The Battery Revolution and the Impact on Mining

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Introduction

- Battery devices in everyday life
- The drive to have Battery Electric Vehicles (BEVs)
- Impact of BEVs on base metals
- BEVs and their use in underground metal mines
- Benefits and risks associated with BEVs in underground mining

Battery Use

Video cameras	Walkie talkies (2 way radio)	GPS devices	Radio controlled toys
			
Cameras	Scanner	Cellular Phones	MP3 players
			
Bluetooth headsets	Smartphones/mobiles	Laptop computers	Shavers
			
Power Drills	Tablets	Portable DVD players	Measuring equipment
			

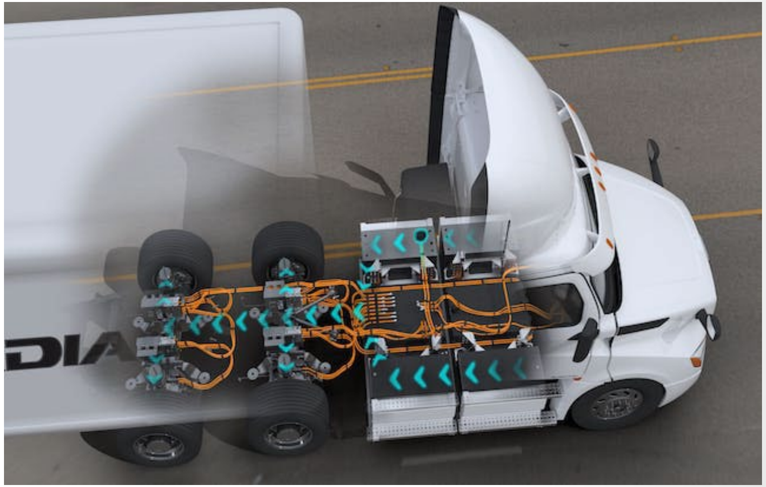
Carbon Neutral Goal

- Climate change, and the goal to minimize CO_2 emissions, is encouraging mining companies to seek carbon neutral operations
- Reducing or eliminating diesel machines is one way to achieve this goal.
- Reducing electrical use at an operation (particularly one that depends on coal or natural gas) will also reduce carbon emissions.
- Carbon neutral achieved by reducing carbon consumed and by offsetting.

Carbon Neutral Goal

- Replacing Internal Combustion Engines (ICEs) with BEVs is considered a viable strategy to reduce CO_2 emissions.
- As the technology advances, and as mining equipment companies increase production of BEVs, more mining companies will likely seek this approach.

Internal Combustion Engine (Mack Truck)

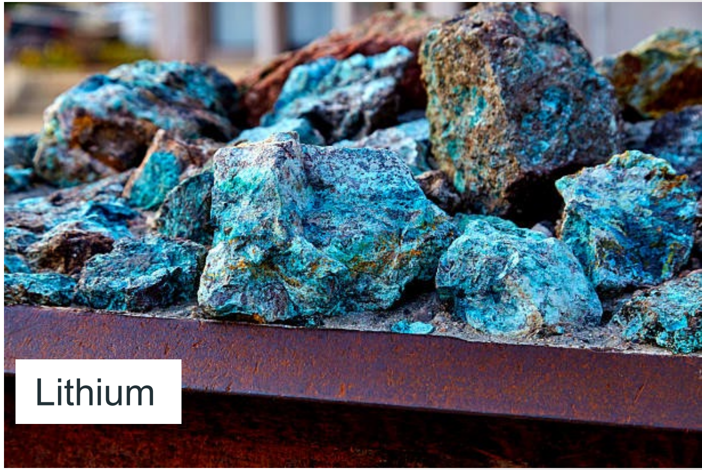


Battery Electric System (Freightliner)

Metals Required to Produce Battery Electric Vehicles

- As the demand for BEVs increases there will be a need for certain metals, including copper, nickel, lithium, cobalt, molybdenum, etc.
- 8 of the USGS 50 mineral commodities critical to the U.S. economy relate to batteries.
- BEVs require 3.5 times more copper than comparable ICE machines*.
- For larger electric vehicles (e.g. haul trucks), this value may rise to 11 to 16 times more copper than ICEs of equivalent size*.
- The EV industry is projected to require 3.7 million tonnes of copper per year by 2040*.

Copper Wire



Lithium

Cobalt

Molybdenum

* Robert Friedland, Ivanhoe Mines, Future Minerals Forum, 11-12 January 2022

Charging Electric Vehicles

- The demand for metal is not just with the BEVs but also with systems used to charge the batteries.
- Renewable energy is metal intensive. Both wind and solar require significant copper.
- The drive to develop grid power storage (battery) will also increase the need for metals.
- Wind power alone is expected to generate an additional 5.5 million tonnes of copper demand by 2028*.

* Robert Friedland, Ivanhoe Mines, Future Minerals Forum, 11-12 January 2022

Charging Electric Vehicles

- One estimation states that by 2030 there will be 20 million worldwide charging points for electric vehicles*.
- BEVs combined with charging points could increase the demand for copper to be 250% higher than produced in 2019*.
- This demand could outstrip copper production and challenge the fabrication of BEVs and associated components.

EVgo Press Release

EVgo Press Release

Sandvik Battery

* Robert Friedland, Ivanhoe Mines, Future Minerals Forum, 11-12 January 2022

Comments on the Future of BEVs

- BEVs will be developed as quickly as possible to meet demand and corporate strategies.
- Energy Storage Facilities are currently online and in production (large battery storage facilities for utility use).
- However, electrical grids will rely on carbon-based energy sources for decades to stabilize electrical power demand.

Natural Gas Power Plant

Power Generation in California

	2020 GWh	Percent
Total System Electric Generation	272,576	
Total In-State Generation	190,913	
CA Hydroelectric	21,414	11.2%
CA Nuclear	16,280	8.5%
CA Coal	317	0.2%
CA Oil	30	0.0%
CA Natural Gas	92,298	**48.3%**
CA Geothermal	11,345	5.9%
CA Biomass	5,680	3.0%
CA Wind	13,708	7.2%
CA Solar PV	27,179	14.2%
CA Solar Thermal	2,277	1.2%
CA Petroleum Coke	197	0.1%
CA Waste Heat	187	0.1%
Net Imports	**81,663**	**30.0%**

From: California Energy Commission Website

Moss Landing, California Tesla Megapack Battery Farm

California has built the world's largest battery energy storage facilities (Moss Landing 400 MW/1,600 MWh expanding by 350 MW/1,400 MWh)

Comments on the Future of BEVs

- Mineral economists are suggesting we could be in a super-cycle for commodities for 10 to 20 years.
- Foresee the need for carbon-based power for many years.
- Reliance on non-domestic sources of minerals could result in geo-political challenges to obtain those minerals.

Types of Battery Chemistries

- Lithium-Ion cells stores, and release energy controlled by an inbuilt electronic battery management system (BMS).
- Types of Li-ion cells include:
  - Lithium manganese oxide (LMO)
  - Lithium Iron Phosphate (LFP)
  - Lithium nickel-manganese-cobalt oxide (NMC)
- The various types of Li-ion battery determine energy density, cycle life, recharging characteristics, calendar life and other battery related features.

Tesla Model S Battery System

Artisan Battery Station

BEVs in Underground Mining

- BEVs in underground mining was initiated before mining companies drive to carbon neutrality.
- Deep, hot mines started investigating the use of BEVs as early as 2010.
- BEVs generate less heat than ICE machines.
- ICE pollutants such as carbon monoxide, nitrogen oxide and diesel particulate matter are eliminated with BEVs.

Artisan A4 / A10 / Z40 LHDs

Epiroc ST4 / ST14 / ST18 LHDs

BEVs in Underground Mining

- Two types of systems are used for underground mining equipment
  - Battery Swapping
    - 4-to-6-hours operation time plus 15 minutes to swap batteries
    - 3-to-5-year calendar life
    - 2500 cycle life
  - Fast Charging
    - 2-to-3-hours operation time
    - 15 min charging time (using ultra fast charger)
    - 5-to-7-year calendar life
    - 20,000 cycle life
    - Requires high currents and may need an upgraded mine electrical system.

MacLean Mine-Mate^{TM} Series CS3 – Cassette Truck

MacLean Mine-Mate^{TM} Series LR3 Boom Lift

BEVs in Underground Mining

Epiroc MT42 BE haulage truck

Sandvik LHD

Normet Spraymec MF 050 VC SD

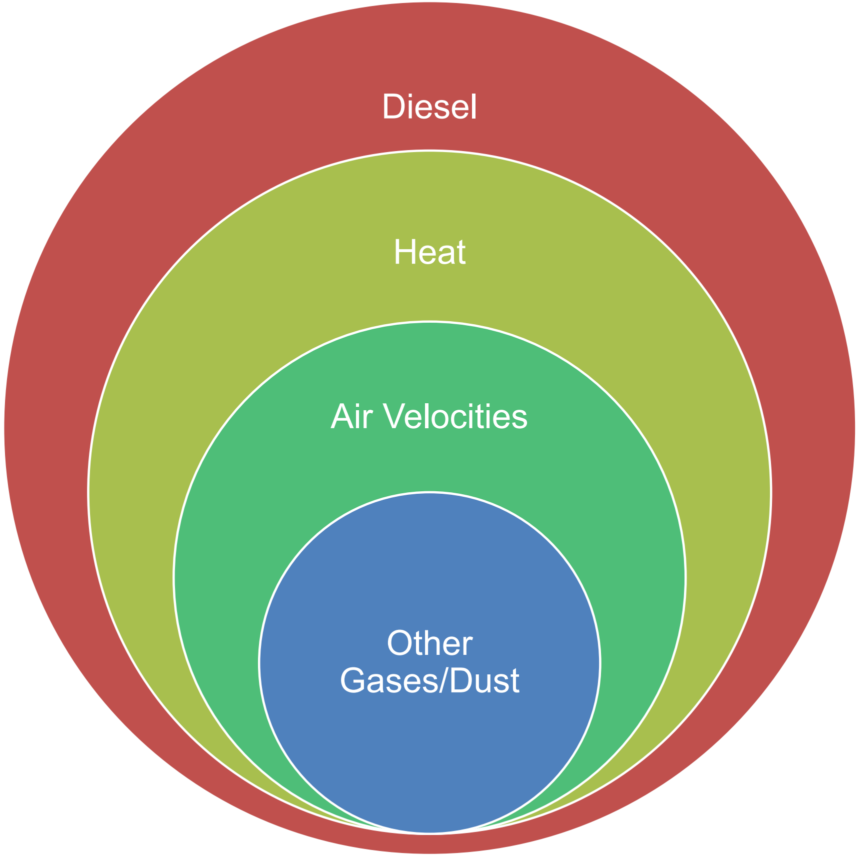
SandvikTruck

Epiroc/ABB Kiruna Truck

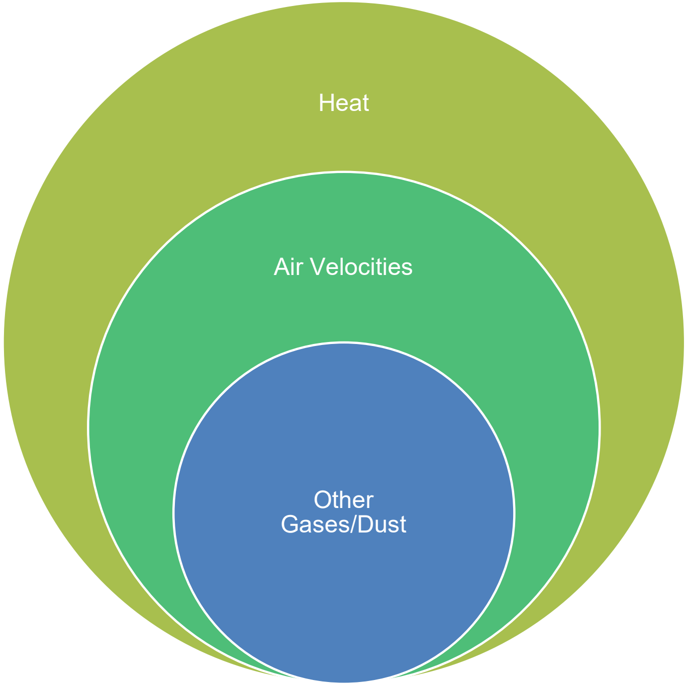
Application of BEVs in Mining

- A number of studies at operating mines have been performed to determine the benefits of replacing ICEs with BEVs.
- These studies invariably show significant reductions in:
  - Total ventilation required in the mine.
  - Capital cost to construct vent raises (due to smaller sizes).
  - Air refrigeration or air heating due to reduced airflow.
  - Total electrical power costs for fans and refrigeration plants.
- A case study showed the following results:
  - 40% reduction in total ventilation needs.
  - 20% reduction in ventilation raise dimensions.
  - 30% reduction in air refrigeration.
  - 45% reduction in total fan power.
  - 40% reduction in total electrical power.
- In addition, the unpredictability of air quality from diesel engine emissions is eliminated.
- If the mine is in cold climates, a significant reduction in air heating is realized with BEVs.

Minimum Airflow Requirement with Diesel



Minimum Airflow Requirement with BEVs



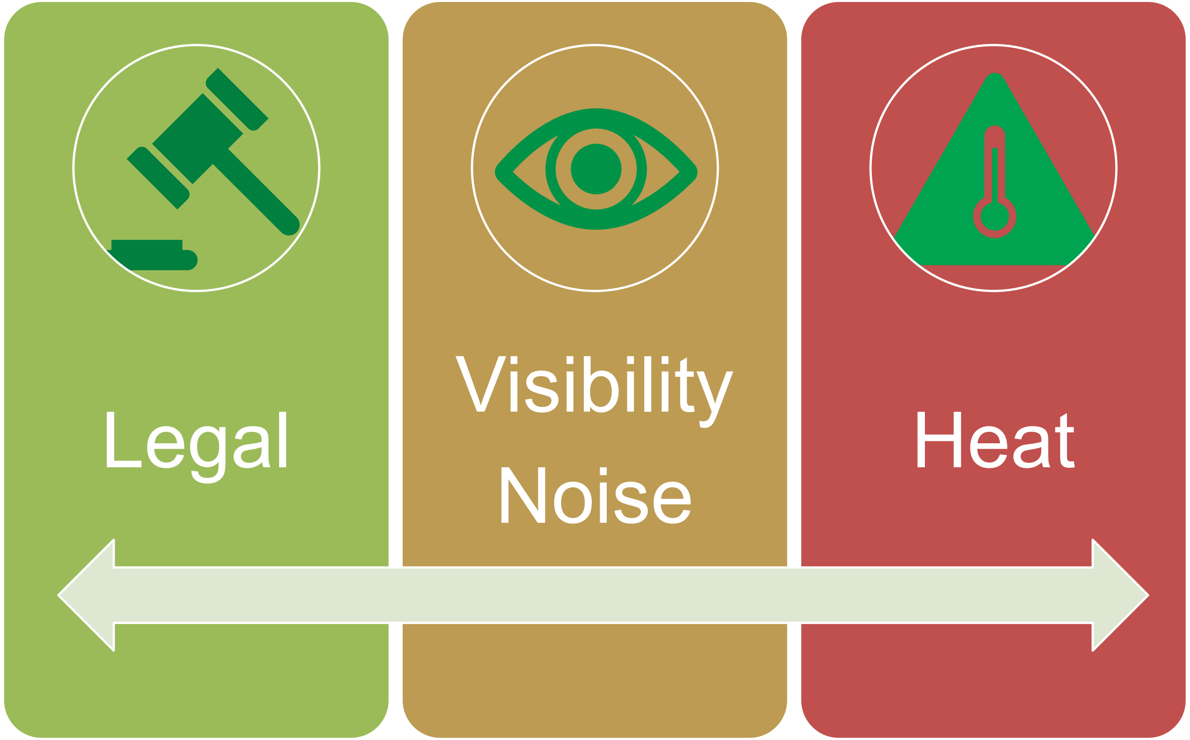
- Better air quality due to reduced amount of diesel particulates.
  - Positive impact on long-term health of employees.

Much cleaner air!

Summary of Atmospheric Contaminants by Activity	Units	Diesel Mine LOM Total	Electric Mine LOM Total
Sulphur Dioxide (SO_2)			
Diesel Fuel	t SO_2	3.7	-
Carbon Dioxide (CO_2)			
Diesel Fuel	t CO_2	98,645.8	-
Emulsion Explosive	t CO_2	1,154.9	1,154.9
Carbon Monoxide (CO)			
Diesel Fuel	t CO	1,479.6	-
Emulsion Explosive	t CO	213.5	213.5
Other Diesel Fuel Contaminants			
Non-Methane Hydrocarbons (NMHC)	t NMHC	77.5	-
Nitrous Oxides (NO_X)	t NO_X	3.5	-
NMHC + NO_X	t NMHC + NO_X	163.2	-
Diesel Particulate Matter (DPM)	t DPM	8.2	-
Other Emulsion Explosive Contaminants			
Nitric Oxide (NO)	t NO	7.4	7.4
Nitric Dioxide (NO_2)	t NO_2	0.7	0.7
Nitrous Oxides (NO_X)	t NO_X	10.0	10.0
Total Atmospheric Contaminants			
Sulphur Dioxide (SO_2)	t SO_2	3.7	-
Carbon Dioxide (CO_2)	t CO_2	99,800.8	1,154.9
Carbon Monoxide (CO)	t CO	1,693.1	213.5
Nitric Oxide (NO)	t NO	7.4	7.4
Nitric Dioxide (NO_2)	t NO_2	0.7	0.7
Nitrous Oxides (NO_X)	t NO_X	13.5	10.0
Non-Methane Hydrocarbons (NMHC)	t NMHC	77.5	-
NMHC + NO_X	t NMHC+NO_X	163.2	-
Diesel Particulate Matter (DPM)	t DPM	8.2	-

(source: SRK 2019)

Ventilation Designs with BEVs



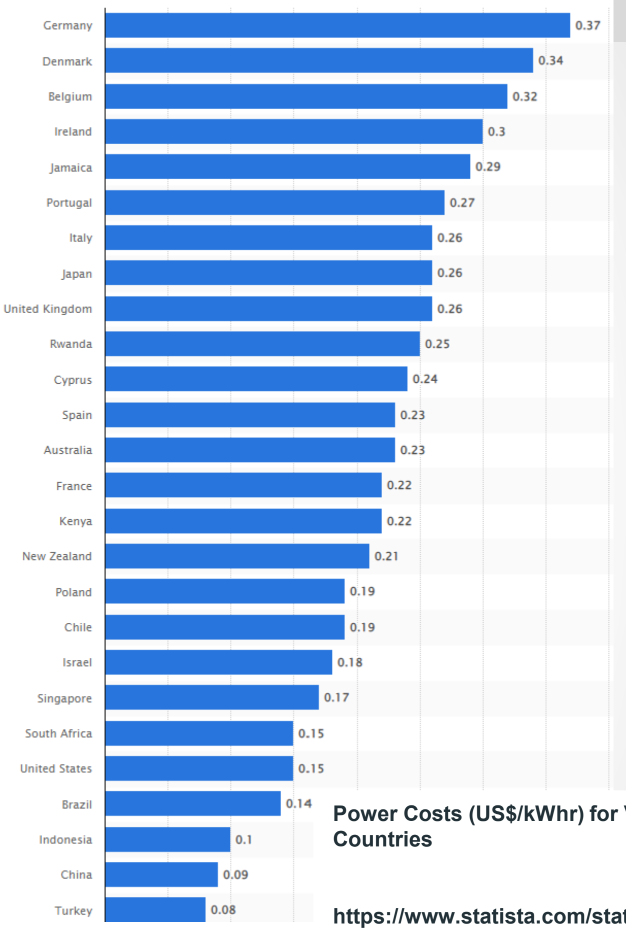
Dust

Blasting Fumes

In-Situ Gases

Costs & Budgeting

- Capital
  - Acquisition costs are higher for the electric units compared to their diesel counterparts. BEV implementation is approximately 15 to 20% higher than diesel.
  - Additional infrastructure is required for charging, whether on-board or swappable.
- Operating
  - Diesel costs vs Electricity rates.
  - Reduced ventilation requirements.
  - Potential for lower maintenance costs (fewer moving parts in BEVS, fluids, filters, etc.)



Power Costs (US$/kWhr) for Various Countries

https://www.statista.com/statistics/263492/electricity-prices-in-selected-countries/

Comparison Between BEVs Operating Cost with ICE Operating Cost

- In addition to ventilation savings, BEVs use less energy than ICEs. As an example:
  - 60 kWh of BEV energy equivalent to 6 liters of diesel fuel.
  - 15 BEVs operating 310 days/yr. consume 279,000 kWh (at 0.12 $/kWh equals a cost of $33,500.
  - Equivalent diesel machines consuming 10 kWh/liter at 33% efficiency would require 85,000 liters/yr. (22,400 gal/yr.) Fuel cost of $3.85/gallon equates to $86,240/yr.

Infrastructure & Maintenance

- Sizing of electrical grid - ability to handle the vehicle fleet requirements
- Different types of chargers and location of charging stations
- Skillsets of the workforce will be modified – more electricians and technicians and fewer mechanics

Normet Utimec MF 500 Transmixer SD

MacLean Bolter Series 900

Ventilation Summary

Reward

- Lower Ventilation CAPEX/OPEX
- Reduced ventilation airway dimensions
- No diesel emissions from equipment

Risk

- Undersize ventilation system
- Less flexible operation
- Control of gases/fires
- Heat/dust mitigation
- Limits to haulage distance with BEVs for long ramps

Risk Management

- Ventilation planning
- Thermal modeling
- Phased ventilation models
- Airway size sensitivity analysis
- Fire/transient time modeling

Health & Safety Considerations

- Fire
- Collision avoidance may become more difficult for people used to hearing the machine coming down the drift
- Less noise and vibration due to the motor now being electric
- Electrical shock from BEVs

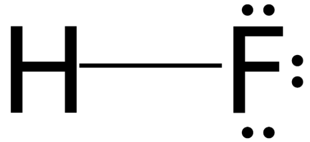
Risk: Mine Fires with BEVs

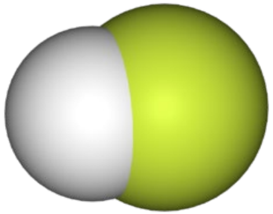
- Battery fire risks arise from:
  - External damage (collision)
  - Over-charging or discharging of battery
  - Inappropriate towing (not disconnecting regen system prior to towing)
  - Defects or internal short circuit leading to thermal runaway and exothermic reactions in the battery
  - Malfunctioning charging systems

Risk: Mine Fires with BEVs

- Potential gases from a battery fire:
  - Hydrogen fluoride (HF),
  - Hydrogen cyanide (HCN),
  - Carbon monoxide (CO),

  - The flourine content inside lithium-ion cells may also form phosphorous oxyfluoride (POF_3)
  - Additional fire gases will be from equipment hoses, plastics, tires, etc





BEV Fires (Automobiles)

From: “A Review of Battery Fires in Electric Vehicles”, Fire Technology, January 2020

Risk: BEV Fire

- Studies have shown:
  - The heat released and hazard of a BEV fire are comparable to that of an ICE fire, however, some BEVs can generate significant heat in a short period of time.
  - However, once the battery is involved in the fire, there is greater difficulty in suppressing the fire due to burning battery packs (inaccessible)
  - Can cause re-ignition without sufficient cooling

Risk: BEV Fire Fighting

- Lithium-Ion fires can be
  - Difficult to extinguish
  - Require large quantities of suppressant
  - May re-ignite if not cooled sufficiently
- CO_2 or chemical extinguishers may suppress the fire, but will not cool down battery pack
- Water sprays are effective but may trigger more electrical faults over time and react with lithium to release hydrogen gas
- It can take significant water to extinguish a BEV fire (a Tesla automobile took 28,000 gallons of water to extinguish a car fire)
- Re-ignition without sufficient cooling

Risk: BEV Fire Fighting

- Isolate BEV fire source
  - Restrict access and evacuate affected operations
  - Allocate available fire fighting resources to incident
    - Shutdown all non-emergency related water supplies
- Immobilize equipment
  - BEV power may be “hibernating”. Care must be taken to avoid contact with controls, trams or accelerators.
- Disable Power
  - Automatic shutdown of high voltage feeds from battery
  - Disconnect power from any charger or charging station

Risk Management with BEVs

- Know what types of BEV vehicles are on site
- U/G location of vehicles (Vehicle Tracking)
- Locations of BEV Charging Stations and Storage (with quantities)
- Training of OMR to electrical and mechanical trades people
- Continue research and development on best practices with BEV fires
- Updated and peer reviewed designed emergency response plan that is trialed and reviewed on a regular basis
- Well-versed Emergency Response group

Risk Management with BEVs

- Strategic placement of charging stations and storage during planning stage (ex. Near Exhaust)
- Fire doors / Fire Suppression
- Equipment Parking/Charging Locations
- Proper handling and removal of excess batteries
- Remote Gas Monitoring
- Advanced monitoring in charging stations (Video/Thermal)
- Access to water (Drop headers / water pressure)
- Ventilation
- Transportation for Mine Rescue teams

Summary

- Battery electric vehicles will have a dominant impact on metals
- Demand for base metals could exceed current supply
- BEVs for mining application is increasing
- Planning for BEVs requires engineering for location of battery charging stations, effective equipment operation, and safety.
- Additional training of personnel in maintaining and operating BEVs.
- BEV fires can be challenging to extinguish and a detailed safety plan is necessary on how to fight BEV fires, escapeway planning and location of charging stations.
- Proper planning for long term BEV operation is required.

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