John Chadwick looks at new battery powered trackless machines going into the production environment and trials of others

Cutting the cord

Battery Electric Vehicles (BEVs) are exciting the world at the moment and that includes those in the underground mining environment. They are also exciting the exploration sector as companies look to develop new lithium mining operations and those for other high-tech minerals required by EVs. And of course the copper market has benefitted greatly with sustained high prices over recent months.

Canadian mines and OEMs are at the forefront of much of the work in battery use underground. RDH Mining Equipment, as a pioneer in battery electric mining equipment technology, is now working with strategic partners in Latin America to assist mines there in transitioning to battery power. Having been in use underground since 2011, RDH's battery electric powertrain technology has been extensively tested in the field. As a company focused on innovation, RDH continues to expand its battery electric line and offers all of its available equipment models with a battery electric powertrain option. RDH claims to be "the OEM that first successfully brought battery power to hard rock mining."

In Chile, RDH has partnered with Royal America, an industry expert in Industrial Electric/Battery solutions. After 30 years in operation, Royal America has become the largest supplier of electric machinery in Chile, and, says RDH, stands out for its quality service and experience.

Sierra Metals, committed to being a leading corporate citizen in Peru, has taken the first step in transitioning to battery equipment with a RDH battery powered LHD at its Yauricocha mine. As the first mining company in Latin America to make the transition to battery powered mining equipment, Sierra Metals, with a focus on continuous improvement, could not ignore the health, environmental, operational and cost benefits of battery technology over its diesel and electric cable counterparts. After looking at the various battery electric equipment options available on the market, Sierra Metals decided to partner with RDH. Many mines are hesitant to take the leap to battery electric equipment, but Sierra Metals, like many other operators, felt reassured knowing RDH has over seven years of underground experience with battery electric powertrain technology and has been in the underground mining equipment industry for over 30 years.

Elcora Advanced Materials Corp is one of the new breed of exploration and mine development companies very focussed on materials for EVs. Elcora was founded in 2011 and has been structured to become a vertically integrated graphite and graphene company. Elcora mines, processes, and refines graphite. That graphite is converted to graphene or graphite powder for Li-ion batteries. As part of the vertical integration strategy, Elcora has secured high-grade graphite from its interest in the operation of the Ragedara mine in Sri Lanka, which is already in production. Elcora says it "has the tools and resources for graphite and graphene vertical integration." Most recently it has announced the development of graphene infused Lithium-ion batteries for fast charge applications.

Graphene among other applications has exceptionally high electrical and thermal conductivity. Currently li-ion battery technology is restricted by recharging time which Elcora plans on addressing through the application of graphene properties. Given these characteristics graphene could significantly improve the performance of lithium-ion battery technology and result in a major impact in the future of Li-ion applications.

Pictured here working underground, the Muckmaster 3TEB, RDH's 1.15 m³ (1.5 yd³) capacity LHD, designed for narrow vein mining and ideal for operations trying to minimize ventilation costs. RDH now offers battery electric powertrain on its complete line of equipment

Elcora is uniquely positioned to develop graphene infused Li-ion batteries for several reasons. It produces high quality graphene in its advanced graphite processing facility on-demand and it also produces high purity Lithium-ion anode battery powder from the same facility. It has its own in-house Lithium-Ion R&D Battery Lab

Elcora supplies the feed-stock for both graphene and anode powder fabrication processes and has expertise in graphene and Lithium-ion battery technology and is presently working with strategic partners in development of applications.

Elcora may improve Lithium-ion battery performance by optimising thermal and electrical conductivity of the electrodes. Battery electrodes use carbon black as a conductivity promoter. The carbon black used in traditional electrodes may be replaced/supplemented with graphene produced using Elcora's environmentally friendly processing techniques. The highly conductive graphene should influence charge transfer kinetics, allowing for faster charging times compared to conventional electrode formulations.

Unlike carbon black, high-quality graphene

has a relatively short shelf life (weeks if not days) and requires understanding of proper dispersion techniques. Elcora can produce its own graphene that can be used in electrode formulation experiments immediately after fabrication. This synergy ensures that the graphene is of the highest quality before being infused into the battery electrode.

Elcora's goal is to develop proprietary battery technology that can store more capacity and deliver more power at lower cost.

New large truck

Artisan Vehicles now offers the Z40 haul truck. "Our new 40 t truck, the largest all battery powered truck ever to be put underground, will make its debut in January of 2018. Now mines that struggle with heat and ventilation have a new and more powerful tool to increase their production."

The Z40 haul truck is a ground up design that seamlessly integrates what Artisan describes as "the most capable and proven battery electric powertrain available in the mining industry with the latest and most coveted features of any haul truck on the market today.

"The Z40 raises the bar of what is possible and enables an all new level of production and cost reduction for underground hard rock mine companies.

"We have discovered a powerful combination," said Mike Kasaba, Artisan's CEO, "Using the very best techniques for machine design and our many years of experience with battery powertrains has led us to create a new class of machine. A class that directly impacts and improves underground production. Our truck's capabilities, performance, and benefits on ventilation and cooling are changing the hauling equation in the most positive way in a generation."

Kirkland Lake Gold, a fast growing and innovative leader in the mining industry will be the first customer for the Z40. "KLG continues to challenge conventional thinking and perceived limitations on production and cost reduction and their bets are paying off.

"We believe in battery technology and in Artisan as our technology partner. Their machines are powerful and reliable and have helped us achieve our production targets at Macassa." said Tony Makuch, CEO of Kirkland Lake Gold.

Kirkland Lake already has an Artisan LHD, which was delivered to its Taylor mine in late 2017, the company's first battery powered underground loader. The A4 (4 t) LHD is the first underground battery loader in the Timmins underground mining camp. "We are extremely proud to be a part of Kirkland Lake Gold's future," said the statement.

Artisan A4 LHD delivered to Kirkland Lake Gold's new Taylor mine

The Taylor mine is the company's newest gold mine with significant exploration potential. It is a high-grade cornerstone asset for the Company. The mine is located approximately 70 km west of the Holt Mill and ore is trucked daily for processing and refining.

More truck experience

MacLean Engineering is another company that has done a lot of work on underground battery haulage and has now completed some 200 km of ramp run trials on its battery electric BT3 Boom Truck, the purpose of which was to address the question of range anxiety on high-tramming units in underground mines, "one that we hear routinely from mining companies and engineering consulting firms around the globe. These ramp trials are allowing us to validate performance modelling assumptions with actual performance data from the real world and real conditions of an underground mine," MacLean reports

"An EV material haulage unit like a boom truck needs to be able to carry as much as 16,000 kg of cargo up 15% and higher grades across rough road beds, so the question of how long /how far it will last underground is always going to be one of the first asked by potential customers evaluating the total cost of ownership for EV fleets.

"We've learned two key things from our ramp run trials to date: 1) you need to engineer the mining cycle, not just the battery cycle; and, 2) the user experience of battery electric vehicle technology remains as important as the technology itself – UX meets BEV.

"Connecting the battery cycle with the mining cycle rests on planning for opportunity charging – taking advantage of the duty cycle flexibility that onboard charging provides to plug into the mine's existing electrical grid during loading or unloading or at lunch break.

"With this type of planned, quick top-up (for example 20 minutes of recharging on every

Maclean-BT3- battery boom-truck

second run during the duty cycle), you can maintain enough state of charge to achieve continuous EV mobile fleet operation across a full shift.

"The grade of the ramp, the weight of the load, and the condition of the roadbed all impact the opportunity charging requirements of a BEV material haulage duty cycle, but not to the extent that opportunity charging, well thought out, can't respond to. And in this case, range anxiety essentially disappears."

The same issue of user experience holds true for harnessing the full potential of regenerative braking on battery electric underground mining vehicles. "What we have learned from our trials is that the feel of brake holdback going down-ramp is new for operators, so the full potential of down-ramp re-generative braking, especially with a full load (up to 35% of the up-ramp energy use restored), isn't always maximised. The other learning is that the condition of the roadbed is an important factor in maximising regenerative capability. So the grader will be an integral part of underground mines' EV fleets.

"Operators in the diesel engine context can fill up their diesel tanks at the beginning of a shift and not think about it again. In a battery electric mine it comes down to the renewed importance of good training – switching out diesel fuel for battery electricity on mobile equipment is as much of a user experience exercise as it is an engineering exercise."

MacLean is supplying a fleet of battery powered mobile underground mining equipment to begin development and eventual production at Goldcorp's Borden project. Borden, near Chapleau, Ontario, is expected to be the world's first 100% diesel-free hard rock mine to proceed to development, with portal and ramp construction begun in early 2017. Mine development is expected in Q4 2018 with extraction of a 30,000 t bulk sample planned for that quarter. Commercial production is expected in 2019.

MacLean has been innovating for mobile equipment safety and productivity in the underground hard rock environment since 1973 and battery power, engineered for life underground, is the latest chapter in the company's mining R&D focus. The MacLean EV Series (electric vehicle) battery propulsion system leverages high power, high efficiency, and long cycle life battery chemistry, sophisticated battery management and vehicle monitoring capabilities, as well as onboard charging that ensures compatibility with existing mine infrastructure.

MacLean's Fleet Electrification program was initiated in 2015 and is now able to offer customers a battery tramming/battery operating option on all units across the company's ground support product line (bolters, shotcrete sprayers, and transmixers), ore flow product line (water cannons, secondary reduction drills, and mobile rockbreakers), and utility vehicle product line (boom trucks, scissor lifts, ANFO/emulsion loaders, cassette carriers, personnel carriers, water sprayers, and fuel/lube trucks). Of note, the engineered integration of the various battery power and drive train components that make up the MacLean EV Series propulsion system was supported by a research and development collaboration with the specialised engineering firm MEDATech.

CMTI Group is Sibanye Stillwater's technology partner, supporting the miner's mechanisation drive. Notably, the company's technologies have already played an important part in helping a leading platinum miner reduce safety-related stoppages at its Rustenburg operations (South Africa) in the 2017 financial year. Similar successes have been achieved at Bathopele platinum mine near Rustenburg, while CMTI Group's MT100 (shown here) and MT 1000 ULP equipment has been operating in Burnstone gold mine in Balfour, Mpumalanga.

Sibanye Gold is using the equipment to mine panels at heights of 1 m, as opposed to the current 1,5 m. By now being able to extract significantly more gold-bearing ore and reduce waste-rock extraction, the mine will increase its yields and reduce its waste-disposal costs. Certainly, this is in line with Sibanye Gold's recent announcement that it is researching technology to make its mining operations safer and more productive. The process is being driven by mining operational executive and mining engineer, Peter Turner, who has also highlighted the important contribution of remote-controlled ULP technologies.

CMTI Group's MT100 has a maximum height of 420 mm and a battery life of seven hours. This versatile machine can be equipped with any two attachments, such as a sweeper, scraper and dozer with an 850 kg dozing capacity. This allows the re-mining of inaccessible areas that still contain some reserves in the form of fines

"Goldcorp is a longstanding customer and so a fitting inaugural home for our battery power fleet. What's more, this is a world-class project that is setting the bar in the mining industry: improving the working conditions of miners, making the extraction of certain ore bodies economically viable, and driving technology investment by OEMs like MacLean," noted President Kevin MacLean. "It's a win/win for everyone involved, so on behalf of the team at MacLean Engineering I want to salute Goldcorp for their initiative, and thank them for their continued faith in the innovation, safety, and underground performance focus at the heart of our engineering and manufacturing efforts."

"I came up from working underground in Sudbury, Ontario in the early 1960s just as battery powered units on rail were being replaced by diesel engine, rubber tyre mobile fleets, so the arc of my mining career over the past 50+ years has come full circle," added Founder and Chairman Don MacLean. "The next generation of battery propulsion technology, provided it is engineered to perform in the hard rock mining environment, opens up a whole new range of possibilities for mining companies looking for diesel-free options to reduce ventilation and surface infrastructure costs, and protect workers' health."

Hatch's Michel Carreau notes that "after decades of development and refinement, these technology shifts are coming on strong and fast. The examples of success we see are fuelling optimism for more. Goldcorp's Borden Lake operation near Chapleau, Ontario, is Canada's first totally electric underground mine. It is confirming that smaller-sized, electrically powered equipment can be perfectly serviceable in smaller operations. The lithium batteries they use are not yet ready for big sites with larger trucks and high-volume mining equipment. But it's only a matter of time."

Battery miniLoader

Aramine stresses that one of the biggest issues driving electric power in underground mining is the air pollution affecting people's health. To solve this issue, the French company made the first diesel miniLoader® with an exhaust purifier a few years ago and then an electric machine with cable, which has already helped reduce the mine ventilation problem and reduce costs in comparison to diesel machines. Marc Melkonian, Aramine President, said: "The battery-powered machine was already in our mind but this technology was not enough reliable at the time and very expensive."

Now, after two years of R&D, Aramine says it has a reliable and competitive battery product. The machines were tested in customer mines before launching and they are today in operation

The Aramine L140B has the same or even more breakout force than a diesel machine. The autonomy is approximately four hours depending on application and usage, which allows mucking three to four faces in one shift

in different mines. The L140B was entirely developed and designed around a fully integrated battery system. Diesel fuel tank and filters but also hydrostatic transmission and related systems have been eliminated and a full electrical transmission has been integrated. This eases the maintenance burden and considerably reduces the downtimes.

As Aramine battery-powered machines use an electric transmission, this allows adjusting the torque depending on the condition of the roadbed in order to give just enough power and avoid tyre spin.

The charging system is very simple as the charger is integrated to the machine and a simple plug to the wall is required. The charging system doesn't need a big electrical installation as the power needed is about 7 kW (in comparison to the 45 kW needed for an electrical machine with cable). An optional version features a quick disconnect battery module in order to replace easily the batteries and run the machine full time.

This new miniLoader L140B is an optimised and advanced version of the L120B and can carry more capacity, 1.3 t. That is to say 20% more productivity per shift with the same autonomy and energy consumption. "We really trust this battery powered innovation and customers are already seduced by the L140B proven by our order book," said Melkonian.

CAT power

The Underground Mining group within Caterpillar has a proof of concept battery electric LHD mucking at a mine site in Canada. The initial build and validation testing of this R1300G test unit began in early 2017 at the Caterpillar Peoria Proving Grounds.

The test machine is a proof of concept for packaging and performance of a lithium based energy storage solution Caterpillar plans to bring to the LHD market. The Cat® R1300G proof of concept does not represent a final design that will go to market. After testing, Caterpillar will launch a full-fledged new product introduction program that follows a more in-depth, rigorous design and validation process.

"Our customers are planning for deeper mines with very high ambient rock temperatures where ventilation costs are pivotal to making the mine viable," said Jay Armburger, Product Manager with responsibility for underground technology. "One means of reducing ventilation demand is through electrification of the mining equipment."

With over 250 patents in the electric drive and energy storage fields, and products like the D7E dozer, F-Series asphalt pavers, 794 AC and 795F AC large mining trucks, the recently introduced 988K XE wheel loader, and even microgrid technology, Caterpillar has fully integrated electric drive train technology and components to bring to underground machines.

The program started with a full production study and data analysis of the diesel machine in order to set a baseline. Once this was accomplished, the transformation of the R1300G to a battery electric proof of concept began. The modifications included removing the engine, transmission and torque converter then reconfiguring the engine end frame to accommodate the battery boxes and electric motors. The result is a battery electric powertrain driving a conventional and mechanical drivetrain (drive shafts and axles).

The R1300G proof of concept is an older machine without the benefit of efficient electro-hydraulics. As a result, it will drive worst case scenario loads on the batteries. Of course the design of the new loader will enhance battery life through the use of load sensing hydraulics driven by piston pumps such as those on the new Cat R1700. The less refined proof of concept machine will yield solid understanding of heat generation and cooling needs, performance criteria, space claim and safety considerations in the day-to-day operation of the machine.

With the help of several customers who have visited the proof of concept and operated it at the proving grounds, Caterpillar is getting feedback to help drive the program forward. All of the customers who have visited the machine agree that pursuing a system that is rechargeable on the machine is the right path forward. Recharging on the machine prevents the mine from incurring additional infrastructure costs or from having to manage or store replaceable battery packs. Instead, Caterpillar is focusing on fast charging of

Jay Armburger, Product Manager Underground Technology Solutions for Caterpillar reports: "We are still very early in the underground testing of our R1300 proof of concept battery electric machine, but thus far - we are very pleased with its demonstrated performance. It's a testament to Caterpillar's deep expertise in machine applications, electric drive and energy storage systems. And I can't stress enough the importance of having fully engaged partners in this type of endeavor. With help from these partners, we had the machine disassembled and down the mine shaft within two working days. Once underground - the parts came together and the machine was fully outfitted with diagnostic equipment within three days. After completing all the necessary system check outs on the machine and charger, we managed to put the LHD to work just before the Christmas holiday - hitting its first muck pile on the 18th. This is a very exciting time in the program, and our on-site team of engineers will continue to put it through its paces for the next several weeks. We're also looking forward to getting the machine into the hands of experienced operators to obtain their feedback on the operational performance."

the batteries on the machine such that an operator can take a quick break and come back to a charged machine. In addition to developing the LHD itself, the program has been prototyping a robust charging station. The technology behind the charging station is unique to Caterpillar and uses Cat components and technology.

As with all new product introductions, Caterpillar will listen to its customers and put new designs through their paces before releasing a machine. The chemistries and technologies behind battery development are evolving rapidly. Change is inevitable, and the development team will continue to evaluate these changing technologies to better serve mining customers.

"We tried hard to break this machine and technology before sending it to Canada in September," Armburger said. "With the results we've seen so far, we're confident this R1300G proof of concept is giving us the answers we need to develop a machine that is safe and lives up to the Cat brand promise of durability and reliability. In the end, Caterpillar is well positioned to develop an optimized machine—from power generation to tyre rotation."

Atlas Copco's extensive line

Following the success of its Scooptram ST7 Battery, Atlas Copco hosted a customer event launching the new Boomer M2C Battery jumbo at its Lively location in Sudbury, Canada. The event "showcased exciting innovative battery technology that is poised to change the landscape of the mining industry moving forward. Attendees were given the opportunity to view our diesel-free equipment up close and learn the benefits of implementing this technology in future mining projects."

With the addition of the battery drill rigs, Atlas Copco now offers a full underground mining portfolio that includes loaders, trucks, face drills, ground support and production drills with diesel-free options. "The Boomer M-series face drilling rigs have become a key piece of equipment for mining and tunnelling applications. As part of our commitment to continuous improvement, the face drilling rig has benefitted from a comprehensive upgrade, focusing on improved safety, increased robustness, battery power, automated functions and lower operational costs."

Thanks to its efficient and powerful electrical motor and battery drivetrain, the Boomer M2C Battery is able to perform long tramming in challenging conditions without any emission at all. This means a safer working environment underground with better air quality. At the same time, the drill rig will charge the battery while drilling the face so there is no need to stop for charging during tramming. All this has been achieved without changing the size and usability of the machine. The benefits are summarised as follows:

- The electric drive eliminates diesel emissions and minimises the need for ventilation
- Thanks to the onboard charging there is no need to stop and charge. The Boomer M2C Battery will charge during drilling and you can go directly to the next face when finished drilling
- Large battery capacity and powerful motors provide the ability to outperform diesel machines in most applications
- Like all Atlas Copco equipment, the Boomer M2C is automation ready. Add the functions you need, when you need them.

Using an efficient and powerful electrical motor and battery drivetrain, Atlas Copco's Boomer M2C Battery is able to perform long tramming in challenging conditions without any emission at all

The 100% electric Scooptram ST7 Battery from Atlas Copco was unveiled last May 1; it is fully battery operated. Battery power minimises the need for mine ventilation, while offering the same or better performance as diesel. That reduces cost for infrastructure as well as the long term operational costs.

"Compared to a tethered machine the battery powered Scooptram has the flexibility of the diesel but without the limitation of the trailing cable. Cutting the cord means cutting costs and adding flexibility to your underground operations." With zero emissions and up to an 80% reduction in heat generation compared to diesel power, the cost of installing ventilation is minimised and the expensive refrigeration of mines can potentially be eliminated in the long run.

Each little detail matters when it comes to designing a powerful, 7 t loader. Besides the major change from diesel to battery Atlas Copco says it also focuses on small, but smart functions to create big savings. "For example, the Scooptram ST7 Battery is also equipped with the Atlas Copco unique traction control to increase tyre life up to 30%. Together with the fact that battery vehicles enable longer service intervals, it increases overall up time and thus productivity," says Erik Svedlund, Global Product Manager - Electric Vehicles - Underground Material Handling.

Operator comfort and productivity is a big priority, which is why the Scooptram ST7 Battery has excellent visibility and intuitive, ergonomic controls in an ROPS/FOPS approved canopy for safe ergonomic operations. The telematics system provides production data and online trouble shooting. The Scooptram ST7 battery is automation ready meaning it can be equipped with smart functions like the option teleremote control that allows control of multiple loaders from a safe remote location.

"The new Scooptram ST7 Battery shares most parts with the successful diesel Scooptram of which hundreds have been sold-to-date around the globe. Service and repair are therefore no problem, even in the most remote locations.

Some months ago, Andreas Nordbrandt, President of Atlas Copco Underground Rock Excavation Division stated: "Our customers' future is electric." Atlas Copco will continue to support all customers who rely on diesel-driven equipment but the decision to completely advance beyond diesel is a definitive move. "It's high time to look forward and leave fossil fuels behind," said Nordbrandt. "We must consider the mining industry's carbon footprint and assume our responsibility as an industry leader".

"Zero emission machines already offer the same or even better performance as diesel, and this is only the beginning, productivity and profitability will only improve from here." says Svedlund.

"Electric and battery-powered vehicles is the future in underground mining," declares Nordbrandt. "Besides the lower running cost of the machines themselves, there are considerable savings to be had in ventilation and cooling. But most importantly, electric machines contribute to a safer and healthier work environment for miners everywhere".

Sandvik LTO battery technology

Sandvik introduced three new battery powered underground mining machines in 2016 at MINExpo - a battery-powered LHD, the Sandvik LH307B, with new technology for emission-free underground loading and hauling; a battery powered drill jumbo, the DD 422iE and a battery

powered dozer, the Sandvik LZ101LE.

The LH307B's payload of 6.7 t is moved using components that are shared with the diesel Sandvik LH307, with much the same performance characteristics. Using the charging station's "quick charge," Sandvik LH307B can be ready for use in some 15 minutes. The LH307B is also compatible with Sandvik mine automation and information management systems. Its lithium titanate oxide (LTO) battery technology enables rapid recharging, providing continuous operation with a single battery pack – there is no need to swap batteries during or between shifts. Liquid cooling guarantees a long battery lifetime across a broad range of ambient temperatures – in fact, sufficient to cover the useful service life of the loader itself. The single-battery strategy offers several tangible benefits: eliminating the need for spare batteries and/or a dedicated crane and battery swap area effectively cuts capex costs.

The LTO battery offers:

- High energy density (+177 Wh/kg)
- 15,000 to 20,000 life cycles
- Deep consistent power cycle
- Quick charge – nominal 2 hours operating on 15 minute charge cycle with external battery cooling (no battery swap needed).
- Can be topped, re-charged when not fully discharged, without damage to the battery

The Sandvik LH307B is available with a service pack designed to keep the loader productive 365 days a year. The service pack includes maintenance kits for each and every service interval, together with planned repairs of major components over the equipment's life. These repairs will be planned in line with actual component condition, giving consideration to the mine's production schedule and minimising downtime.

The fully battery-powered dozer Sandvik LZ101LE will improve the underground working environment since there are no emissions or increased heat generation from the engine. "

It has a push capacity of up to 4 t and is remotely operated, enabling operators to work at a safe distance and avoid spending time under an unsupported roof. "The Sandvik LZ101LE dozer is an important addition to the low-profile Sandvik portfolio as the supplier aims to help customers mechanise the entire operating cycle. With improved safety, productivity and minimised ore dilution, Sandvik low-profile drill rigs are an ideal choice for working in tabular orebodies, such as platinum and chrome mines. These rigs have been designed for cleaning areas in sections as low as 1.7 1.1 m with optimum performance."

The Sandvik DD422iE embodies all the advantages of battery powered units, reducing dramatically the potential health impacts of diesel particulate matter (DPM) and other underground engine emissions that also often dictate high mine ventilation costs. This Is one of the industry's first highly automatic development jumbos with an electric driveline system. It uses electric battery power instead of a diesel engine to eliminate emissions during tramming. It consumes no fuel and generates less heat and noise than conventional drivelines.

The DD422iE is enabled and ready for the digitalised era of underground mining. Optional Gold and Platinum automation packages includes iSURE drill planning, analyses and optimisation tool. This will help your planning team to find optimum pattern for the drilled holes resulting less over break and better pull out per each blast. Also a wide range of drilling data are collected including numerous productivity and MWD related information and this can be visualised and analysed round after round as development advances. DD422iE is also built to compliancy with Sandvik AutoMine Drilling, OptiMine remote monitoring and Fleet data management systems.

BEV 101

The Global Mining Standards and Guidelines Group's (GMSG) BEVs Underground Sub-Committee held two workshops in Montreal and Sweden in December to create the next edition of the recommended practices guideline. Each workshop built on the other to reach a consensus on what information must be added to V2. Some of the new potential topics to be included are:

- A new Operations section, including emergency response and training for maintenance and operators
- Guidelines for creating a business case, and a comparison of BEV to tethered technology
- Recommendations for standardisation of charging systems: connectors and protocols for communication
- Expanded discussion about the use of pantographs
- Information on how to build a basic BEV simulation, including formulas
- Revisiting of E-stop requirements and master disconnects
- Revisiting of resistive braking
- Expanded Performance Standards section, revising the data sheets, performance parameters, and making the section more user-friendly

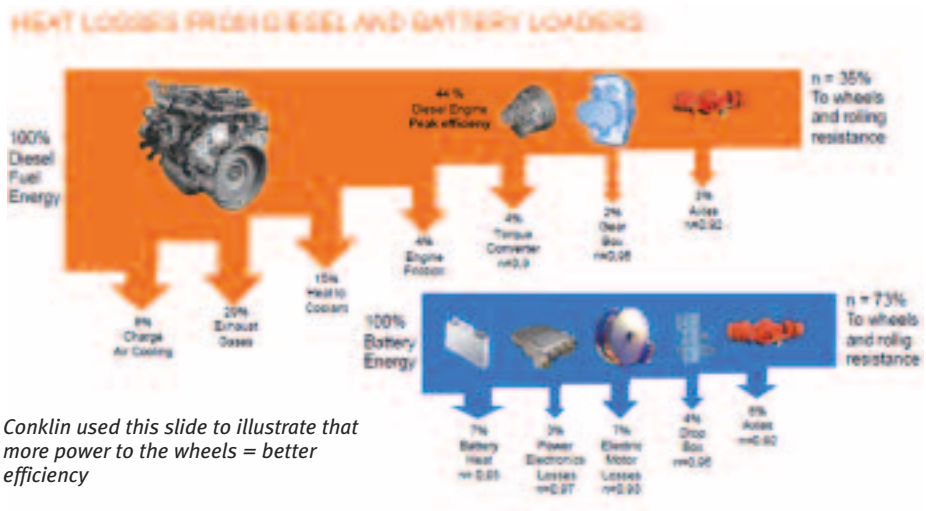
Since the publication of *Recommended Practices for Battery Electric Vehicles in Underground Mining* there has been much interest from OEMs, mining companies, OTMs, and consulting companies. A major OEM already considers the guideline required reading for engineers, and several mining companies are creating a joint RFP based on its specifications.

"Technology is rapidly advancing and we want to stay current. V2 will unquestionably be an invaluable resource for the Underground Mining industry," the GMSG states.

Presentations from GMSG's 2017 Future Mining Summit in Stockholm, Sweden, December 4-5, can be found at http://www.globalminingstandards.org/fms2017-news/

Efacec is a world leader in battery charging technology. Mike Anderson, CEO of Efacec USA, outlined the GMSG EV Charger Guideline. Chargers should be located at least 6.1 m (20 ft) from fuel storage and dispensing areas. Charging equipment is dependent on the following:

- Mine charging philosophy
  - AC vs DC
  - Onboard versus off-board
- Mine Environment - dusty, hot, cold, amount of water
- BEVs operating in the mine
  - Connector interface
  - Charger to EV Communications protocol
  - Capacity of batteries in the BEVs
  - Battery chemistry for AC charging
- Jurisdiction and applicable electrical codes.
- Safety, installation, and maintenance considerations:
  - Comply with local and federal health and safety regulations
  - Adequate access around the charger for service/maintenance
  - Level installation pad
  - Ventilation/cooling of the charging area, depending on ambient temps



Conklin used this slide to illustrate that more power to the wheels = better efficiency

- Clearly marked parking area for BEVs
- Limit the amount of water and mud around the charger
- Charging cable management/retraction system
- Remote E-Stop button near where EV is charging
- Upstream overcurrent and lockout disconnect protection.

Rich Zajkowski, Energy Storage Safety & Compliance Engineer with GE Transportation provides the following useful definitions:

Cell: basic functional unit, consisting of an assembly of electrodes, electrolyte, container, terminals and usually separators that is a source of electric energy obtained by direct conversion of chemical energy

Electrolyte: liquid or solid substance containing mobile ions which render it ionically conductive

Lithium Metal Cell: cell containing a non-aqueous electrolyte and a negative electrode of lithium or containing lithium

Lithium Ion Cell: secondary cell with an organic solvent electrolyte and positive and negative electrodes which use an intercalation compound in which lithium is stored. N.B. A lithium ion battery does not contain lithium metal

Battery; one or more cells fitted with devices necessary for use, for example case, terminals, marking and protective device

Battery System: Battery plus enclosure, battery management system, thermal management system and connections to BEV and battery charger.

Selecting a Li-ion cell chemistry should consider:

- Power rating (W)
- Energy rating (Whr)
- Safety characteristics
- Minimum recharge time
- Operating environment
- Cycle life
- Cost.

Zajkowski explains that a battery management system is a system that monitors individual or groupings of cells, ensures cells operate in their safe zone and balances charge levels of individual cells. It should measure, monitor & communicate:

- Cell voltages, currents and temperatures
- Energy consumed by the vehicle
- System state of charge (SOC)
- System depth of discharge (DOD)
- Overall battery health and capacity.

Looking further forward

Matthew Conklin, Chief Mining Engineer of the trans4mine group, Sandvik Mining and Rock Technology, presented some "other possible next generation BEV opportunities" to the GMSG workshop:

- New battery technology
- Induction charging
- Incorporate pantograph use (automated off-board charging)
- Ultra fast charging
- Trolley assist (onboard charging in motion)
- Hybrid/battery electric.

Much more can be researched via the GSMG and the CMIC (Canada Mining Innovation Council). ***IM***