

EXPERT ROUND TABLE EVENT

BATTERY ELECTRIC VEHICLE (BEV) FIRE SAFETY IN TUNNEL CONSTRUCTION



20TH SEPTEMBER 2023
HAGERBACH TEST GALLERY, SWITZERLAND

EXECUTIVE SUMMARY

The recent introduction of battery electric vehicles (BEV) to the tunnelling and mining industry has shown there to be positive benefits in reducing carbon through reduction of fossil fuel use and increasing significantly operational safety, yet also reduced whole life equipment and project costs. As typically experienced with changes in technology, despite all the positive attributes of BEV underground equipment, there are nevertheless legitimate concerns going along with the new technology such as the fire safety of high-capacity batteries, their operating range and required charging infrastructure.

The SubSpace Energy Hub invited knowledgeable key stakeholders from the industry for an Expert Round Table Event held in the Hagerbach Test Gallery (VSH) in Switzerland on the 20th September 2023. The roundtable objective was to understand in more detail the fire risk concerns, what fire tests that have conducted so far and what the current risk mitigation measures are implemented.

The goal is to address BEV concerns and gain broader industry acceptance, and therefore accelerate integration of BEVs in tunnel construction projects so as we as a whole industry benefit from healthier, safer and lower carbon processes.

Following the round table event, several activities will be progressed by the partners of the SubSpace EnergyHub to support the industry in the usage of BEV such as to develop more appropriate state of the art recommendations for vehicle safety features, safe operator use, fire mitigation measures and training for BEVs used in a tunnel environment.

THE MAIN CONCLUSIONS FROM THE MEETING CAN BE SUMMARISED AS FOLLOWS:

1. Tunnel projects are increasingly obliged to be focused on sustainability and in particular the reduction in carbon. This is currently being achieved by reduced embedded carbon in construction materials and by adopting BEVs using green energy supply.
2. Tunnel and mining equipment manufacturers are focused on development of BEV versions of their offering and expect diesel powered units to be phased out by the end of the decade. They also will come up with different business models to make the use of BEV economic competitive.
3. The health and safety of the tunnel team is enhanced through BEV adoption by no harmful emissions such as DPM, low noise, low heat and low vibrations.
4. From battery fire testing also at VSH Switzerland, battery fires indeed release energy very quickly, but also reduce quickly to low energy fires that can be extinguished with water hydrants. It is important that battery cells are flooded with water to fully extinguish residual fire risks. The round panel observed that designed-in water flooding systems or other active suppression and cooling systems is a good practice for vehicle design and should become state of the art.
5. Experts consider that BEV fire loads are smaller than the equivalent diesel powered vehicles. This needs further assessment.
6. Fire safety is a design priority in tunnel BEVs. Fire risks are mitigated through numerous levels for safe operation in the underground environment to a level far in excess of those currently used on diesel engine vehicles. These levels start with low fire risk battery cell chemistry choice, active and passive fire protection and cooling design of battery packs, battery pack casing and secure location on the vehicle, state of the art battery management systems that have early warning and shut off features, and finally active fire suppression systems should a fire occur.
7. Fire fighters can tackle any type of fire if they understand and are informed of the high voltage features and fire load related to battery cell types on a BEV. The firefighting experts recommend having clear firefighting instructions and training for each vehicle type.
8. In both mining and tunnelling industries there has been no BEV fire to date. Risk studies for the Norwegian Road Authorities has shown that BEVs present the same if not lower risk of causing fires than diesel vehicles, and adequate firefighting measures are in place to extinguish BEV fires.
9. Standards for underground BEV design follow Euronorms for heavy highway vehicles like goods trucks and buses etc.
10. BEV adoption in the mining industry is more advanced and more widely used compared with the tunnelling industry.

THE ROUND TABLE EVENT EXPERTS WERE AS FOLLOWS:



Felix Amberg
President
Amberg Group – Switzerland



Jan Eriksson
Head of Safety
Implenia – Sweden



Christoph Mueller
CEO
Virturail – Austria



Ross Dimmock
VP Tunnelling
Normet Group – UK



Andreas Achermann
Safety Engineer
SUVA – Switzerland



Philipp Strueby
Co-Founder
Motics – Switzerland



Keith Bowers
Tunnel and Systems Director
COWI – UK



Michael Kompatscher
General Manager
Hagerbach Test Gallery – Switzerland



Tony McDonald
Head of Engineering
Xerotech – Ireland



Christof Ziegler
Equipment and New Technology
Normet – Switzerland



Michael Derungs
Firefighter
Schutz und Rettung Zurich – Switzerland



Søren Randrup-Thomsen
Head of Risk Safety
Ramboll – Denmark

TOPIC 1: EXPLORING THE ADOPTION OF BEVS IN TUNNEL CONSTRUCTION AND MINING: CLIENT PERSPECTIVES, CONTRACTOR EXPECTATIONS AND CONCERNS ABOUT BEV FIRE SAFETY

MODERATOR – **ROSS DIMMOCK** – VP TUNNELING – NORMET

JAN ERICSSON (IMPLENIA – HEAD OF SAFETY – SWEDEN)

KEITH BOWERS (COWI/LTC – TUNNEL AND SYSTEMS DIRECTOR – UK)

SØREN RANDRUP-THOMSEN (RAMBOLL – HEAD OF RISK SAFETY – DENMARK)

ANDREAS ACHERMANN (SUVA-SWISS HEALTH AND SAFETY INSURANCE – SAFETY ENGINEER – SWITZERLAND)

ROSS DIMMOCK – VP TUNNELLING – NORMET GROUP, UK

“SubSpace Energy Hub is tackling head on ‘Global Boiling’ by reducing emissions in tunnelling projects. So far, Norway seems to be the only country taking a lead on this topic. Why are other countries not doing following suit? We don’t have clear answers. Norway has 7 major cities implementing carbon zero construction processes. BEVs present beneficial hygiene factors such as no harmful emissions, low noise and cooler operating temperatures, whilst battery fires are a great concern with tunnel contractors. Are these concerns legitimate and proportionate, and what is the industry doing about it? In mining the fire risk topic is understood and the implementation of BEVs is more rapid.”

KEITH BOWERS – TUNNEL & SYSTEMS DIRECTOR – COWI, UK

“The National Highways client in the UK has set an ambitious goal to progressively achieve net-zero emissions from construction and operation over the next 25 years. As the national vehicle fleet changes through the growing adoption of zero tailpipe emissions vehicles it is apparent that operational life emissions will reduce greatly. As a result, the focus is moving to construction phase emissions which remain a significant issue. The primary contributors to construction emissions are concrete, steel, and diesel. This has prompted the exploration of green energy construction equipment alternatives to replace diesel machinery. These alternatives include Hydrogenated Vegetable Oil (for transitional use), Hydrogen, and Battery Electric Vehicles (BEV) along with tethered electric plant. Key considerations in evaluating BEVs as an option include assessing fire risk, time to charge, range, availability, the maturity and diversity of the plant supply chain and the accessibility of green power sources. Consideration of all these is necessary to determine the relative merits of BEV and other green plant solutions.”

SØREN RANDRUP-THOMSEN – HEAD OF RISK SAFETY – RAMBOLL, DENMARK

“Recent detailed risk assessments of Battery Electric Vehicle (BEV) fire safety conducted for the Norwegian Public Road Administration, which seeks a 50% reduction in construction equipment emissions by 2030, indicate that BEVs are as safe as, if not safer than, Internal Combustion Engines (ICEs). The risk assessment accounts for both available fire statistics and for detailed consequence models for injuries and fatalities given a fire occurs. Fire statistics for ordinary diesel/petrol vehicles and BEVs in Norway demonstrate significantly lower fire frequencies, making fires in electric cars less probable than in diesel cars. There are uncertainties related to these statistics, but they do none the less show a tendency also being applicable for larger construction machinery. Although BEVs may have higher consequences due to the potentially longer-lasting fires, risk-reduction measures are in place, with e.g., efforts in Denmark to explore battery flooding systems for emergency response. Ultimately, the evaluation suggests that, in terms of overall risk, BEVs and diesel vehicles are comparable. The risk assessment has been provided to the Norwegian Road Administration and is currently undergoing evaluation, with potential further detailing required from Ramboll’s perspective.”

JAN ERIKSSON – HEAD OF SAFETY – IMPLENIA, SWEDEN

“Implenia’s early planning stage clients express a preference for subcontractors to utilize electric vehicles (EVs) like loaders, excavators, and trucks, although this isn’t a mandatory requirement, and no economic compensation is offered. Concerns regarding EV safety have been fuelled in Sweden due to media reports of EV fires, despite a significant number of car, truck, and bus fires occurring annually. In response, clients have extended the standard backup air supply in rescue chambers from 8 to 24 hours, with potential expansion to 72 hours for battery transformation projects. Tunnelling projects face unique challenges with inner linings, as clients worry about the prolonged burn time and potential for ignition of inner linings in case of EV fires. A fire protection handbook suggests that after 5-10 minutes, the fire becomes impassable, and after 10-15 minutes, it can be safely traversed.”

ANDREAS ACHERMANN – SAFETY ENGINEER – SUVA, SWITZERLAND

“In Switzerland, specific types of Li-ion batteries such as NMC in Electric Vehicles (BEVs) are prohibited in underground construction due to their fire behaviour, unless a complex and costly Battery Management System (BMS) with a Performance Level d on its safety functions is implemented. To mitigate fire risks, the use of battery types such as LiFePO4 or LTO, known for their non-flammable characteristics, is strongly recommended.”

TOPIC 2: ENHANCING SAFETY IN MODERN BATTERY ELECTRIC VEHICLES: PROACTIVE RISK MANAGEMENT, BATTERY PACK DESIGN, AND RECENT FIRE TESTING AND RESEARCH APPROACHES

MODERATOR – **MICHAEL KOMPATSCHER** – CEO – HAGERBACH TEST GALLERY – SWITZERLAND

TONY MCDONALD (XEROTECH – HEAD OF ENGINEERING – IRELAND)

PHILIPP STRUEBY (MOTICS – CO-FOUNDER – SWITZERLAND)

CHRISTOPH MUELLER (VIRTURAIL – CEO – AUSTRIA)

CHRISTOF ZIEGLER (NORMET – ALIVA TECHNOLOGY AND OFFERING – SWITZERLAND)

MICHAEL DERUNGS (SCHUTZ UND RETTUNG ZURICH – FIREFIGHTER)

MICHAEL KOMPATSCHER – GENERAL MANAGER OF HAGERBACH TEST GALLERY – SWITZERLAND

“In 2017/2018 and 2019/20, Hagerbach conducted two published research projects on batteries for the Swiss road authority, specifically focusing on lithium-ion and NMC batteries for cars (not construction machines) to evaluate the risks and mitigation measures in underground environments. The findings indicate that Battery Electric Vehicle (BEV) fires with NMC Li-Ion batteries in enclosed spaces can result in partially atypical emissions of CO₂, Co, Ni, Mn, Fluorides, and Lithium. This scenario increases toxicological risks, particularly in post-cleaning phases, highlighting the importance of distinguishing between extinguishing water and cooling water. However, BEV fires with Li-NMC batteries in closed rooms will not critically contaminate large, ventilated infrastructures, will not induce significant changes in accident management procedures, or will not significantly diminish the value and availability of facilities. Current fire protective standards and test procedures apply and “vehicle fire remains vehicle fire”

MICHAEL DERUNGS – FIREFIGHTER – SCHUTZ & RETTUNG CITY OF ZURICH – SWITZERLAND

“For firefighters, the key challenge isn’t the type of vehicle but rather handling battery fires, which are more complex. They need technical specs of the BEV and should be integrated into site incident management from the start, with regular joint training. Learning from Formula-E, where batteries have water inlets for overheating, similar safety measures should be applied in construction sites.”

CHRISTOPH MULLER – CEO VIRTURAIL

“In VirtuRail applications, battery systems must adhere to safety specifications outlined in EN62619 or the Automotive standard ECE R100, which is currently under review with a focus on battery management system functional safety. Findings from the Astra report on battery investigations at Hagerbach Test Gallery highlight that the primary danger to batteries is mechanical damage, followed by high temperatures, shortcuts on the high voltage side, and external fires overheating the battery. To mitigate these risks, a safety pyramid of countermeasures is implemented. Mechanical battery protection takes precedence, followed by certified Battery Management Systems (ECE R100 or EN62619), Vehicle Control Systems, Thermal Management, and Emergency Cooling. Protecting against shortcuts poses challenges due to plastic connectors that are not mining or tunnelling resistant, while mining-proof metal connectors remain a technical challenge. VirtuRail also enforces operational protections such as restricted charging zones, maintaining battery state of charge between 20% and 80%, and adhering to manufacturer current limits. Emergency Cooling / Flooding possibilities and optimal battery usage further reduce fire risks, with Battery Management Systems (BMS) playing a role within this comprehensive safety framework.”

PHILIPP STRUEBY – CO-FOUNDER – MOTICS, SWITZERLAND

“The rapid advancement of battery technology and battery-powered vehicles necessitates a collaborative effort within the industry. It’s vital that stakeholders unite to share knowledge and establish common practices, especially in new developments. This collective effort, enhanced by Motics’ Active Risk Management approach, accelerates innovation, ensuring the creation of safer and more efficient energy solutions. By pooling expertise and setting unified standards, industry players can navigate regulatory landscapes and consumer expectations more effectively. This collaborative ethos will lead to standardized testing protocols, user training, and safety guidelines, ultimately propelling the sector towards a sustainable, technologically advanced future.”

TONY MCDONALD – HEAD OF ENGINEERING – XEROTECH, IRELAND

“Not all batteries are designed the same, it is important to recognise the role that Mechanical, Thermal and Electrical system design plays in minimising the risk of a thermal event. Key measures taken for battery safety include thermal insulation, Xerothem Fire Suppression, and Xerothem Passive Propagation Resistance to help reduce the risk of thermal propagation. Battery designers prioritize risk minimization, whilst using and recharging batteries within their optimal temperature parameters further mitigates the risk of fires. These integrated safety strategies collectively contribute to enhanced battery safety and the Battery Management Systems provide embedded safety monitoring features to provide early warning to operators in the case of a failure”

CHRISTOPH ZIEGLER – HEAD OF TECHNOLOGY, SERVICE BL AT NORMET INTERNATIONAL, SWITZERLAND

“Normet’s approach to battery safety focuses on using the safest Li-ion chemistry from proven cell suppliers, combined with passive and active safety measures. The first line of defence is the fixed installation of the battery pack to the chassis, which eliminates the risks of battery swapping and allows for mechanical structures for protection against ingress, proper fusing, thermal and electrical insulation. Active safety measures, including monitoring of voltage, current, temperatures and electrical insulation, as well as sensors to detect machine rollover, together with power switches that safely isolate the battery, and an automatic non-battery fire suppression system, form the second and third lines of defence. Normet holds today a key position in the electrification of underground mining & tunnelling equipment, with over 70 trained and certified professionals in 14 locations worldwide for service and training, and by participating in risk assessments and information sharing with customers.”

TOPIC 3: DISCUSSION: MANAGING RESIDUAL RISKS AND ADDRESSING INDUSTRY NEEDS AND CONCERNS THROUGH FUTURE SUB SPACE ENERGY HUB PROJECTS

KEY FOCUS AREAS:

THREE CRITICAL AREAS OF DISCUSSION WERE OUTLINED:

- **MANAGING RESIDUAL RISKS AND PERCEPTIONS**
- **INDUSTRY NEEDS AND CONCERNS**
- **COLLABORATIVE PROJECTS FOR CO2 REDUCTION AND ELECTRIC PROPULSION**

MANAGING RESIDUAL RISKS AND PERCEPTIONS:

DRIVING CHANGE AND COMMUNICATION CHALLENGES:

- **COWI** highlighted the need for change driven by business angles, cost-effectiveness, or client demands to meet CO2 targets.
- The potential role of firefighters in ensuring safety during the transition was raised, with firefighter collaboration encouraged.
- **Ramboll**, consulting on risk assessment, stressed the importance of risk analysis but emphasized the need for effective communication to convey risk assessments to both clients and the industry. The discussion also touched on the development of standards for BEVs, recognizing the need for a collective approach to address the evolving technology.

STANDARDS AND JOINT EFFORTS:

- **Xerotech**, the battery designer representative, discussed the importance of designing BEVs through standardized approaches to gain authority for their use.
- Concerns were raised about outdated standards that do not address emerging BEV technologies.

COMMUNICATION GAPS AND RISK PERCEPTION:

- **Virturail**, a representative from tunnelling and automation, highlighted a communication gap between industry experts and clients regarding residual risk. Bridging this gap through factual information and explaining the benefits of BEVs was seen as essential. The role model for safety according to the VirtuRail safety pyramid could help a lot for the common understanding.
- **Amberg**, designer representative, compares the shift from Drill and Blast method to Tunnel Boring Machines (TBMs) in Norway and Sweden, with the shift from Diesel to BEVs, and what could be the lessons learnt from the first example. **Implenia** cites cost as the key factor, with initial BEV purchases followed by rising expenses, leading to their abandonment in favour of diesel equipment due to operational challenges in tunnel environments without suitable infrastructure.

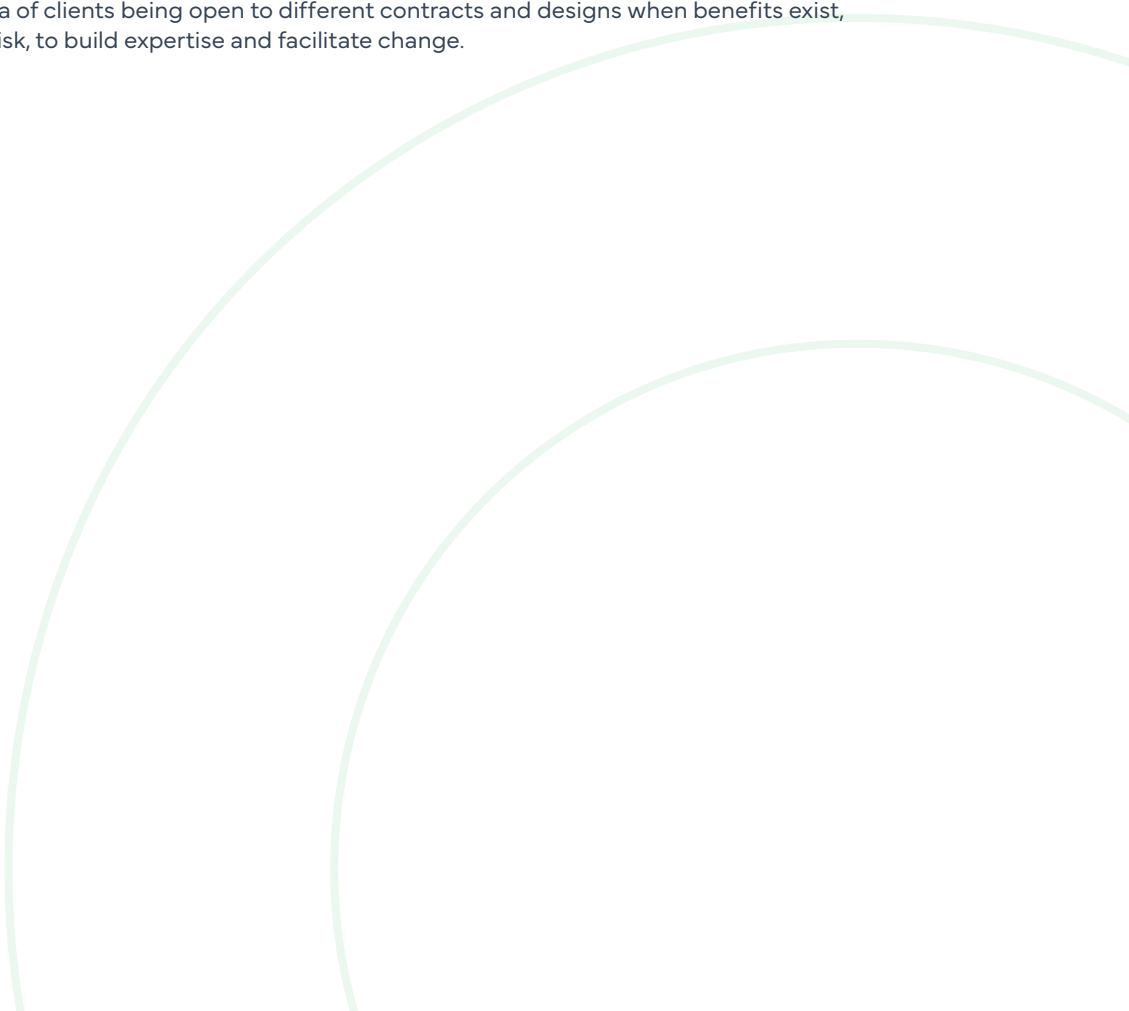
SAFETY AND INSURANCE INDUSTRY INPUT:

- Most site fatalities were attributed to civilians being run over by Equipment rather than BEV fires.
- Stakeholders like **firefighters** and **safety experts** were seen as contributors to assessing risks and promoting BEV benefits.
- **SUVA**, from the insurance industry emphasized the need for concise cost calculations (reflecting also the reduction in ventilation costs in case of BEV application) and fire risk explanations in one-page summary.

INDUSTRY NEEDS AND CONCERNS:

- **COWI** emphasized the necessity of discussing technical aspects in a coordinated manner.
- Stakeholders considered the value of gathering to share perspectives and work collectively.
- **Implenia**, as a contractor, expressed concern about the lack of readily available support for safety and fire protection in planning large projects.
- The urgency of preparing for industry-wide change and the importance of initiating preparations for the next 15 years were highlighted.

STRATEGIES FOR TACKLING CHANGE:

- **SUVA** proposed disseminating information about this gathering to other Insurance social partners in DACH region.
 - **COWI** suggested clear communication of major targets, such as carbon reduction, and using commercial procurement mechanisms to create a conducive environment for contractor actions.
 - Participants explored the idea of clients being open to different contracts and designs when benefits exist, even if it involves economic risk, to build expertise and facilitate change.
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COLLABORATIVE PROJECTS FOR CO2 REDUCTION AND ELECTRIC PROPULSION:

- **Normet's** representative noted varying acceptance levels of BEVs in mining and tunnelling sectors, with mining being more receptive due to perceived benefits and the tunnelling industry faces challenges in demonstrating cost savings compared to long term total cost ownership models in mining.
- **Motics** pointed out that the fear of transitioning to BEVs is due to the lack of a blueprint for achieving CO2-neutral construction sites. SubSpace Energy Hub was seen as a platform for showcasing long-term transition possibilities.

In summary, the discussion highlighted the need for effective communication, client-driven sustainability demands, risk analysis, standards development, and stakeholder collaboration to navigate the transition to BEVs successfully. Challenges included cost, risk perception, and specific environmental considerations, such as in tunnels. Fire risk and safety were central concerns, with the insurance industry stressing the importance of clear and concise information for industry understanding. The urgency of preparing for industry change and initiating long-term preparations was acknowledged and considered a key-strategic focus of the SubSpace Energy Hub. Strategies included clear communication, creating an environment for meaningful action, and showcasing CO2-neutral construction site transitions.