROM and selected machine settings

thyssenkrupp ERC® 25-25

Crusher type	Primary Crusher
Dimensions (height x width x length)	approx.3,950 x 4,450 x 6,175 mm
Weight	approx 185 t
Feed opening (width x height)	2,500 x 1,280 mm
Max material size	approx. 2,000 x 1,500 x 1,000 mm
Throughput	1,500-3,500 t/h

FEED MATERIAL

The test plant was assembled close to a surface stockpile with material characteristics similar to the underground operation. In order to evaluate the particle size distribution (PSD), parts of the pile where separated by loaders into smaller piles of 20-50 tonnes and analysed by a photo-optical particle size analyser. Based on the findings, three different feed curves where blended with the aim to replicate PSD's of the benchmark underground block cave operation.

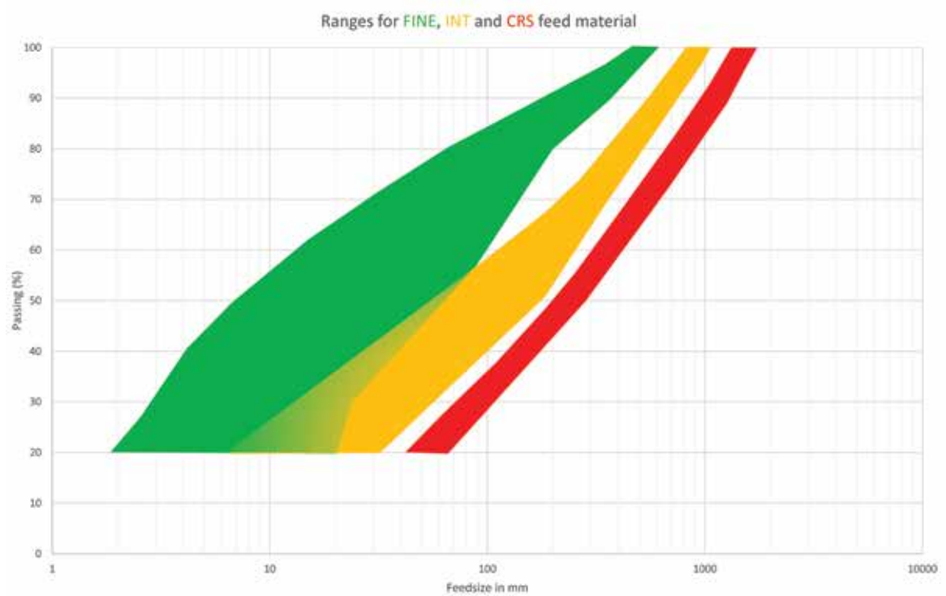
Further noticeable feed material characteristics are:

- Ore type: Gold/ Copper ore
- Bulk density: 1.7-1.9 mt/m³
- Moisture content: 2-6 %
- UCS: Range between 75-250 MPa and design of approx. 150 MPa
- Brazilian tensile strength (BTS): 10-18 MPa
- CERCHAR Abrasion avg. 5.1

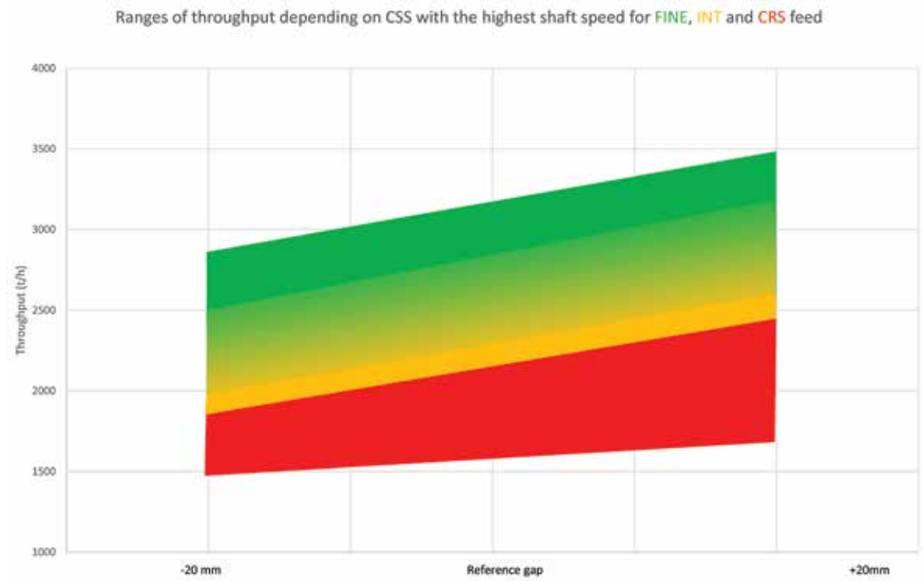
THROUGHPUT

Previous trials with the ERC® 25-25 have shown that the crusher is capable of a throughput performance of more than 3,000 t/h. In contrast to the test in Australia, the feed material was found to be less hard (average UCS 100-120 MPa) and for primary crushers more common settings of 110 mm – 160 mm CSS were in focus.

Normal trends for crushers i.e. that the throughput is dropping with smaller CSS have been seen during the tests in a reasonable consistent manner. The tests showed the ability of the ERC® to capture and crush effectively large rocks of up to approx. 2 m³ volume. What stands out is that throughput increases with increasing eccentric speed. The tests revealed that an eccentric speed at the upper end of the design range offers the highest throughput with a delta



Feed material particle size distribution, early stage = CRS, mid stage = INT, late stage = FINE.



Crusher throughput depending on CSS @ the highest tested eccentric shaft speed, early stage = CRS, mid stage = INT, late stage = FINE.

in capacity of up to 20 – 30% compared with lower speeds. The effect was most evident with the coarser early stage feed and not so obvious with finer mid stage feed.

During the tests two grizzly configurations have been used, initially with a cut size of approx. 150 mm, and later, with the aim of a better product size control, with a cut size of approx. 90 mm. The smaller cut size not only resulted in the desired smaller product size, but unfortunately also in a significantly poorer screening efficiency. The open area dropped from 43% to as low as 24%. This is because the smaller cut size has been applied on the existing assembly and consequently resulted in a significant lower open area. This would not be the case if a specific screen design would be applied for such cut size. In association with a higher amount of coarse particles and wet feed this results in a more choke feed-like condition with an overload on the grizzly and increased carry-over into the crushing chamber. As a consequence, throughput varied more significantly with a smaller cut size.

From a practical standpoint, the trial highlighted an enormous potential for improvement on the integrated grizzly. Bypassing the crushing chamber with a higher amount of undersize fraction via a more efficient grizzly will have an impact on throughput, possible closed side settings and wear rate of the crushing members.

As general finding, the test results obtained regarding throughput of the trial were subject to relatively high variability, which can be attributed primarily to difficulties in preparing a homogenized feed material for each test.

POWER CONSUMPTION:

The key operational factors have been found with the filling level of the crushing chamber and the eccentric shaft speed. Controlled feed and lower shaft speeds results in lower values than choke feed conditions.

The ERC® 25-25 has been operated with an installed power of 630 kW for the crusher drive motor. The actual power consumption found during the trial campaign ranges between 150 kW and 400 kW. Throughout all feed material PSD's and gap settings the lower and medium speeds results in 150 – 300 kW, whereas eccentric speeds at the upper end of the design range pushes the power draw to 300 – 400 kW.

Power consumptions of more than 600 kW for a longer period of time (>30 sec) have only been seen when the crusher chamber was overloaded.

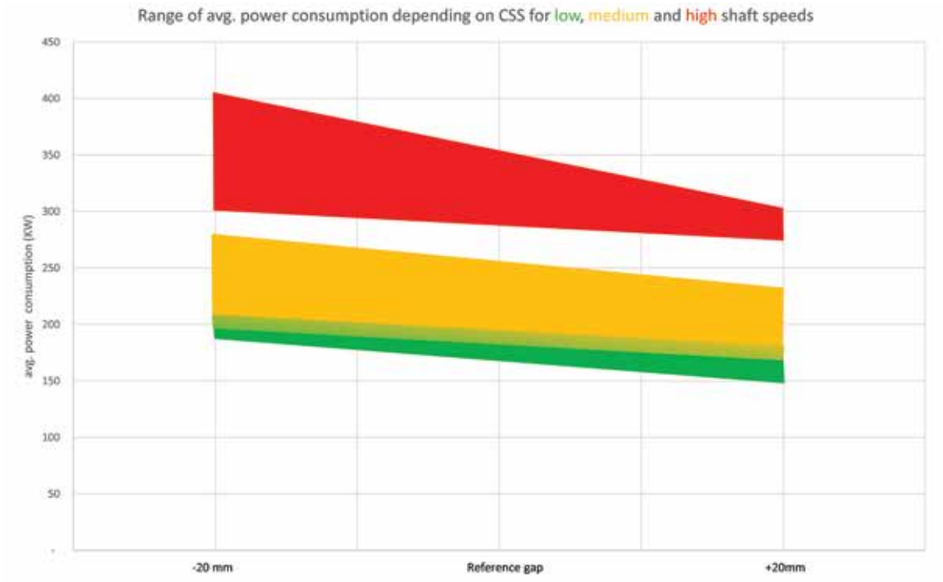
The findings allow the conclusion that under the condition of a controlled feed into the crusher the installed power rating for applications similar to those tested during the trial can be reduced to 450 kW.

With respect to the specific power draw, the test work program has shown that with the ERC® advantage can be gained from higher energy efficiency. The operation data record of the existing thyssenkrupp jaw gyratory crushers type BK 63-75 in Australia shows in comparable ore bodies a specific power draw of approx. 0,3 kWh/t, whereas the ERC® 25-25 has shown an average value of approx.0,15 kWh/t throughout the test.

PRODUCT SIZE

The product size distribution from the ERC® was similar to the values experienced from the jaw gyratory crusher operation at benchmark operation, throughout all cases.

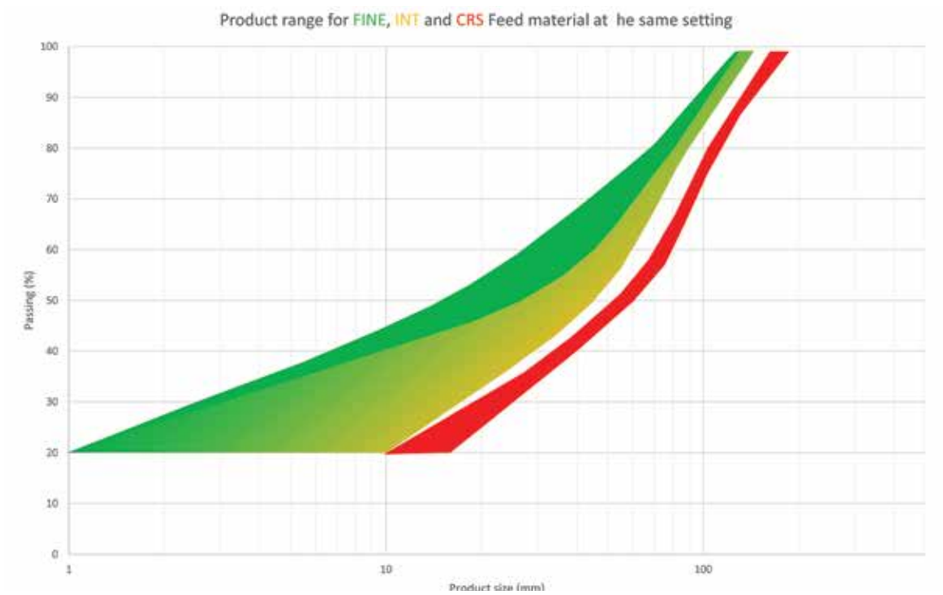
As indicated earlier, the trial has shown a significant benefit of higher eccentric speeds with regards to throughput. A similar positive effect was found in respect to the product size, which decreases noticeably with the speed at the upper end of the design range and was certainly a factor to achieve the benchmark values for product size in the various stages of the block caving operation.



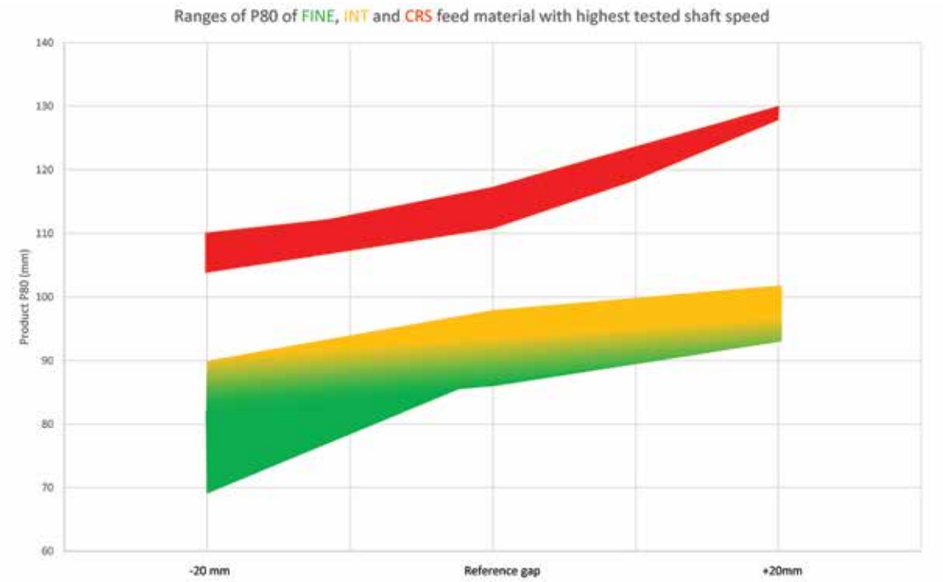
Power consumption depending on CSS @ low, medium and high eccentric shaft speed.

From the feed material characteristics point of view, the particle size distributions for mid stage and late stage were somewhat coarser than it would be expected for the benchmark operation in the Australian underground mine. As mentioned earlier in the throughput discussion, two grizzly configurations have been used during the trial. The tests with coarse feed material were conducted using the grizzly with the 150 mm cut size, whereas the finer feed was presented to the 90 mm cut size grizzly with a much lower open area of approx. 24%. Grizzly efficiency became than a greater issue with overload and carry over effects. In effect, the limiting feature for product size varies with the feed.

Further, it should be noted that the assessment was undertaken without the option to adjust certain machine parameters, which are considered to have an impact on the product size. On the one hand there is the enormous stroke of the machine, which in case of the ERC® 25-25 being used during the trial is close to double of that value applicable for the jaw gyratory crusher. On the other hand, the roll liner geometry was shaped to match requirements of an average primary crushing application. In effect, coarse particles could pass to an extent which certainly causes an impact on the product particle size distributions.



Crusher product size distribution depending on feed material characteristic @ same setting, early stage = CRS, mid stage = INT, late stage = FINE.



Crusher product size distribution P80 depending on CSS @ the highest tested eccentric shaft speed, early stage = CRS, mid stage = INT, late stage = FINE.

As a conclusion on this topic it goes without saying that both the actual grizzly configuration (i.e. cut size, length), the selected machine parameters (i.e. stroke) and liner set up are considered as performance drivers for future applications.

WEAR LINER LIFETIME

Primary crushing performance tests are challenging because of the need to obtain a homogenous feed material mix throughout the limited timeframe of the test campaign. This in particular applies to the performance trials to gain robust results on the liner wear rate where in addition a sufficient tonnage is a must.

In case of the trials it should be noted that the wear life assessment was undertaken based on laser scanning measurements of the crushing members conducted before and after the test campaign with a total tonnage of 200 kt throughout all cases, machine settings and feed PSD's.

The roll liner wear rate matches the benchmark values taken form the matured jaw gyratory crusher installations. As well the scans had shown that the wear was uniform over the whole girth of the roll so that much potential for improvements in comparison to the jaw gyratory crushers can be expected.

The rate for the lower jaw liner has been identified with a question mark, with the given set up, crusher settings and liner design being used during the trials and the restriction that the assessment was undertaken during a rather short consecutive trial period and the total tonnage processed was limited.

Abrasion values obtained from testing of the stockpile material being used for the crusher feed suggest that it is more abrasive than the underground mine material.

Potential improvements both with respect to design modifications to major components (e.g. longer, more inclined grizzly with higher screen efficiency) and liner execution (e.g. shape, thickness, material composition with high alloys) have been identified and made a decisive contribution to the development of the next generation, the ERC® Pro. Initial evaluation on the topic has shown that with those considerations life time can match the jaw gyratory crusher performance but with potential lower maintenance efforts and less downtime.

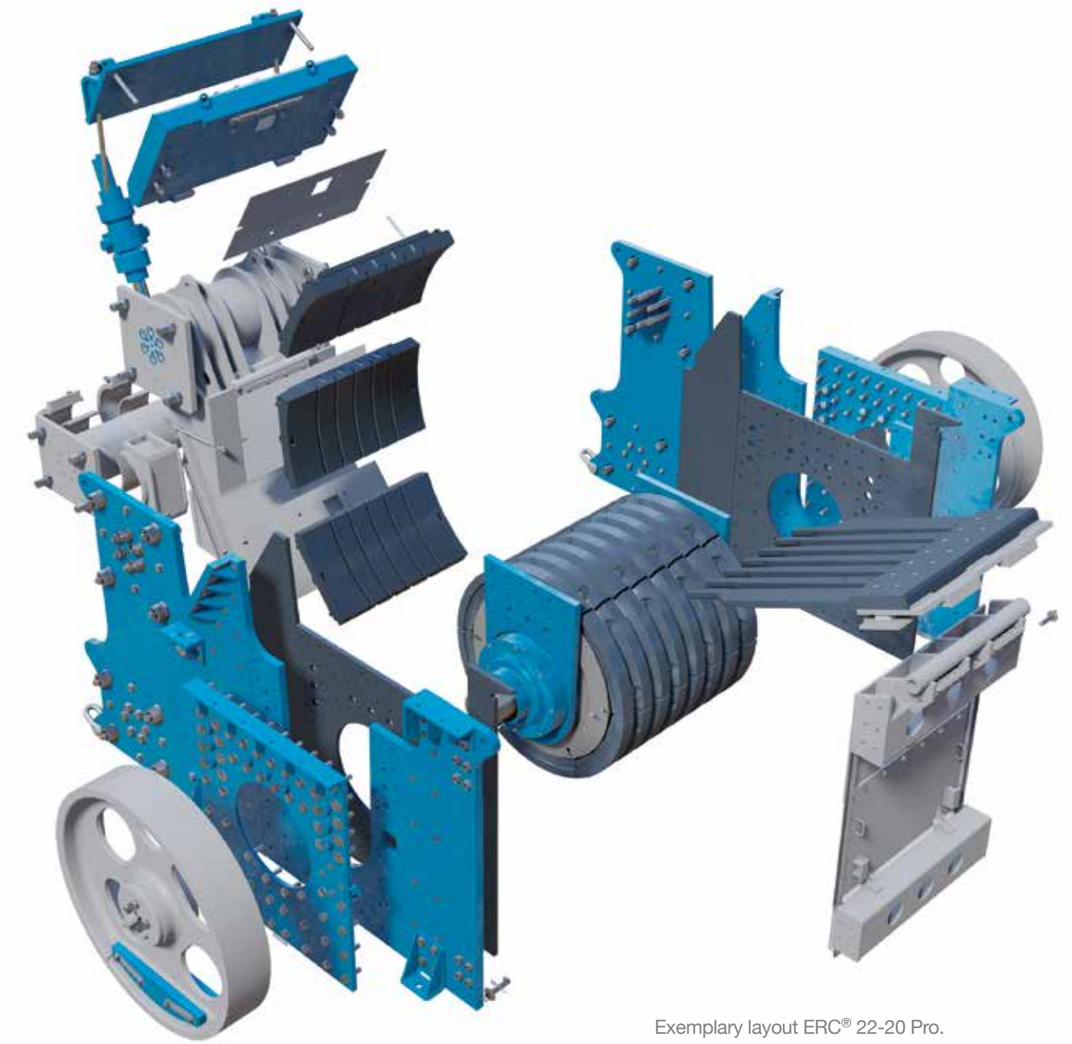
CONCLUSION

Throughput and performance figures match those of the jaw gyratory crusher. Within the range of various machine settings, the test work proved that the benchmark values of 1,500 – 3,000 t/h throughput were achieved in all cases except one set of test conditions with mid stage feed.

The data from the trial indicated that the highest tested eccentric speed at the upper end of the design range can be considered as "sweet spot" for the ERC® at the industrial test plant resulting in the highest throughput, finest product and low loads.

Liner wear rate performance, in particular of the lower jaw liner, has been identified with a question mark, however, keeping in mind that the assessment was undertaken during a rather short consecutive trial period and the total tonnage processed was limited.

The processing performance shown during the trials leaves the conclusion that the ERC® is not only on par with the matured jaw gyratory crusher, with the benefit of a



Exemplary layout ERC® 22-20 Pro.

smaller footprint, but certainly opens up great potential for further improvements.

NEXT GENERATION: ERC® PRO:

The ERC® 25-25 being used for the trial at the Industrial Test Plant is the very first machine of its kind ever built and represents the initial crusher design. Starting from operational experiences with successor machines like an ERC® 18-14 the crusher has been further developed to the current model ERC® Pro. Value drivers identified by thyssenkrupp have been the further increase in throughput, improvement of crusher product quality and extension of lifetime of crushing members and liners.

Simplicity and safety of erection and maintenance were also in focus.

Major modifications at a glance:

1. A longer grizzly with larger open area provides a significantly higher screen efficiency for more capacity and lower wear rate on liners. The rotatable arrangement ensures better accessibility for maintenance.
2. Bearing assembly of the roll is mounted to the housing by means of a modified arrangement which provides more robustness and allows for easier and safer replacement of the roll assembly. With the modified design a base frame is no longer necessary.
3. The modified pivot point of the jaw in combination with a steeper chamber layout pushes crusher capacity, improves reception of crushing forces, reduces bearing loads and increases component lifetime.
4. The newly designed housing made of clean flat steel plates and 100% bolted connections results in more resistance to crushing forces, reduces manufacturing efforts and shortens the erection schedule.
5. New designed liners of jaw and roll with less aggressive shape and more consumable wear material increase up to 2 ½ times more lifetime.

The new ERC® Pro goes down well with potential customers and a number of crushers have been sold meanwhile to Mining Clients for their operations in iron ore, copper and diamonds.

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