Developing Safety Standards for Application of Battery Driven Powertrains

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MDEC Conference, Ontario, Canada
October 8-10, 2019

Outline

- Introduction to electric powertrains
- Functionality and safety
- Safety Standards
- Holistic View
- Conclusions

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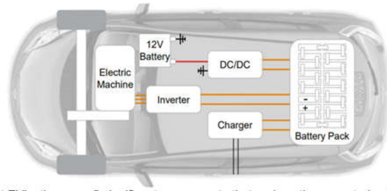
Introduction to Electric Powertrains

State of Industry

- On road light and heavy duty electrification is an irreversible trend to achieve lower emissions and better fuel economy
  - Strong synergies with performance, comfort and autonomous driving
- Off road electrification is being driven by productivity and logistics
- Mining industry has initiated electrification efforts primarily for the lower vehicle emissions and the prospect of reducing air handling costs
- While cost limits rate of electrification growth in other industries, mining industry can realize overall cost reduction
- Energy recovery capabilities also limit heat generation from the powertrain

What is an Electric Powertrain?

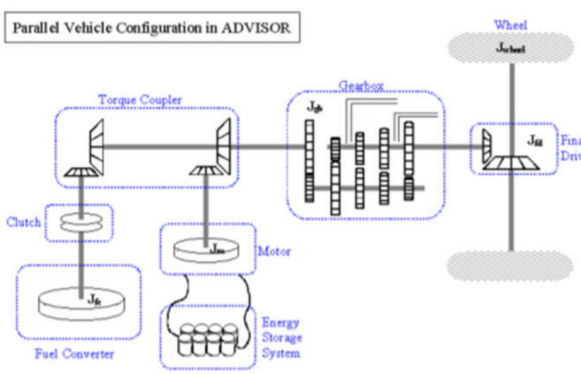
- Conventional powertrains use an internal combustion engine and transmission to propel the vehicle and accessories
- Hybrid electric powertrains use a combination of engine and electric machines with batteries to operate at better efficiency and lower emissions
- Battery electric powertrains only use electric machines and batteries to operate the vehicle

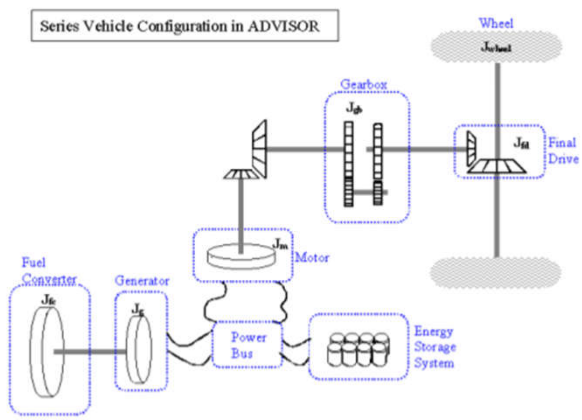


In most EV's, there are 5 significant components that replace the powertrain of a traditional vehicle:
- Electric machine
- Battery Pack
- Inverter
- Charger
- DC/DC Converter

Introduction to EV Powertrain Function and Performance - from a Battery Perspective, Neil Johnson, ARPA-E Range Kickoff Meeting, 2014

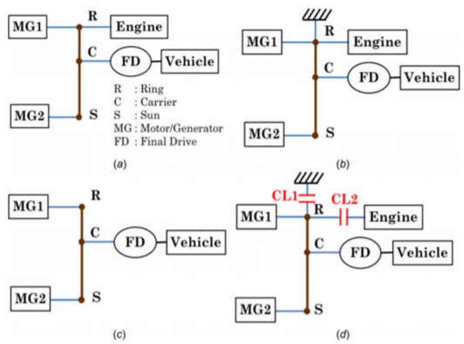
Series vs Parallel Topology



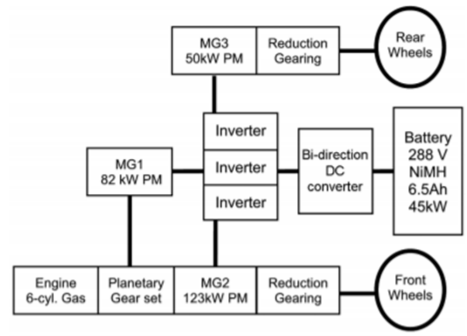


https://www.vehicular.isy.liu.se/Edu/Courses/TSFS03/OH_2011/03_hybrid_handout.pdf

Hybrid Powertrain Layouts



Lever representation of three modes of a modified Chevrolet Volt architecture (without series hybrid mode): (a) hybrid configuration, (b) first pure electric configuration, (c) second pure electric configuration, and (d) combined multimode architecture



The powertrain layout of a hybrid vehicle with a front hybrid powertrain and a rear separate motor.

https://www.vehicular.isy.liu.se/Edu/Courses/TSFS03/OH_2011/03_hybrid_handout.pdf

https://pdfs.semanticscholar.org/5d61/ef709e1772b6bf2eb549c343d4553f474eb3.pdf

https://pdfs.semanticscholar.org/4734/59b51d3570bbbcf8bed3dc28db9c563ebfce.pdf

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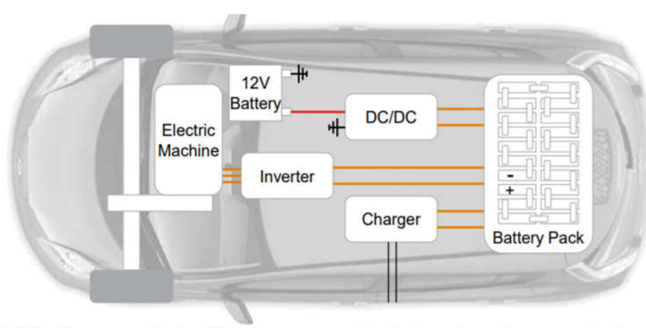
Battery Electric Powertrain



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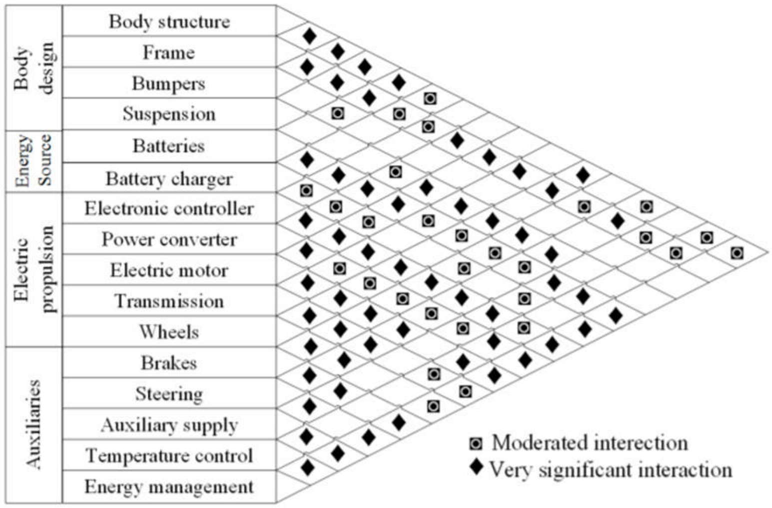
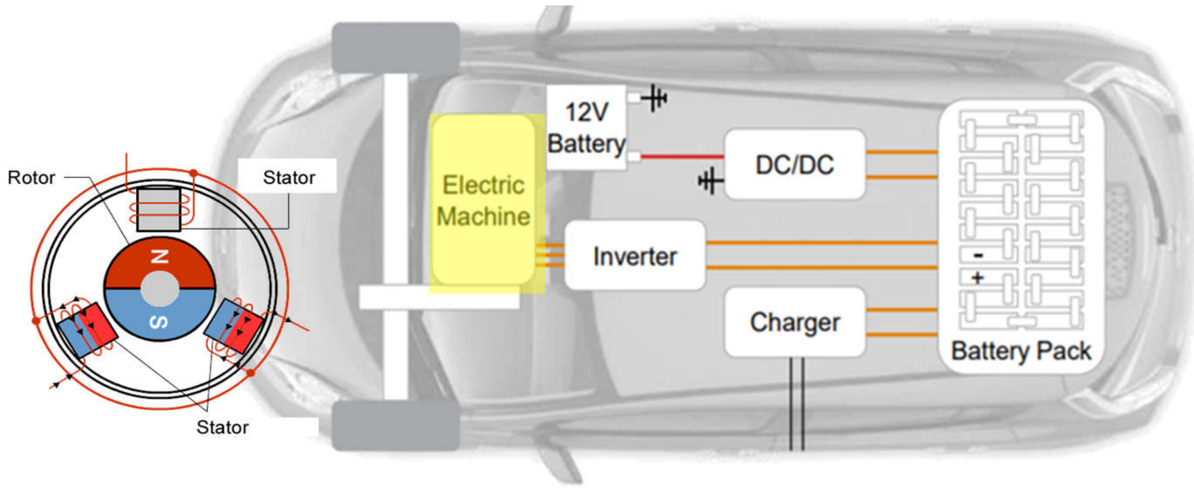
E-Powertrain Component Interactions



A Comprehensive Study of Key Electric Vehicle (EV) Components, Technologies, Challenges, Impacts, and Future Direction of Development
Fuad Un-Noor 1, Sanjeevikumar Padmanaban 2,*, Lucian Mihet-Popa 3, Mohammad Nurunnabi Mollah 1 and Eklas Hossain 4,*, Energies 2017, 10, 1217; doi:10.3390/en10081217

Functionality and Safety

Electric Machine

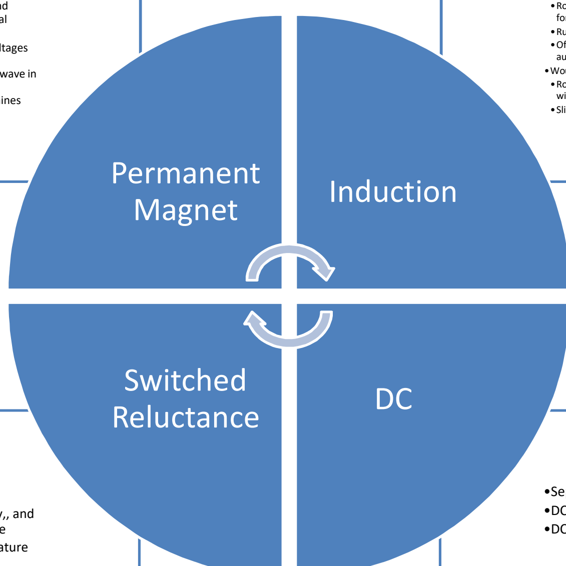


Motor Types

- PM Synchronous Machines (PMSM): Uniformly rotating stator field and induced waveforms are sinusoidal
- PM Trapezoidal or brushless DC machines (PMBLDC): Induced voltages are trapezoidal in nature; phase currents are rectangular/square wave in nature. They are also called electronically commutated machines

- Squirrel Cage IM
  - Rotor has short circuited copper bars that form the shape of squirrel cage
  - Rugged construction and low cost
  - Of greater interest and relevance to automotive xEV
- Wound rotor IM
  - Rotor winding terminals brought outside with slip rings for external connections
  - Slip rings are used for speed control

PMSM

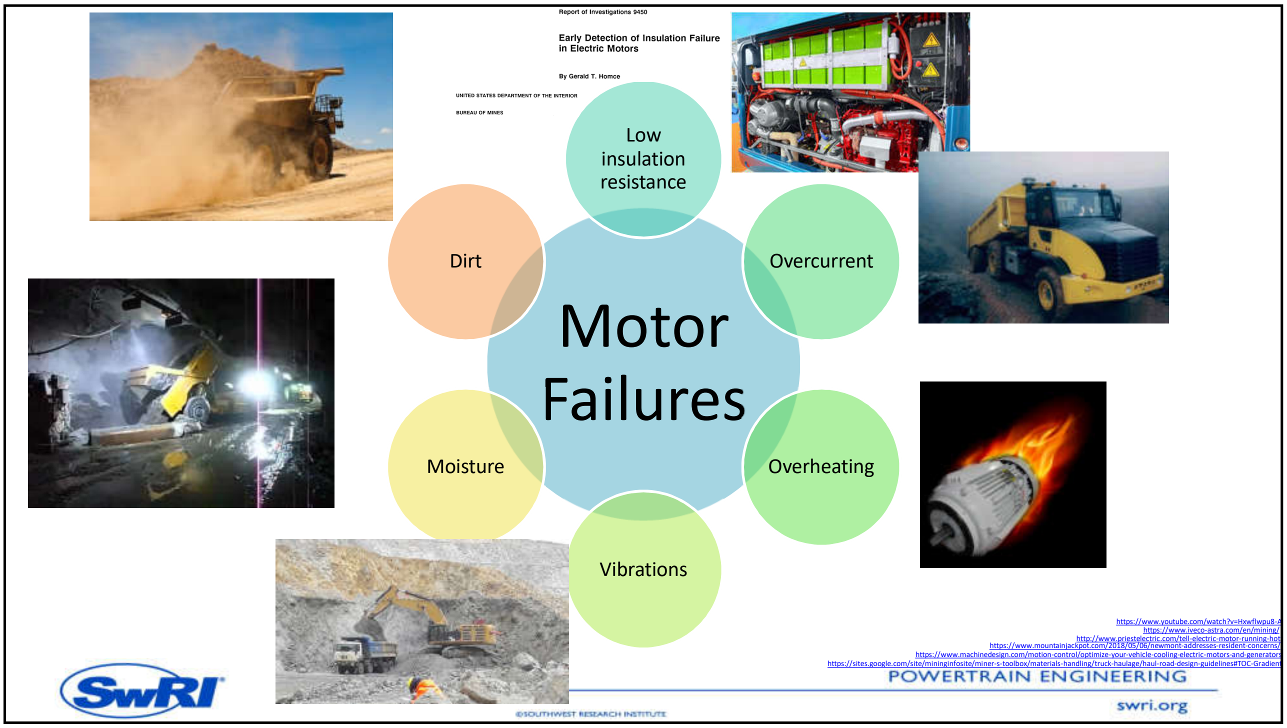


Axial-flux SRM

- Simple and rugged
- Fault tolerance
- High-speed operation ability,, and its features of fault tolerance
- Insensitivity to high temperature

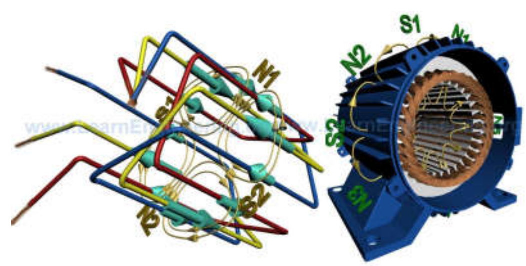
- Separately Excited DC Machine
- DC Shunt Machine
- DC Series Machine

https://www.electricalengineeringtoolbox.com/2016/12/basic-parts-of-three-phase-3-squirrel.html
https://functionbay.com/documentation/onlinehelp/default.htm#!Documents/pmsmpermanentmagnetsynchronousmachine.htm
https://www.intechopen.com/books/switched-reluctance-motor-concept-control-and-applications/switched-reluctance-motor-topologies-a-comprehensive-review



Balance of Magnetic Fields in Rotor

- Like the tires on a car, having a balanced rotor and uniform intensity rotor levitation magnets will make for a smooth running motor. Since there is so little friction with the rotor levitated, the least bit of out of balance or non-uniform magnet strength shows up. Most rotors are going to be a little bit out of balance. The slightest out of balance of the rotor will cause the rotor to bounce around at some rotation speeds similar to car tires. Some speeds are much worse than others. I've noticed that the major out of balance oscillations of my motor are over a rather small range at low rpm. There seems to be another out of balanced condition at very high speeds.
- When running the motor on low voltages, the bouncing around affect of the free end of the rotor can cause the motor to not be able to speed up above the out of balance speed. The bouncing around of the rotor can cause the rotor to fly off the levitation field. When this happens the rotor will crash onto the stator magnets.



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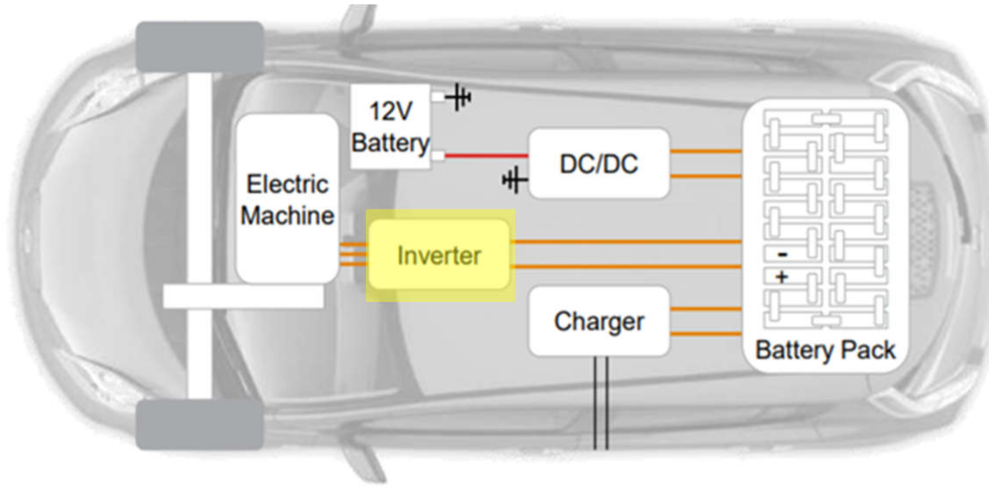
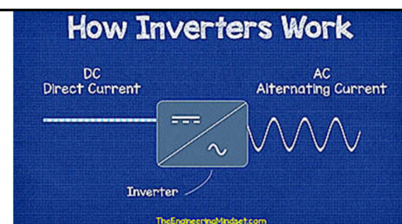
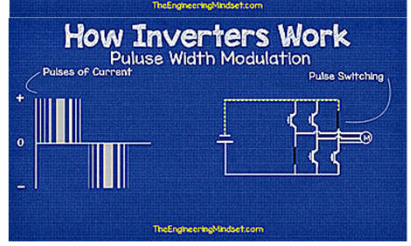
Inverter

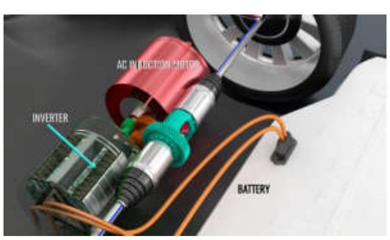


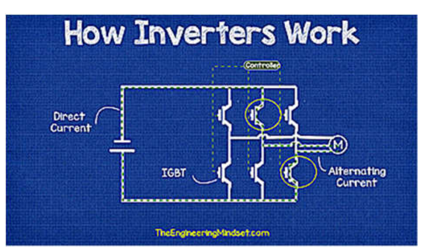
Inverter Functionality

- Battery packs provide direct current (DC) at their output terminals.
- Electric machines are controlled by varying an alternating current (AC) waveform.
- The motor inverter provides this conversion between DC and AC and the torque control functionality.
- Mining vehicles will need more powerful inverters than most EVs due to their shear weight, as the motors will require more power to propel the vehicle.









https://theengineeringmindset.com/how-inverters-work/

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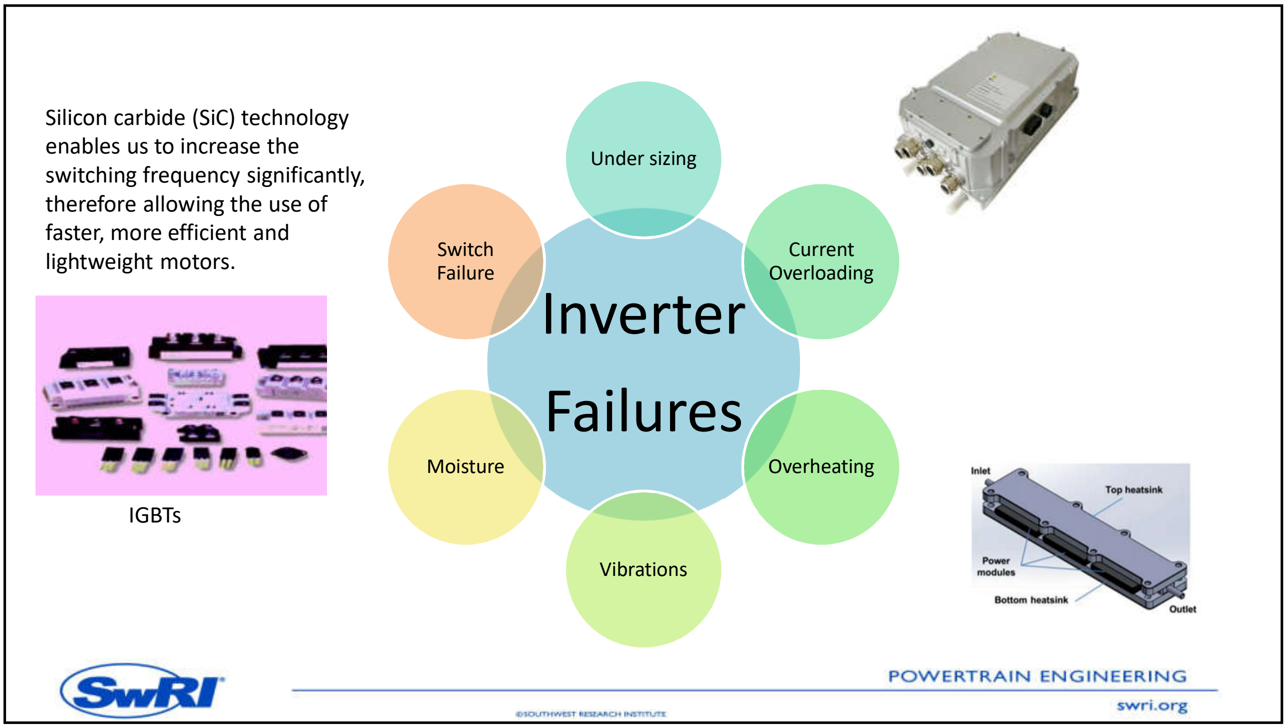
Silicon carbide (SiC) technology enables us to increase the switching frequency significantly, therefore allowing the use of faster, more efficient and lightweight motors.
IGBTs
Inverter Failures
Under sizing
Current Overloading
Overheating
Vibrations
Moisture
Switch Failure
Inlet
Top heatsink
Power modules
Bottom heatsink
Outlet
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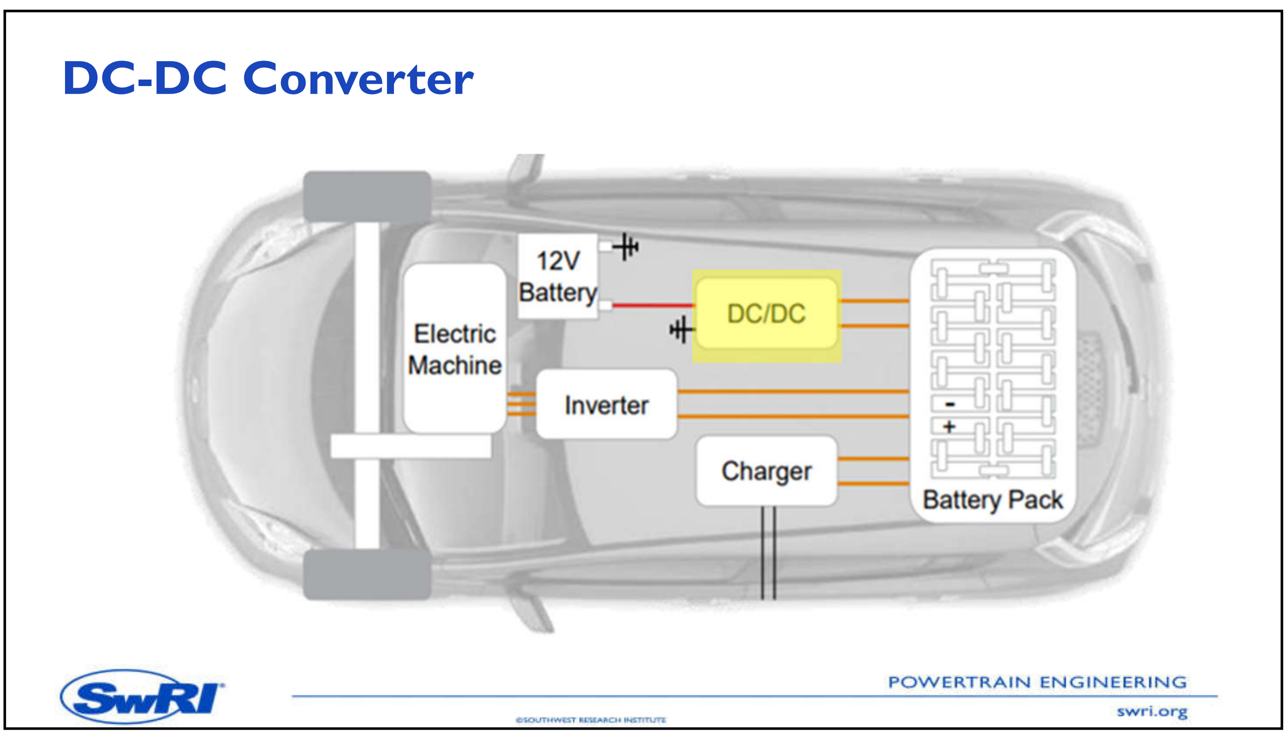
DC-DC Converter
12V Battery
DC/DC
Electric Machine
Inverter
Charger
Battery Pack
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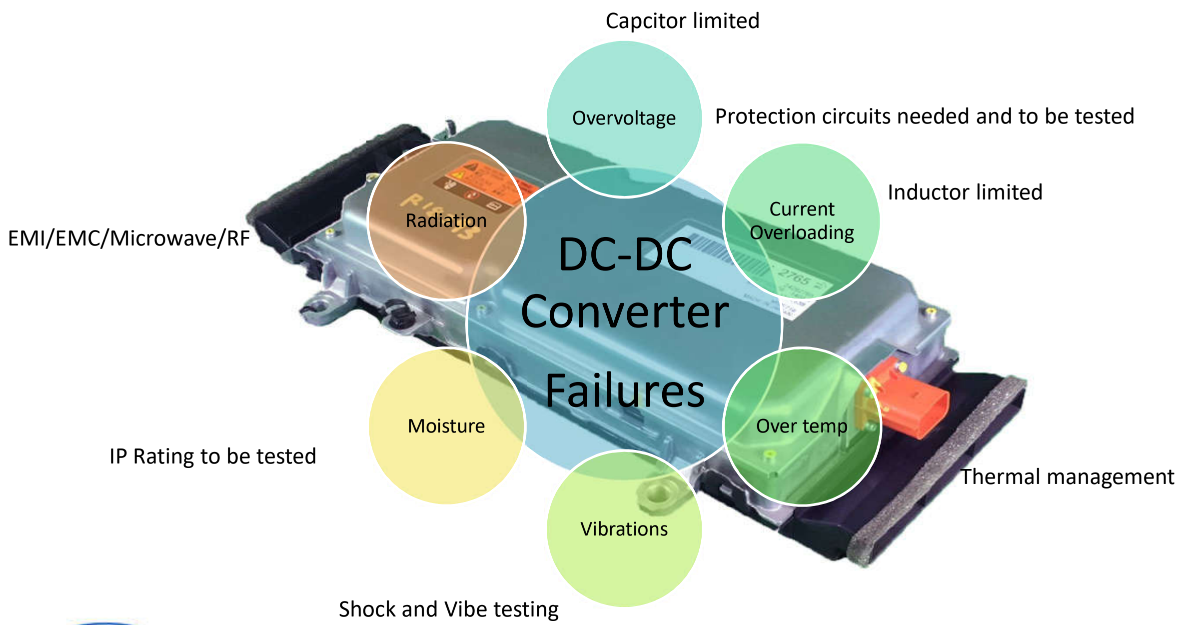

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Protecting the Electrical System

Removal of protection devices and opening of doors or protective covers where there is access to electrical equipment under voltage should be possible only with tools or keys. Any secondary connection between the drive circuit and the vehicle is considered to be an error. Errors of the vehicle body can lead to several hazards like short circuit, electric shock, or uncontrolled operation. All of these present a safety risk in a mining situation to the operator. Operators should be instructed not to open these compartments, unless they are properly trained.

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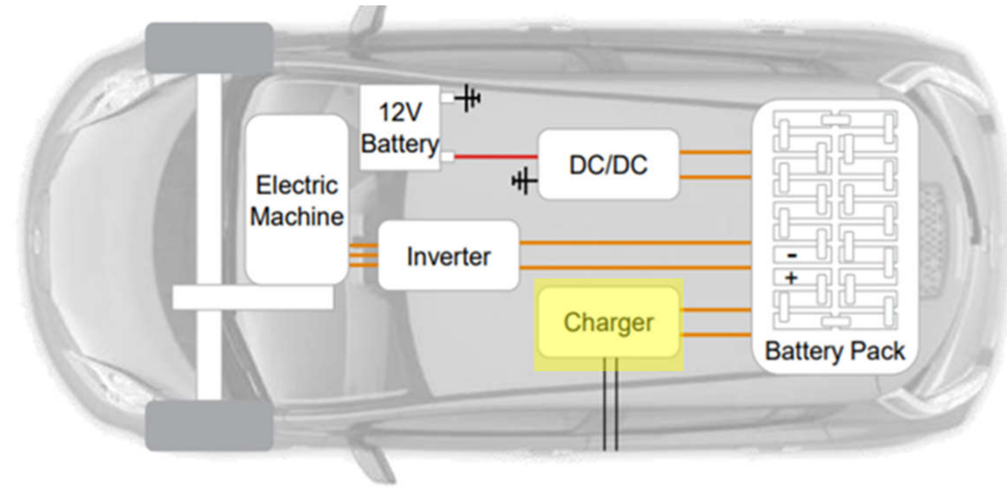
On Board Charger



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On board Charger Failure Modes

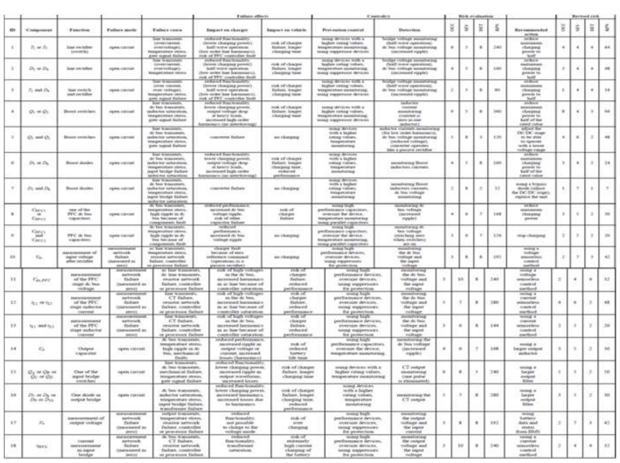

Table to be referenced for examples

Some faults can be easily detected by conventional methods like an overcurrent led to a fusing operation, but some faults can not be detected by conventional methods. For example, if the output capacitor of the charger fails to an open circuit, the output voltage is not changing because of its connection to the battery. In this case, the battery current has a higher ripple than the intended value. This higher ripple may reduce the battery lifetime. In a conventional charger with a full-bridge topology, this fault is not detected if it is not searched for.

The detailed circuit analysis, detection algorithms, post-fault actions and design enhancement recommendations are briefly presented in the developed FMEA table. However, one can refer to [8], [9] for a detailed information, in a circuit level for instance. The FMEA table provides a summary of the selected fault cases, cause of each fault, impact of the fault on the charger and vehicle, detection methods, post-fault actions, risk number and its afterwards improvement.

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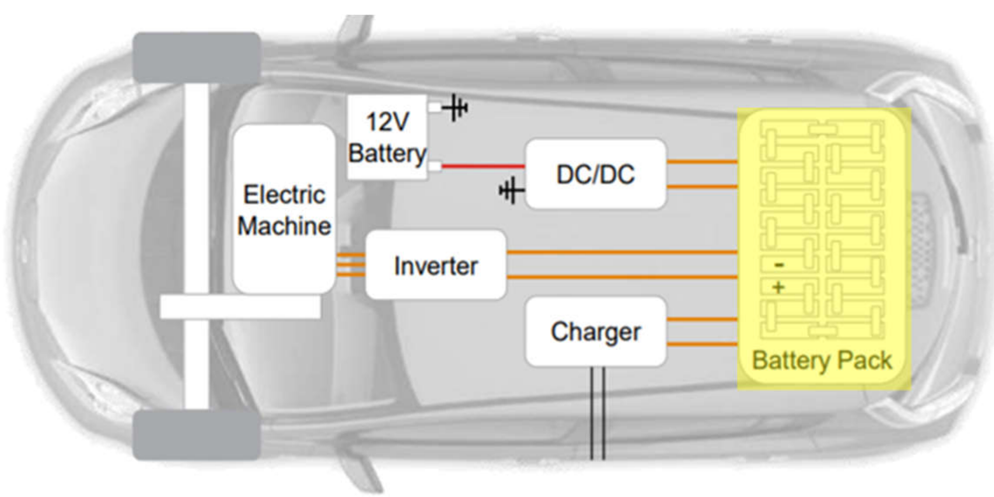
On Board Charger Failure Modes

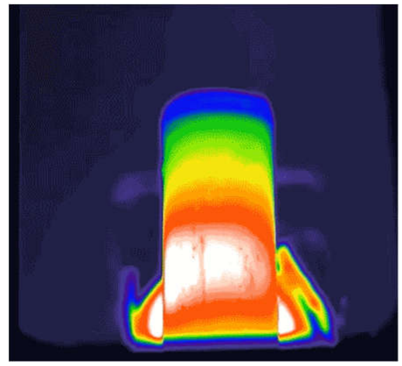
- In the component field of the table, it is stated which component or combination of components have a failure. In the next field of the table, failure mode, the device status after failure is explained. For instance, if one or more diodes are failed, it can lead an open circuit or a short circuit status. The failure causes, are the main roots of the failure that have direct correlation with the occurrence number.
- Failure effects are the next part of the table that shows how one particular case affects the charger and vehicle. This part has direct relation with severity. Prevention control and detection methods are the next fields in the table that show how one can reduce those failures. The risk evaluation is the next part in which risk priority numbers are provided as the result. If one fault is occurred, there are recommended action(s) to enhance the performance or equivalently to reduce RPN for each case, if it is possible. In most of cases, the RPM numbers are reduced after proposed post-fault actions that is equivalent to an increased reliability. As the next step of this work, one can calculate the reliability of the charger to see in a quantitative manner how much reliability improvement is achieved. This table can expanded to cover more faults like the semiconductors failure to an open circuit status.

Battery Pack



Battery Safety

- The battery is the most critical part for electric vehicles. It presents several potential hazards: electrical, mechanical, chemical and danger of explosion. The electrical aspects include protection against electric shock and short circuit. Therefore, it should be provided for protective devices – fuse of the battery. When using multiple batteries it should provide more locking connections.
- Damage to the battery could result in vehicle, personnel, or equipment damage. Damage to the battery can occur with blunt force, vibration, humidity, temperature, over voltage, and over current. Depending on the severity of damage, a battery's lifespan can be shortened, or it can go into thermal runaway.



https://batterybro.com/blogs/18650-wholesale-battery-reviews/tagged/battery-news

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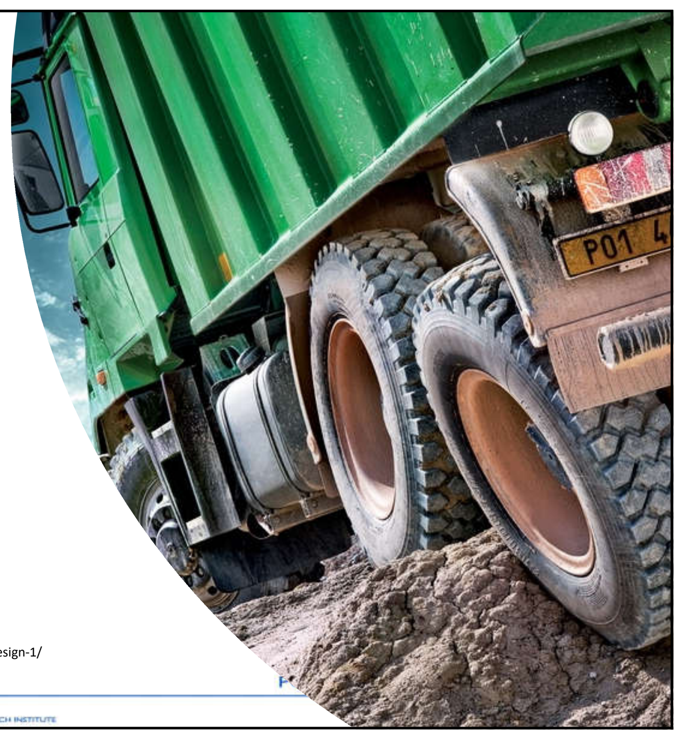
Battery Safety Cont.

- The department that houses the batteries must be designed so it will avoid any unintentional direct contact or short circuit. With regard to the mechanical aspects, since the battery is heavy part of its position it should be determined as to avoid instability of the vehicle and it should be limited to avoid damage in case of accident.
- Mining vehicles need to be stable, as they have weight transfer when lifting or carrying loads that needs to be accounted for.



https://www.tatratrucks.com/why-tatra/tatra-vehicle-design/tatra-vehicle-design-1/

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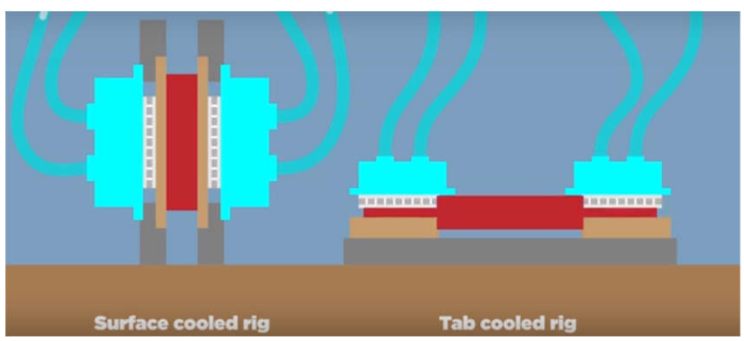
Torsional Rigidity of Batteries

https://www.tatratrucks.com/why-tatra/tatra-vehicle-design/tatra-vehicle-design-1/

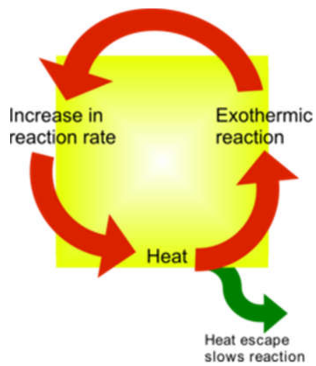
Battery Cooling



Batteries work based on the principle of a voltage differential, and at high temperatures, the electrons inside become excited which decreases the difference in voltage between the two sides of the battery. Because batteries are only manufactured to work between certain temperature extremes, they will stop working if there is no cooling system to keep it in a working range. Cooling systems need to be able to keep the battery pack in the temperature range of about 20-40 degrees Celsius, as well as keep the temperature difference within the battery pack to a minimum (no more than 5 degrees Celsius)

https://avidtp.com/what-is-the-best-cooling-system-for-electric-vehicle-battery-packs/

Failure to Cool a Battery



- Potential thermal stability issues, such as capacity degradation, thermal runaway, and fire explosion, could occur if the battery overheats or if there is non-uniform temperature distribution in the battery pack. In the face of life-threatening safety issues, innovation is continually happening in the electric vehicle industry to improve battery cooling systems.
- Mining Vehicles require large battery coolers, as they tend to have large batteries. These cooling systems need to be designed in spec with mining conditions, as to not break. If the cooling system works through liquid, precautions need to be taken so that the system is well protected from its surrounding, as to not spill large amounts of coolant over the mine.
- If cooling system does fail, the vehicle should not be allowed to send power to the wheels any longer. If on an incline, battery power should go solely to powering the brake booster and allowing the vehicle to lower itself to a flat surface if possible. Once the vehicle is on a flat surface, or vehicle is safely able to be towed, a recovery vehicle should retrieve it and bring it back to home for analysis.

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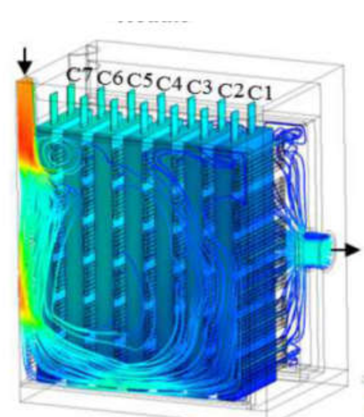
Future Cooling

Since electric vehicles have become so widely used, there is a high demand for longer battery life and higher power output. To achieve this, the battery thermal management systems will need to be able to transfer heat away from the battery pack as they are charged and discharged at higher rates. The heat generated as the battery is used can pose safety threats to the passengers. Due to the high stress and temperatures generated by the batteries, there is an even higher importance on having the correct coolant and additive package. While companies such as Tesla, BMW, and LG Chem can use a traditional liquid coolant for their indirect cooling systems, continued research and development will need to be done on battery packs and coolants to advance electric vehicle safety.



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Heating the Battery

Lithium Battery for Cold Weather Applications | RELiON, Sep 2018

Tesla Model 3 — Cold Weather Tips – Tom Harrison's Blog, Dec 2018

- Substantial range reductions in the cold. Mining operations taking place in cold climates will need to take precautions.
- Regenerative braking is severely reduced because the battery cannot take in the rate of charge energy from braking
- Lithium plating issues

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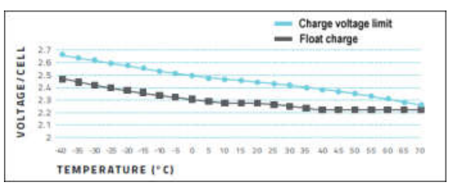

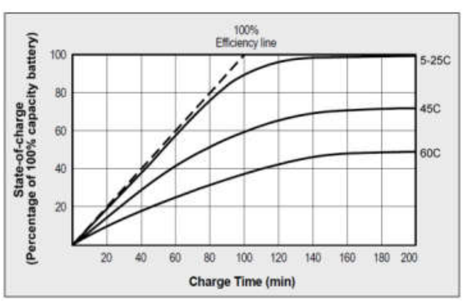

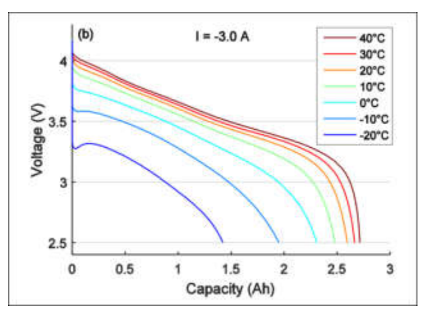

Battery Temperature Charts

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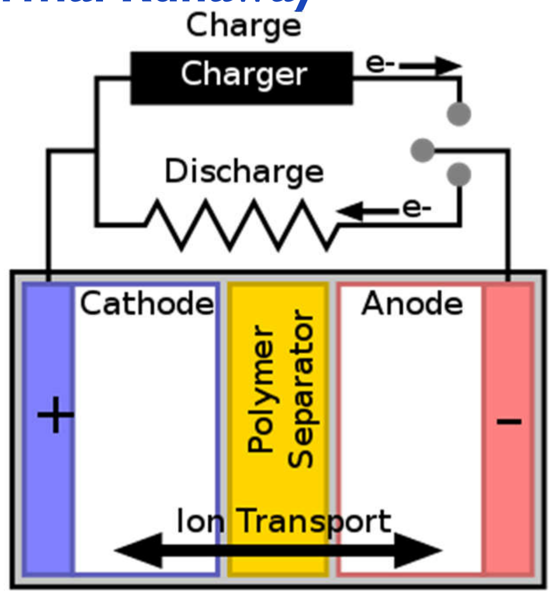
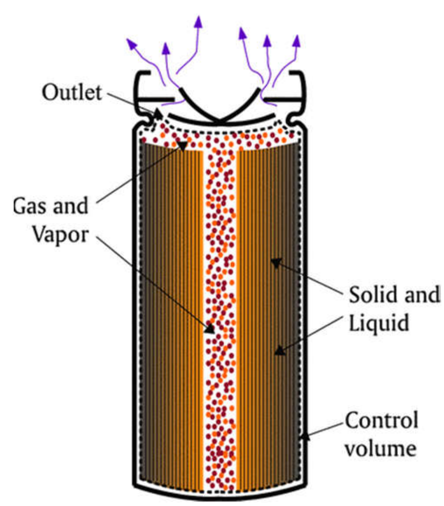
Separators to Prevent Thermal Runaway

- The polymer separator is the most widely used in commercial Li-ion batteries
- If the battery temperature increases to near the separator melting point, the separator pores will close (separator shutdown). The separator shutdown blocks the pathway between the positive and negative electrodes, and stops the electrochemical reactions. The battery impedance will also usually increase during this process.
- The ceramic/polymer composite separator has a higher melting temperature and is more thermally stable than the polymer separator



Cell Venting

- Typically implemented fail-safe mechanisms include safety vents, thermal fuses, and shutdown separators. Safety vents are designed to release extra internal pressure and prevent the continuous increase of internal temperature.
- During thermal runaway flammable gases from the battery materials, including organic electrolyte, will accumulate inside the battery. Allowing the gas accumulation may result in the rupture of the battery. A cell-venting mechanism is designed to reduce the battery's internal pressure and release the gases.
- Venting can reduce the pressure applied on the battery separator and reduce the risk of battery internal short circuit. The concept of a battery vent aims to decrease the pressure built up in the thermal runaway process and prevent battery rupture.



Humidity for Batteries

To prevent water vapor condensation at cooling surfaces inside the battery system, an adsorption unit is applied to reduce the risk of corrosion and electric shorts, especially in hot and humid climates.

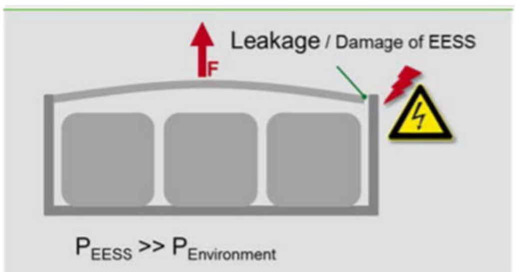


Figure 1: Battery System without pressure balancing

Figure 2: Battery System with pressure balancing

https://www.mann-hummel.com/fileadmin/corporate/04_Unternehmen/5_Download%20Center/05_Produktinformationen/3_L%C3%B6sungen_f%C3%BCr_alternative_Antriebe/Whitepaper_Humidity-Control-Paper_V1-1.pdf

Delayed Failures

- The most widely publicized incident involving a fire happened in 2011 with Chevrolet Volt after it has undergone a crash test in MGA research center. The batteries ignite three weeks later after being subjected to a side impact of 30 km/h as part of the NCAP test. The fire quickly spread to neighboring vehicles. Extensive investigation into the fire showed that a small amount of coolant entered into the housing of the battery at high voltage collision, which caused a short circuit and eventually led to uncontrolled heat state in terms of the temperature.
- LESSON: Mining vehicle's batteries need to go through a series of standard and manufacturer mandated tests whenever they are involved in an accident. Putting a machine back to work after an accident could result in battery decomposition and vehicle failure hours later. Having an operator drive around with a vehicle on the verge of thermal runaway could lead to injury and equipment loss.

https://www.evaluationengineering.com/applications/product-safety/article/13007366/fire-protection-engineers-address-liion-safety

Switch In Case of a Crash

- Risks from an accident include potential electric shock from damaged systems that are turned off during or immediately after crash. Because of this, the association recommends that manufacturers of electrical vehicles install switches that will stop the energy from the battery case in accident. The location of these switches must be standardized for security. Drivers of towing services also need to be well informed and trained on how to deal with hybrid and electric vehicles. The danger can be reduced if people from emergency services have easy access to batteries and if vehicle manufacturers create unique location for exclusion to all electric and hybrid vehicles.
- Pathways and routes should be planned so that tow vehicles have access to a damaged EV. All kill-switches should be able to be activated no matter what position the vehicle is it.

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Working with batteries

- On the Mining Safety portal we have emphasized the importance of wearing personal protective equipment. This requirement also extends to those working in the battery charging room. The Personal protective equipment (PPE) required when working with batteries includes: Approved face shield and goggles Approved acid-resistive gloves with gauntlets of at least 6 to 8 inches Approved full-length rubber apron Slip- and acid-resistive footwear with protected toe Nonconductive tools, including scrapers, mops and brushes Adequate number of ABC re extinguishers that are properly inspected/maintained Adequate amount of neutralizer Workers should protect open cuts or lesions with plastic patches. They should also refrain from carrying batteries by their terminal posts and always use an appropriate strap or cradle.

https://www.miningsafety.co.za/dynamiccontent/125/battery-charging-rooms-and-mining-safety

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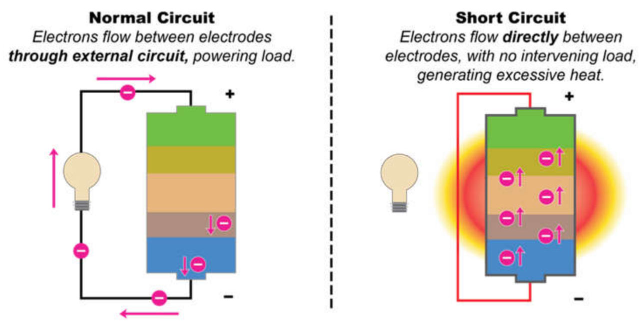
BMS Short Detection

- *Internal Short Detection*: Internal Li-Ion cell shorts have been proposed by researchers as the primary reason for initiation of a thermal run away. Quality BMS designs have algorithms to directly detect both early onset and longer term wear-out aggregation of internal cell shorts and notify the vehicle operator to replace the defective battery/module. An option can be to automatically take action to discharge the battery/module to prevent or reduce the likelihood of a spontaneous thermal run away event.
- Safety Redundancy: Redundancy is a common in mission critical applications. It can be used by BMS and modular system design structure to improve battery system safety by shutting down dangerously defective sections of the battery system and then continuing operation at reduced capacity until replacement or repairs can be made.



Fuel Gauge and Performance

Vehicles that include a high voltage RESS, may be equipped with a gauge that indicates propulsion system state of charge. This gauge may be similar in format and operation to fuel gauges used on conventional ICE vehicles. The ISO symbol for RESS, described in ISO 2575, may be used as the identifying icon and should be located near the vehicle RESS state of charge gauge. If the high voltage RESS is the only power source for the vehicle, vehicle performance capability (maximum speed, acceleration, hill climbing ability, etc.) should not vary appreciably throughout the span from indicated 'FULL ' to 'EMPTY'.

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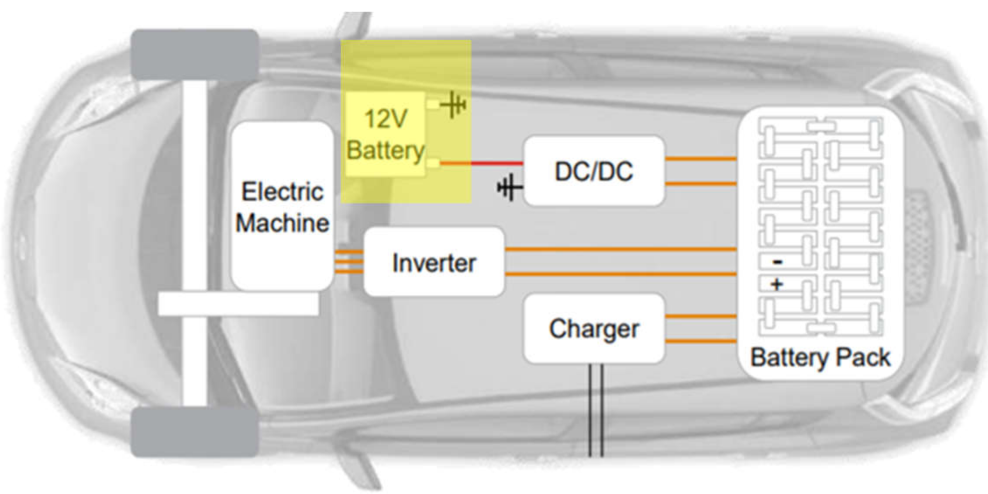
Fuel Gauge and Performance cont.

If the vehicle is designed to provide a reduced level of performance as the high voltage RESS state-of-charge becomes depleted (to protect RESS life, provide a "limp home" feature, etc.), a separate indicator shall be activated to alert the driver when this reduced level of performance is invoked. This indicator and its corresponding reduced level of vehicle performance should be explained in the owner's manual. In case that the high voltage RESS is the only power source of the vehicle, whenever there is sufficient RESS state-of charge to propel the vehicle, including all normal and reduced performance operating modes, there shall be no discernible degradation in the performance of critical vehicle safety systems such as lighting, braking, steering, etc.

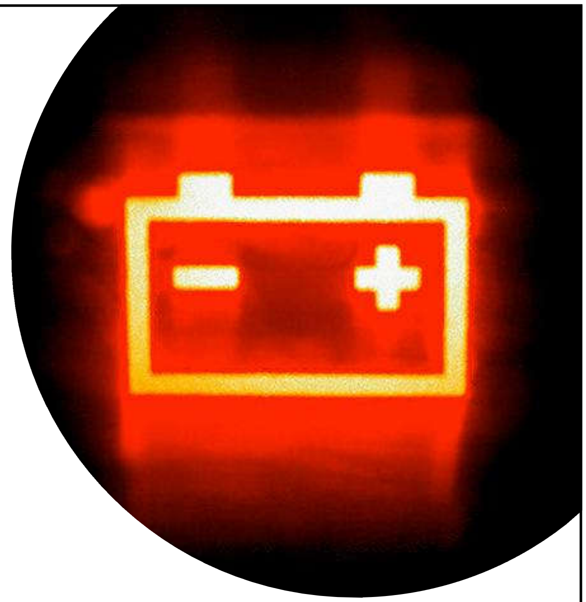
https://www.miningmagazine.com/partners/partner-content/1264239/volvo-a45g-articulated-hauler

Accessories



Accessory Draw

- Even if the EV is turned off, overtime the battery will discharge due to attached accessories. Therefore, an EV with a low charge should not be parked for long periods of time away from a recharge station. If the accessories of an EV were to drain the battery, it would be difficult to move the vehicle into position to recharge. Complete discharge of the Lithium-ion battery will also reduce its effective life and charge capacity.
- Mining Operators will need to be aware of their battery usage when using the large power absorbers on their vehicles, as they could get the vehicle stranded if they did not leave the drive wheels with enough power to get back to the charging station.



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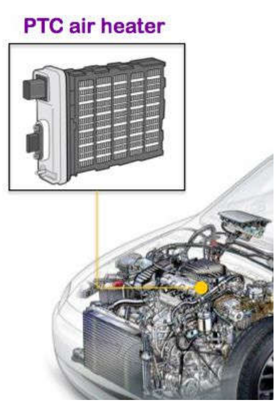
PTC Heater Failure Modes

FAILURE MECHANISMS OF CERAMIC PTCS			
CAUSE	**FAILURE PHENOMENA**	**CONSEQUENCE**	**REMARKS**
OVERVOLTAGE			
Exceeding the maximum rated voltage or the minimum hold voltage by at least 25 %.	Heat generated by Joule effect is greater than the heat which can be dissipated. The temperature of the PTC rises above the temperature corresponding to the resistance maximum. The material enters a NTC zone with a thermal runway.	Short flame (self-extinguished), a burn hole, melted soldered joint, detached leads falling out of the ceramic. Depending on available power a **short circuit** is also possible.	A voltage spike (e.g. lightning pulses) ranging from microseconds to milliseconds will not provoke any failure of this type as the energy is too low to heat the PTC above its maximum resistance. Depending on the thermal capacity of the ceramic, overvoltage of short durations (< 1 s to 10 s) will not provoke failure.
OVERCURRENT DENSITY			
Exceeding the maximum current of the metallization layer.	Current density is above that which the contact can withstand. The contact can be a combination of lead-solder, metallization layer or clamping contact and metallization layer.	Burned electrode, small sparks, eventual flashover, positive resistance shift. **Fails open.**	In practice, this current is hardly ever reached, as the ceramic bulk resistance is sufficient to restrict unacceptable increases. Only in special cases, such as voltage spikes with high energy (> 100 A) can this current be exceeded.
OVERPOWER			
Exceeding the maximum overload current at a specified voltage or a combination of current and voltage which are not guaranteed by the manufacturer.	PTC ceramics are poor thermal conductors. High power can introduce thermal gradients as high as 1500 °C/cm. This gradient will provoke mechanical strain due to thermal expansion mismatches. Two different phenomena can occur: Overpower in the low-ohmic region (below the switch temperature) due to very high inrush currents, when the power per mm3 is exceeded. Overpower above the switch temperature occurs when a combination of final voltage and maximum current during switching is exceeded.	In both cases, there will be ceramic rupture (fragmentation) on the hot-spots in the ceramic and/or thermal stress points. **Fails open.** For high voltage types (> 400 V) a possible local hot-spot can drive the ceramic into thermal runway. This special condition can generate the same consequences as described in 'Overvoltage'.	The maximum power that a ceramic PTC can have is also influenced by the way he is attached to the electrical contacts. Large thermal masses on the electrodes reduce the maximum power a ceramic can sustain.
THERMAL SHOCK			
Caused by an uneven power distribution within the ceramic during switching from the low-ohmic to the high-ohmic region.	The heat generated in the ceramic is not evenly divided over the ceramic body. This means that some parts will heat up faster than others (the centre heating up the fastest). These temperature gradients will provoke expansion mismatch.	Ceramic breaks into two parts. This breaking up of the ceramic can be a slow process induced by micro-cracks every time they are tripped in certain conditions. **Fails open.**	When thermal shock is caused by micro-cracks, the cracking-up or breaking of the ceramic is not always visible on the surface.
REDUCTION EFFECT			
Caused by any unstable material (such as: wax, potting material, glue, lacquer, thermal sleeves, aggressive (washing) fluids and reducing gases; being in close contact with the PTC.	An unstable material surrounding or even touching the ceramic will typically disintegrate or burn at high temperatures. This is an oxygen consuming phenomenon. When in close contact with the PTC, the material may react with oxygen of the grain boundaries, thus reducing the PTC ceramic and in turn its maximum rated voltage or hold voltage.	See 'Overvoltage'.	
NUMBER OF CYCLES			
Repetitive tripping of ceramic PTC (even within specified power handling capabilities).	Repetitive cycling introduces micro-cracks at the solder joints. This phenomenon is based on re-crystallization of the solder when thermal stress is applied. The number of cycles a normal PTC ceramic can have is dependent on the final temperature reached every cycle. A normal range of cycles can range from 100 to 5000.	Leads become detached and small sparks can occur between the detached lead and the ceramic. **Fails open.**	When micro-cracks are present due to power handling inside the ceramic bulk, the number of cycles can also be limited. Short term peak-temperatures, as in an electronic lamp ballast application, can handle a higher number of cycles (usually > 20000). A clamped PTC ceramic can handle a much higher number of cycles due to a free contact movement during heating up (number of cycles > 300000). Cycling at low ambient temperature is more severe because of the large difference between initial and final temperatures.



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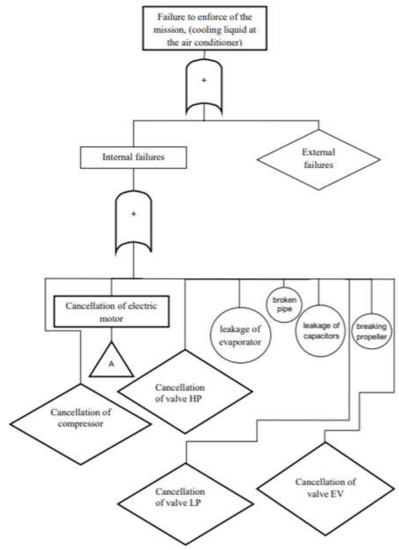
A/C Failure Modes – Critical for Mining

- Coolant or refrigerant leaks
  - The most common source of air-conditioning problems is a leak in the sealed system, especially in older cars. A leaking seal or hose can be difficult to spot visually, and getting your gas charge checked and system serviced once a year is the best way to identify any leaks present in the hoses and seals. Picking up a leak early can save you costly repairs that would occur if the leak went unnoticed.
- Faulty compressor
  - If your air conditioner produces loud noises when activated, this can be due to a faulty compressor, using the wrong type of compressor lubricant or an issue with refrigerant pressure. When you have determined that the noise is not coming from the engine, have your compressor checked by a professional technician, as it may need to be replaced.
- Faulty thermostat
  - Uneven temperatures in the cabin are often the result of a faulty thermostat, meaning the component will need to be replaced. If you have a manual air conditioner, fluctuating temperatures could also be due to a faulty control switch, temperature sensor, pressure cut-out switch or compressor clutch.
- Faulty Electronics
  - As manufactures continue to incorporate more and more electronics into the air-conditioning system for the purpose of increased performance and passenger comfort, the scope of air-conditioning repairs increases. Your air-conditioning system could be mechanically perfect and full of gas but still not operate due to an electrical fault. If you experience a sudden loss in cooling, your car could have an electrical fault.
- Bacteria
  - If you notice bad smells when you use the air-conditioning, this is likely due to a build-up of bacteria or mold and mildew in the evaporator coils. This can be easily cleaned out by professional technicians.



http://eaas-journal.org/survey/userfiles/files/v4i104%20Mechanical%20Engineering.pdf

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Safety Standards

SAE Cross Compatible EV Standards

SAE J-537 Storage Batteries (WORK IN PROGRESS)
SAE J-1634 Electric Vehicle Energy Consumption and Range Test
SAE J-1711 Recommended Practice for Measuring the Exhaust Emissions and Fuel Economy of Hybrid-Electric Vehicles
SAE J-1715 Hybrid Electric Vehicle (HEV) and Electric Vehicle (EV) Terminology (WORK IN PROGRESS)
SAE J-1797 Recommended Practice for Packaging of Electric Vehicle Battery Modules
SAE J-2289 Electric-Drive Battery Pack System, Functional Guidelines
SAE J-2293 Part 1 Energy Transfer System for EV Part 1, Functional Requirements and System Architecture
SAE J-2293 Part 2 Energy Transfer System for EV Part 2, Communications Requirements and Network Architecture
SAE J-2344 Guidelines for Electric Vehicle Safety
SAE J-2380 Vibration Testing of Electric Vehicle Batteries
SAE J-2464 Electric and Hybrid Electric Vehicle Rechargeable Energy Storage System (RESS) Safety and Abuse Testing
SAE J-2889 Measurement of Minimum Sound Levels of Passenger Vehicles
SAE J-2910 Design and Test of Hybrid Electric Trucks and Buses for Electrical Safety
SAE J-2929 Electric and Hybrid Vehicle Propulsion Battery System Safety Standard – Lithium-based Rechargeable Cells (WORK IN PROGRESS)
SAE J-2950 Recommended Practices (RP) for Transportation and Handling of Automotive-type Rechargeable Energy Storage Systems (RESS). (WORK IN PROGRESS)

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NFPA Cross Compatible EV Standards

Document Title
NFPA 1 Fire Code
NFPA 30A Code for Motor Fuel Dispensing Facilities and Repair Garages
NFPA 70 National Electrical Code (NEC); Article 220, Branch Circuit, Feeder and Service Calculations; Article 625, Electric Vehicle Charging Systems; Article 626, Electrified Truck Parking Spaces; and other req.
NFPA 70B Electrical Equipment Maintenance
NFPA 70E Electrical Safety in the Workplace
NFPA 289 Fire Test for Individual Fuel Packages
NFPA 450 Guide for Emergency Medical Services and Systems
NFPA 471 Recommended Practice for Responding to Hazardous Materials Incidents
NFPA 472 Competence of Responders to Hazardous Materials/Weapons of Mass Destruction Incidents
NFPA 556 Guide on Methods for Evaluating Fire Hazard to Occupants of Passenger Road Vehicles
NFPA 921 Fire and Explosion Investigation
NFPA 1000 Fire Fighter Professional Qualifications Series (1000 – 1081)
NFPA 1192 Recreational Vehicles
NFPA 1500 Occupational Safety & Health Standards for Fire Fighters
NFPA 1561 Emergency Services Incident Management System
NFPA 1600 Disaster Planning and Emergency Preparedness
NFPA 1670 Standard for Technical Rescue Incidents
NFPA 1710 Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments
NFPA 1720 Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations and Special Operations to the Public by Volunteer Fire Departments
NFPA 1851 Selection, Care, and Maintenance of Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting
NFPA 1971 Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting
NFPA 1999 Protective Clothing for Emergency Medical Operations

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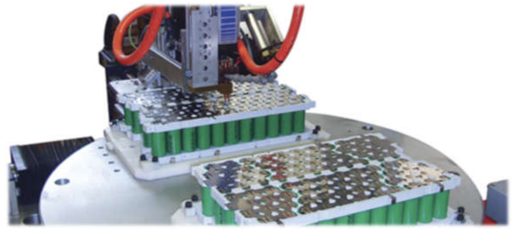
Cell Testing Standards by Industry

Type of Testing	Transportation
Performance or Characterization	USABC PHEV Manual IEC 62660-1 IEC 61982 ISO 12405-1
Cycle and Calendar Life	FreedomCAR (SAND 2005-3123) EUCAR* IEC 62660-2 IEC 61982 ISO 12405-1
Abuse or Safety	SAE J2464 FreedomCAR (SAND 2005-3123) EUCAR* BATSO UN 38.3 UL 2271 UL 2580 ISO 12405-1



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ISO Standards for EVs

Recommended Industry Standard	Topic	Jurisdiction	Citation
ISO 6405-1:2017	Standardizes symbols on operator controls and other displays on multiple types of earth-moving machines as defined in ISO 6165:2012	International	International Organization for Standardization, 2017a
ISO 6405-2:2017	Standardizes symbols on operator controls and other displays on specific machines, equipment, and accessories as defined in ISO 6165:2012	International	International Organization for Standardization, 2017b
ISO 6165:2012	Terms and definitions and identification structure to classify earth-moving machines	International	International Organization for Standardization, 2012a
FMVSS 141	Minimum sound requirements for BEVs to warn persons that BEV is underway	USA	United States National Highway Traffic Safety Administration, 2013
ISO 3450: 2011	Minimum performance requirements and test procedures for service, secondary, and parking brake systems of wheeled and high-speed, rubber-tracked earth moving machines	International	International Organization for Standardization, 2011a
CAN/CSA-M424.3-M90 (R2016)	Minimum performance criteria for the service braking, secondary braking, and parking systems for rubber-tired, self-propelled underground mining machines	Canada	CSA Group, 2016a
ISO 13849-1:2015	Safety requirements and guidance on design and integration of safety-related parts of control systems, including software	International	International Organization for Standardization, 2015b
ISO 13849-2:2012	Procedures and conditions to validate—by analysis and testing—specified safety functions, the category achieved, and the performance level achieved by the safety-related parts of a control system designed in accordance with ISO 13849-1:2015	International	International Organization for Standardization, 2012b
ISO 14990-1:2016	General safety requirements for electrical equipment and components incorporated into earth-moving machines as defined in ISO 6165:2012	International	International Organization for Standardization, 2016a
ISO 14990-2:2016	Safety requirements for electrical equipment and components incorporated in externally-powered (mains-connected or dedicated generators), electrically-driven earth moving machines	International	International Organization for Standardization, 2016b
ISO 14990-3:2016	Safety requirements for electrical equipment and components incorporated in self-powered (utilizing on-board electric power sources) electrically-driven earth moving machines	International	International Organization for Standardization, 2016c
ISO 13766:2006	Test methods and acceptance criteria for evaluating the electromagnetic compatibility of earth moving machines as defined in ISO 6165:2012	International	International Organization for Standardization, 2006
ISO 15998:2008	Performance criteria and tests for functional safety of safety-related machine-control systems using electronic components in earth moving machines and equipment as defined in ISO 6165:2012	International	International Organization for Standardization, 2008
IEC 60068-2-6:2007	Standard procedure to determine the ability of components, equipment, and other articles to withstand specified severities of sinusoidal vibration	International	International Electrotechnical Commission, 2007
IEC 60050-826:2004	Vocabulary related to electrical installations on residential, industrial, or commercial premises	International	International Electrotechnical Commission, 2004
E/ECE/324/Rev.2/Add.99/Rev.2	Safety requirements of vehicle electric power train	International	United Nations, 2013
ISO 13850:2015	Functional requirements and design principles for the emergency stop function on machinery, independent of the type of energy used	International	International Organization for Standardization, 2015
IEC 60204-1:2016	General safety requirements of electrical, electronic, and programmable electronic equipment and systems to machines not portable by hand while working	International	International Electrotechnical Commission, 2006b
UL 2231-1	Requirements to reduce the risk of electric shock to the user from accessible parts in grounded or isolated circuits (external to or on-board) for charging BEVs	USA	UL, 2012a
ISO 6469-3:2011	Requirements for electric propulsion systems and conductively connected auxiliary electric systems of electrically propelled road vehicles for the protection of persons inside and outside the vehicle against electric shock	International	International Organization for Standardization, 2011b
ST/SG/AC.10/11/Rev.5	Criteria, test methods, and procedures for classifying dangerous goods	International	United Nations, 2009
ST/SG/AC.10/1/Rev.17	Model regulations on the transport of dangerous goods	International	United Nations, 2011

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IEC/UL Standards

Recommended Industry Standard	Topic	Jurisdiction	Citation
E/ECE/324/Rev.2/Add.99/Rev.2	Safety requirements of vehicle electric power train	International	United Nations, 2013
ST/SG/AC.10/11/Rev.5	Criteria, test methods and procedures for classifying dangerous goods	International	United Nations, 2009
J2288_200806	Standardized test method to determine the expected life cycles of BEV battery modules	International	SAE International, 2008
UL 1642	Requirements to reduce the risk of and injury from fire or explosion when lithium batteries are used or removed from a product and discarded	USA	UL, 2012b
UL 2580	Evaluates the ability of the electrical energy storage assembly (e.g., battery packs and combination battery pack-electrochemical capacitor assemblies and the subassembly/modules that make up these assemblies for use in BEVs) to safely withstand simulated abuse conditions and prevents exposure of persons to hazards as a result of the abuse	USA	UL, 2013
CAN/CSA-E62660-1:15	Performance and life testing of rechargeable lithium-ion cells for propulsion of BEVs and hybrid electric vehicles	Canada	CSA Group, 2015a
CAN/CSA-E62660-2:15	Test procedures to observe the reliability and abuse behaviour of rechargeable lithium-ion cells for propulsion of BEVs and hybrid electric vehicles	Canada	CSA Group, 2015b
IEC 62133-2:2017	Requirements and tests for safe operation of portable sealed rechargeable lithium cells and LIBs containing non-acid electrolyte	International	International Electrotechnical Commission, 2017
IEC 61508:2010	Aspects to be considered when electrical/electronic/ programmable electronic systems are used to carry out safety functions	International	International Electrotechnical Commission, 2010
IEC 62061:2005 (plus amendments)	Requirements and recommendations for the design, integration, and validation of safety-related electrical, electronic, and programmable electronic control systems for machines	International	International Electrotechnical Commission, 2015
M421-16	Minimum requirements for electrical work and electrical equipment operating / intended to operate at a mine	Canada	CSA Group, 2016b
US CFR Parts 100–177	United States Code of Federal Regulations on Transportation	USA	United States Office of the Federal Register, 2012
Canada TDG	Transportation of dangerous goods regulations	Canada	Transport Canada, 2016
IMDG 2014, 2016	International Maritime Dangerous Goods Code. IMDG 2014 in force as of January 2016; IMDG 2016 in force as of January 2018	International	International Maritime Organization, 2017
IATA Dangerous Goods Regulations	International Air Transport Association Dangerous Goods Regulations	International	International Air Transport Association, 2017
ISO 14990-1:2016	General safety requirements for electrical equipment and components incorporated into earth-moving machines as defined in ISO 6165:2012	International	International Organization for Standardization, 2016a
ISO 6165:2012	Terms and definitions and an identification structure for classifying earth-moving machinery	International	International Organization for Standardization, 2012a

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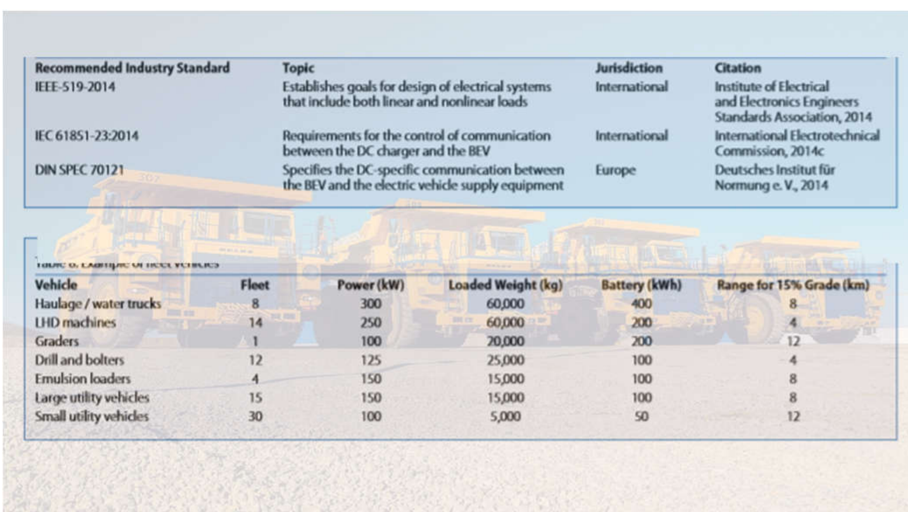
Charging Standards for Fleet Vehicles



Recommended Industry Standard	Topic	Jurisdiction	Citation
IEEE-519-2014	Establishes goals for design of electrical systems that include both linear and nonlinear loads	International	Institute of Electrical and Electronics Engineers Standards Association, 2014
IEC 61851-23:2014	Requirements for the control of communication between the DC charger and the BEV	International	International Electrotechnical Commission, 2014c
DIN SPEC 70121	Specifies the DC-specific communication between the BEV and the electric vehicle supply equipment	Europe	Deutsches Institut für Normung e. V., 2014

Vehicle	Fleet	Power (kW)	Loaded Weight (kg)	Battery (kWh)	Range for 15% Grade (km)
Haulage / water trucks	8	300	60,000	400	8
LHD machines	14	250	60,000	200	4
Graders	1	100	20,000	200	12
Drill and bolters	12	125	25,000	100	4
Emulsion loaders	4	150	15,000	100	8
Large utility vehicles	15	150	15,000	100	8
Small utility vehicles	30	100	5,000	50	12

http://www.belaz.by/en/press/news/2019/belaz_90_ton_dump_trucks_are_n/

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Safety Gaps

Surface vs Mining Safety

Mining EVS have to worry about…

- Methane/Gas Explosions
- The size/potential energy of the battery if it were to go into thermal runaway.
- Dirt/Debris damaging motor or insulation
- Combustible Atmosphere
- Lack of data signal
- Route Planning
- Loose/unstable surfaces
- Rock Falls

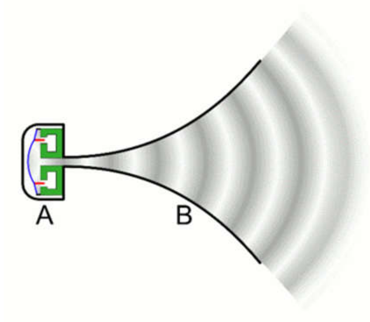
Surface EVS have to worry about…

- Crash Test Standards
- High Speeds

https://www.mining.com/university-of-utah-center-for-mining-safety-and-health-excellence-39505/

Artificial Noise

- The European Union just announced all existing EVs will have to emit some kind of sound or noise by July 2019, even when traveling at slow speeds (SAE J-2889)
- The National Highway Traffic Safety Administration under the Obama administration, calls for car makers to require all hybrid cars and EVs to produce noise when travelling under 19 MPH.
- Miners working underground need to be able to hear if there is a large EV moving around them.



https://futurism.com/electric-vehicles-quiet-dangerous-noise

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Accessories for Mining Vehicles

- Brake Booster (Electric Pump on EV)
- Hotel Accessories (Lights, radio)
- Air conditioning
- Electric Fan vs. Clutch fan in Hybrids
- HVAC (powered by electric motor)
- Power Steering (electric power steering. Also found in ICE)
- Cabin heat powered by electric heater
- Motor/hydraulic systems for vehicle intended purpose (aka, the dumping system for a haul truck)
- Electric Forced Induction for Hybrids

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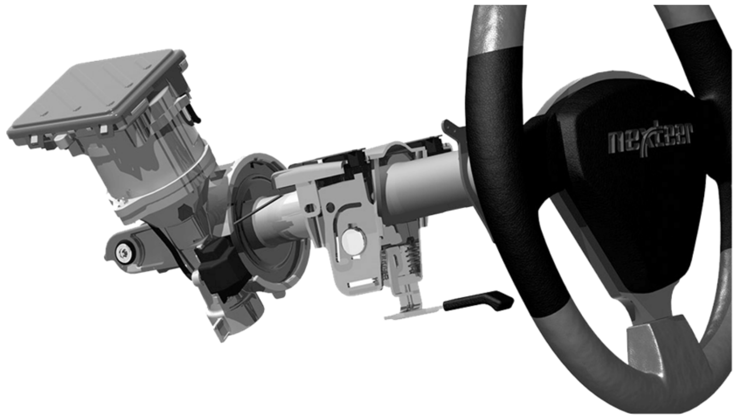
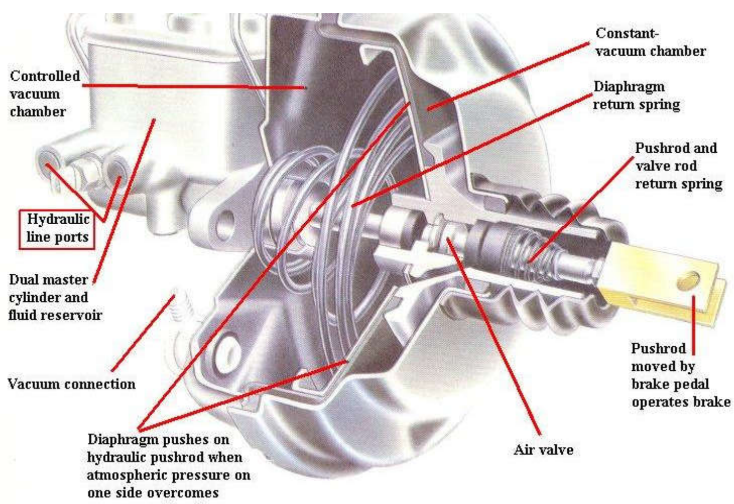
Power Steering

- Cooling fans can either be electronically powered or clutch powered if hybrid.
- Lights and radio powered the same way.
- Electronic power steering exists in ICE vehicles, and is easily integrated into EVs. Mining vehicle will need more robust EPS systems than normal EVs, because their weight and wheel size require more energy to turn.



https://www.nexteer.com/electric-power-steering/column-assisted-electric-power-steering/

Friction Brakes



https://carfromjapan.com/article/car-maintenance/brake-booster-works-braking-system/

Large Accessories

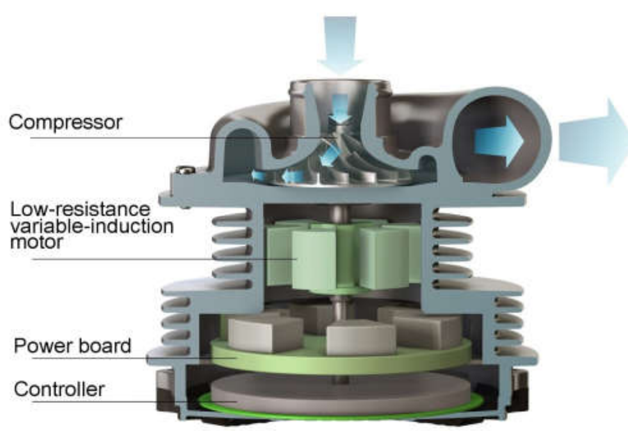
- Excavators
- Draglines
- Drills
- Roof Bolters
- Continuous/Longwall Miners
- Rock Duster
- Scoops
- Haul Truck

- All require their own specialized system to accomplish the tasks they are made for. These systems tend to require high energy input. Battery must be able to handle outputting the energy required for these large pieces of machinery.

https://careertrend.com/list-6399909-list-mining-equipment.html https://www.cgtrader.com/3d-models/vehicle/industrial/3d-industrial-and-mining-vehicles

Electric Forced Induction (Hybrid System)

- As engines downsize and pressurize, e-supercharging offers the ability to size a compressor for a power target without sacrificing low-rpm drivability. It does so by filling in the torque-less void below the turbo's threshold for creating boost. Eliminates lag that would have existed with an exhaust powered turbocharger.
- A malfunctioning forced induction system could lead to low power or heating issues. Both affect drivability and safety.



https://simanaitissays.com/2014/08/11/electrically-forced-induction/

Cabin Temperature Control

- EVs must use electrically driven compressors for AC, and electrical(resistive) heaters for heating (as opposed to belt driven AC and hot coolant in ICE). Resistive heaters work by increasing resistance with heat, which allows them to be quite efficient.
- Cabin temperature is important for miners, as they need to be able to focus on controlling their machinery, not trying to combat uncomfortable working conditions. A distracted operator, either from overheating or being too cold, poses as safety risk to people and equipment around them.

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Effect of Air-Pressure on Lithium-ion

- In this study, an experimental test has been designed to determine the effect of external pressure on several electrical parameters such as GEIS, current, voltage, capacity variation and dynamic pressure generation for a pouch cell. Overall, GEIS measurement results indicate that the external static pressure couldn't change "ohmic contribution" but it could improve ion diffusion under pressure from 0.125MPa to 1MPa. Li-ion pouch cell can generate a dynamic pressure during charging and discharging around 50% SOC, this dynamic pressure generation coincides well with the capacity variation profiles. Moreover, the speed of dynamic pressure depends on current rate. Current rate does not influence the dynamic pressure with the ampere hours charged, however, it influences the cell voltage between 35% SOC and 65% SOC. To charge a cell, the high pressure generates with a high current rate. Based on these results, automotive industry could optimize the design of battery package.
- Pressure increases as the distance below ground increase. Charging a battery may be more efficient the further underground it is placed. However, there may be significant drawbacks that make deep bellow surface charging unviable.

Characterization of external pressure effects on lithium-ion pouch cell, 2018, IEEE, Yuan Ci Zhang et. al

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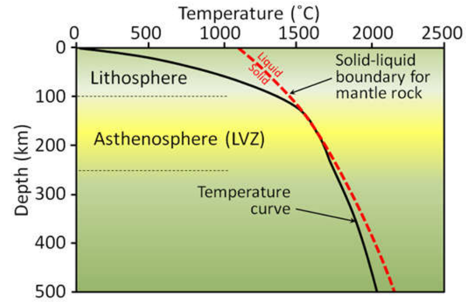
Temperature Gradients

- Observed temperature gradients in the Earth's crust ranges from 10 K/km to as high as 50 K/km. Typical temperature gradients are between 20 and 30 K/km. (paraphrased)
- Pressure increases greatly with depth from the study in the notes.
- In the Western Deep mine, refrigerated air is pumped through where the miners work, to lower the temperature to 28 degC. The refrigerated air causes the pressure to increase to 2x surface pressure due to the increase in air density.



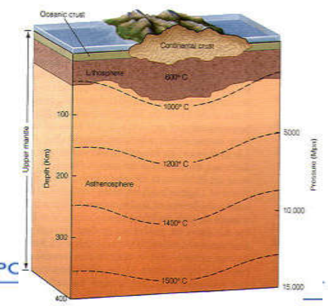


Image: https://www.tankonyvtar.hu/en/tartalom/tamop425/0033_SCORM_MFFTT600120-EN/sco_03_03.htm

Image: https://opentextbc.ca/geology/chapter/9-2-the-temperature-of-earths-interior/

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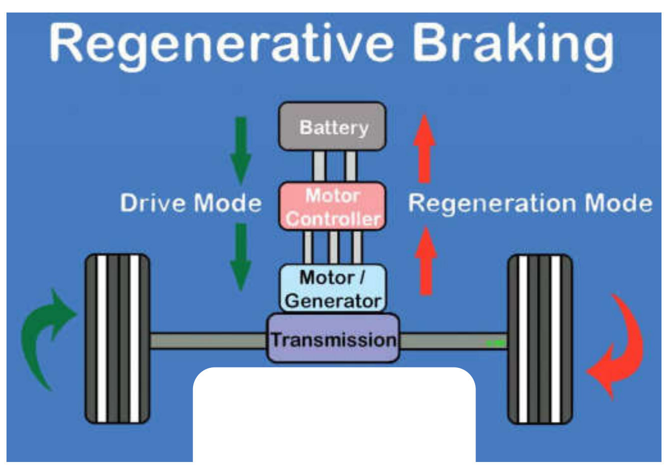
Brake Design

- In terms of regenerative braking there should be some security references. In some cases the level of deceleration is limited and is not sufficient for immediate braking. The effect of regeneration braking can be reduced when the battery is fully charged. For these reasons primary friction braking system should be able to stop the vehicle under any circumstance.



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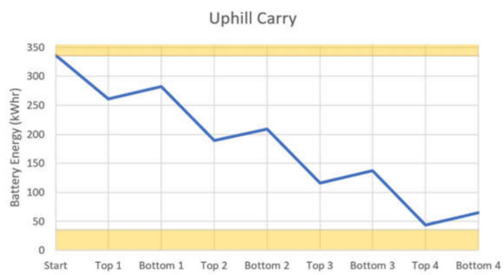
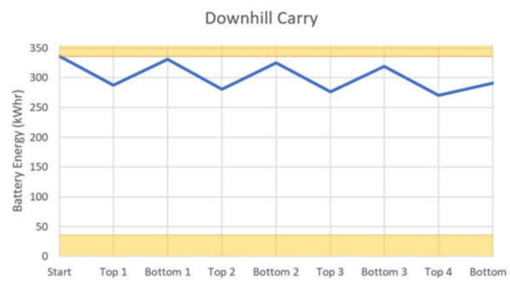
Regenerative Braking Power Savings

- Raghu Das, CEO of analysts IDTechEx advises, "The power needed is over 500 kW but, for this, a battery pure-electric version will have a major win over diesel or even fuel cell hybrid because it recovers a huge amount of electricity in regenerative braking during descent – about 40 kW for 30 minutes giving 800 kWh 'free' per working day instead of burning brake disks, a huge win."
- Talk about the importance of planning routes here.





Regenerative Braking Issues

- Regenerative braking can be a double-edged sword. A fully charged BEV that needs to make a long downhill journey may not be able to store the braking energy, and would rely on friction braking or braking resistors. It is best to avoid this situation altogether through careful planning, for example by positioning charging locations at the bottom of a ramp, or limiting the amount of charge taken on if a downhill trip is anticipated.
- While braking distance and feel should not be greatly changed when regenerative braking is inactive, operators must be aware of the switch to fully frictional brakes. If the friction brakes become too hot, there should be a system override to stop the vehicle, and let the brakes cool. An alternative solution to this is to have a cooling system activate on the friction brakes when they are in sole use. The cooling system should not be used if regenerative braking is active, as power absorption will be stunted.

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Fail Safes

- If inverter fails, or any part of the regenerative braking system fails, braking power should be directed to the friction brakes.
- Opposite, if friction brakes fail, braking should be done by regenerative system.
- At anytime if one of these systems fails, the vehicle should be required to be fixed immediately as if both friction and regenerative systems fail, there will be a loss of braking.

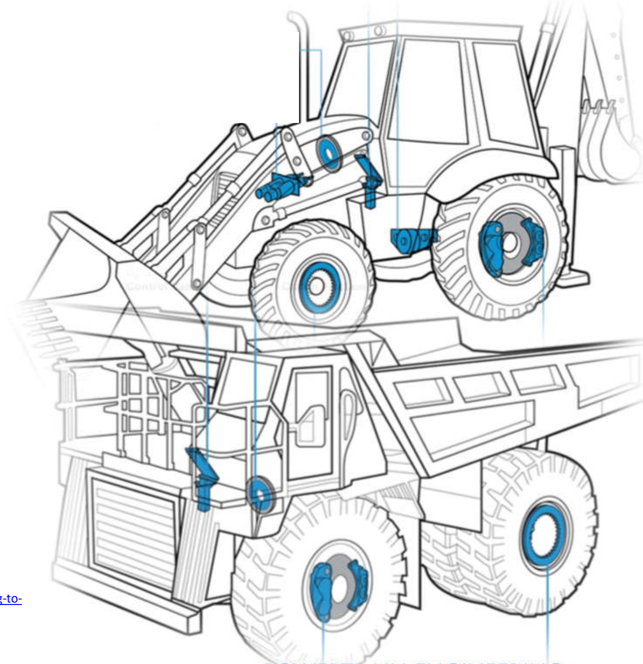
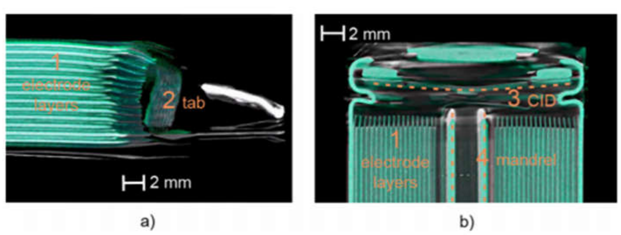


Image: https://www.oemoffhighway.com/drivetrains/brake-system/article/10342711/brake-designs-changing-to-meet-larger-vehicle-needs
Image: http://www.carlislecbf.com/markets/

Vibration

- The mechanical design of a battery cell and especially the fixation of its internal components determine whether a cell can withstand vibrations and shocks. (Article goes very in depth on the testing)
- Mining vehicles will suffer many vibrations, so the batteries need to be designed to handle that.



Superimposed μCT images of a) terminals of pouch cell and b) positive pole of 18650 cell shaken in z-direction (white = before tests, green = after tests). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Holistic View

Off Board Chargers

- One possible remedy to these concerns is to use one OEM for the BEV drivetrain to standardize the entire mine. Experience has shown that dictating to OEMs the type of equipment and technology to use on board their BEVs stifles innovation, leads to complications, and yields a poorer product. This approach also increases risk because the mine completely depends on a single vendor
- As with the commercial BEV industry, the solution for mining BEVs may be to standardize the charging interface. Once the connector, voltage range, and communications between the charger and BEV are agreed upon, a BEV from one OEM could be connected to a charger from another OEM. An obvious consideration is to adopt a standard from the commercial BEV industry. However, the demands of a mining BEV differ from those of a passenger BEV. The entire charging arrangement needs to be rugged to withstand the harsh mining environment. The connectors, charger, voltages, charge rates, and communication methods need to be suitable for a mining BEV drivetrain and battery. If these issues can be addressed, then the mining industry would benefit from the research and development already invested by the commercial BEV industry. If not, then the development of a "mining only" interface may be the only solution.

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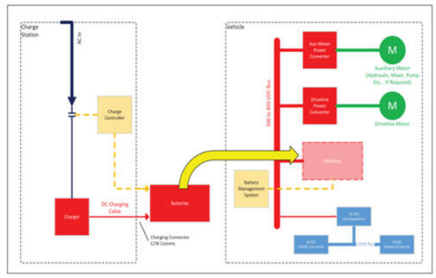
Off Board Chargers Pros and Cons

Pros

1. BEV size and weight are low because charging equipment is not on the BEV.
2. If practical, chargers can be located in cool and contaminant-free areas.
3. High-capacity chargers are feasible because size and weight are not issues.
4. Multiple BEVs can share one charger if connectors and communication protocols are compatible between BEVs.
5. Off-board charging is the charger standard in parallel industries such as public transport and port equipment.
6. For proprietary charging interfaces, the responsibility for the entire system (i.e., drivetrain, batteries, and charger) lies with the OEM.
7. BEV OEMs can focus on building high-quality mining BEVs, rather than developing or supplying chargers. Similarly, electrical equipment suppliers can develop rugged BEV chargers, without entering the BEV business. It is feasible for an OEM to build both chargers and BEV drivetrains, as long as the charging interface is standardized.
8. Those in charge of procuring mobile equipment are free to purchase any type of BEV from any OEM.
9. The fixed plant department are free to purchase and install charging infrastructure regardless of the BEV OEM.
10. For equipment operators (instructed persons defined in International Electrotechnical Commission, 2004), a simple and consistent charging interface across the mine eliminates confusion and additional training. The type of BEV or location within the mine is irrelevant— simply plug in the BEV and initiate the charge.
11. From a risk perspective, the worry that "all eggs are in one basket" is greatly diminished. If one OEM has a technical issue, only one relationship is affected. If an OEM goes out of business, the mine does not have an entire fleet of unsupported equipment and infrastructure.

Cons

1. Space must be allocated in the mine to house charging equipment.
2. The BEV must move to a specific location to charge.
3. Greater potential exists for a variety of chargers, leading to handshaking and communication problems between the charger and BEV.
4. Pantograph-based systems are delicate and prone to malfunction



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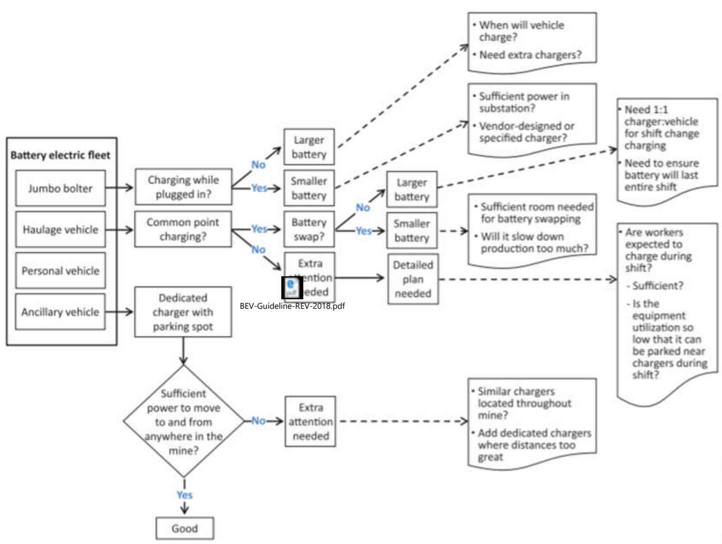
Infrastructure



Courtesy GMG

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Facilities

- An eye wash system is vital in case any employee comes in contact with battery acid. The system should easily accessible and be as close as possible to the work area without causing any adverse exposure. A best practice is to have fixed-pipe eye wash/showers system with a drain, as compared to relying on gravity-fed units.
- Unobstructed distance: wash stations shall be located in an area that requires no more than 10 seconds to reach—that's approximately 50 feet. If it is a high hazard, consult a medical professional to determine the appropriate distance for harsh acids and caustics (high hazard=closer distance). Eye wash water ow: 3 gallons per minute for at least 15 minutes. Water temperature: Tepid, which is defined as 60°F to 100°F. Plumbed eye wash/shower inspection: The station should be activated weekly to verify proper operation and tested annually. All inspections, activations and testing shall be documented and maintained on le. Identification: The location of the eye wash station should be in a well-lit area and identified with a signage. Training: All employees who might be exposed to a chemical splash should be trained in the use of the equipment.

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Maintenance and Inspections of Batteries

We need to emphasize the importance of proper maintenance and inspections of both batteries and facilities: Batteries need to be properly maintained - This means they should be clean, properly charged and allowed to cool after charging. Batteries must also include cables in good repair and contain the correct fluid levels. Don't allow anyone who has not been properly trained to attempt to service a battery. Be sure the battery servicing area is clean, uncluttered and free of ignition sources. Battery racks should be frequently inspected for damage, corrosion, weld/fastener quality and roller functionality. Always consult manufacturer's operations manuals for details on specifications and care. Allow only trained and qualified employees to work on chargers.

Gas Sensors

https://www.conspec-controls.com/gas-detection-mining-industry.html

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Smoke Detectors in Battery Charging Stations

Smoke detectors are suitable for use in battery charging stations. Carbon monoxide monitors should only be used as fire detectors in battery charging stations in conjunction with a hydrogen detector, as hydrogen from the charging process can affect the CO sensor. If the CO sensor and hydrogen sensors both show increased readings then hydrogen pollution may be the cause of the apparent rise in CO, although a visual inspection will be necessary to confirm this. If only the CO reading increases it may indicate that a fire has broken out.

Safety Procedures When Charging Batteries

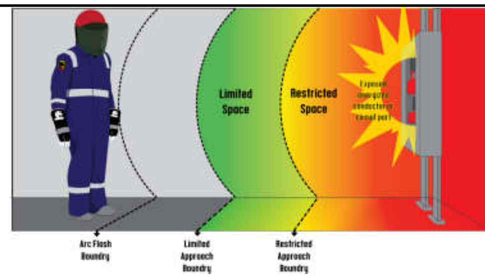
Always secure a battery prior to moving or exchanging it. This normally is accomplished using manual stops and/or powered rollers on the battery changer to prevent the battery from falling off the changer. Chargers should be robustly mounted to a permanent fixing. Chargers should be connected with a suitable lockable isolator/breaker that is compatible with the charger. The charger should be installed to the manufacturer's recommendations. Full service access should be allowed for the trucks, batteries and chargers – taking note of all necessary access points.

General Fire Precautions

The main stages of the fire and explosion assessment process are to:

- Identify the hazards - the potential sources of ignition and materials that would cause a fire or explosion to spread
- Consider the precautions already in place for the prevention and mitigation of each fire and explosion hazard
- Evaluate the likelihood of a fire or explosion occurring due to a particular hazard
- Consider the consequences of a fire or explosion, and decide who might be harmed and how
- Determine what further measures are necessary to prevent, control or mitigate a fire or explosion
- Record significant findings; these should be included within the fire protection plan and the explosion protection plan required by regulation 4(2) of The Mines Miscellaneous Health and Safety Provisions Regulations 1995
- Review the risk assessment periodically, or when you think that a change in circumstances will significantly affect the risks to which people are exposed (e.g. moving from a non-gassy to a gassy seam).

Arc Flash



- Arc flashes can occur for a wide range of reasons. In most cases, the root cause will be a damaged piece of equipment such as a wire. It could also be a result of someone working on equipment, which makes it possible for the electricity to escape from the path it is normally confined to.
- Even when there is a potential path outside the wiring, the electricity is going to follow the path of least resistance. This is why an arc flash will not necessarily happen as soon as something is damaged or an alternate path is made available. Instead, the electricity will continue down the intended path until another option that has less resistance becomes available.

→ **Dust** - In dusty areas the electricity may begin passing outside the wiring or other equipment through the dust.

→ **Dropped Tools** - If a tool is dropped onto a wire, for example, it can damage it and allow the electricity to pass into the tool. From there, it must find another path to continue on.

→ **Accidental Touching** - If a person touches the damaged area, the electricity may travel through his or her body or at least out of the normal path, creating an arc flash.

→ **Condensation** - When condensation forms, the electricity may escape the wiring through the water, and then the arc flash will occur as the electricity seeks its destination.

→ **Material Failure** - If a wire is damaged to the point where the electricity has trouble passing through, the path may be more resistant than going outside of the wire.

→ **Corrosion** - Corrosion can create a path outside the wire, at which point the arc flash occurs.

→ **Faulty Installation** - When equipment is installed improperly it can make it difficult or impossible for electricity to follow the intended path, which can cause an arc flash.

: http://www.blackstallion.com/resource-hub/industry-standards/what-is-an-arc-flash.html

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Arc Flash Damage

Potential Human Injury:

→ **Burns** - Second and third degree burns can occur in a fraction of a second when someone is near the arc flash.

→ **Electrocution** - If the arc flash travels through a person, he or she will be electrocuted. Depending on the amount of electricity, where it enters the body, and where it leaves, this can be fatal.

→ **Auditory Damage** - Arc flashes can cause extremely loud noises, which can cause permanent hearing damage to those in the area.

→ **Eyesight Damage** - Arc flashes can be very bright, which can cause temporary or even long-term damage to the eyes.

→ **Arc Blast Damage** - An arc blast can create a force that is thousands of pounds per inch. This can knock a person through the area several feet. It can also cause broken bones, collapsed lungs, concussions, and more.

Potential Property Damage:

→ **Heat** - The heat from an arc flash can easily melt metal, which can damage expensive machines and other equipment.

→ **Fire** - The heat from these flashes can quickly cause a fire, which can spread through a facility if not stopped.

→ **Blasts** - The arc blast that can result from an arc flash can break windows, splinter wood in the area, bend metal, and much more. Anything stored within the arc blast radius can be damaged or destroyed in just seconds.

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Arc Safety

- Whenever a machine needs to be worked on in any way, it should be completely de-energized. De-energizing a machine is more than just turning it off. All machines should be shut down and physically disconnected from any power source. Once disconnected, a voltage check should also be done to ensure there is no latent energy that was stored up.
- Ideally a lockout tagout policy should be in place, which will put a physical lock on the electrical supply so that it cannot be accidentally plugged back in while someone is working on it.
- It should be very rare, but there are some cases when machines must be worked on while they are still energized. When this is the case, all employees working in the area should be required to wear proper personal protective equipment.
- The specific PPE that is worn should correspond to the maximum potential risk based on the amount of electricity going through the machine. Having head to toe personal protective equipment can help to prevent serious injury or even fatalities should an arc flash occur while the machine is being worked on.
- Whenever possible, circuit breakers should be put in place on all machines. These breakers will quickly detect when there is a sudden surge in electricity being drawn and stop the flow immediately. Even with circuit breakers, an arc flash can occur, but it will only last a fraction of the time since the electrical current will be cut off.
- Even a very brief arc flash can be deadly, however, so circuit breakers should not be seen as a sufficient arc flash safety program.

https://www.creativesafetysupply.com/articles/arc-flash/

Image: https://www.jjkeller.com/shop/Product/Lockout-Tagout-Tag-Danger-Do-Not-Operate-Equipment-Locked-Out-By

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Arc Flash Prevention

- The first step in reducing the dangers of arc flash incidents is to perform an arc flash risk assessment. Safety managers who perform the examination (as outlined in NFPA 70E) can improve safety by:
- Collecting equipment data
- Identifying modes of operation
- Identifying bolted fault currents
- Identifying arc fault currents
- Identifying the devices' protective characteristics and duration of potential arc
- Documenting voltages and equipment classes
- Identifying working parameters
- Determining incident energy for equipment
- Identifying the required personal protective equipment (PPE)
- Identifying the arc flash boundary (1)

- Clay veins and related features have also been responsible for documented mine disasters. On November 9, 1888, 40 miners were killed by a gas explosion at Shaft No. 2, Frontenac, KS. It was noted in the investigation that the operation had "never seen gas in the mine except when cutting horsebacks or slips" [Humphrey 1960]. At the Hillside No. 1 Mine in Johnstown, PA, five miners were killed by a gas explosion on August 9, 1928. The explosion was caused when "a nonpermissible mining machine cut through a clay slip in a room face, releasing gas, which was ignited by an arc from the machine" [Humphrey 1960]. Only in-mine experience can alert the operator to potential gas emission problems due to the presence of clay veins. If excessive gas emissions are encountered when mining through these features, then underground mapping of clay veins is needed to predict their locations in future developments. Since clay veins frequently can extend hundreds of feet along a given trend [Chase and Ulery 1987], predicting a vein's occurrence in a developing section will allow the operator to anticipate and/or alleviate the potential problem. (2)

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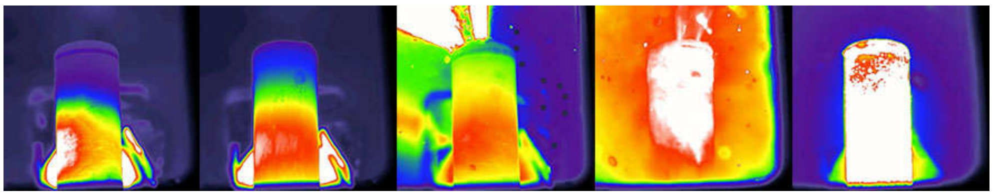
Lithium-ion Fires

For the most part, a lithium-ion battery fire can at best be cooled, contained and suppressed. Extinguishing a lithium-ion battery fire with 100% certainty is not always possible due to the unpleasant issue of thermal runaway. Lithium-ion battery fires do not require oxygen to burn and can be considered by nature a chemical fire. As with any chemical fire, extinguishing by conventional means, e.g. water, can often exacerbate the situation to such a point that an explosion cannot be excluded.



Often a source of lithium-ion battery fires comes from the battery management unit itself. This argument is based on the over-reliance on battery management electronics to prevent fire events. Installing a lithium-ion system without a battery management system (BMS) is still common and can lead to fatal consequences. The most common cause of a lithium fire besides charging related fires is designing the battery safety concept exclusively around the BMS.

Extinguishing Lithium-ion Fires

- Safety experts say the only way to extinguish a lithium-ion battery inside a car is with thousands of gallons of water, much more than what it takes to stop a fire in a typical gasoline engine. The other option is to just let it burn itself out.
- One of the first things first responders learn: Never cut an orange cable, a color reserved for wiring in excess of 60 volts. These can be found not just in the front or rear of a car but also running behind side panels. Most gasoline-powered vehicles have no orange cabling at all, since they use electrical charge powered by a standard 12-volt battery. A typical EV operates at closer to a potentially deadly 400 volts.

https://www.bloomberg.com/news/articles/2019-03-25/tesla-fires-what-first-responders-don-t-know-about-fiery-evs

Image: https://www.coroplast.de/en/products/wires-and-cables-for-automotive-and-industrial-applications/high-voltage-and-charging-cables-for-electric-mobility/

Image: https://www.vehicleservicepros.com/vehicles/powertrain/fuels-and-fueling-systems/article/10978524/dont-let-your-technicians-get-fried

Extinguishing Lithium-ion Fires Cont.

Tesla publishes emergency response guides for all of its vehicles to help fire departments properly handle accidents involving the high-voltage cars. In the firefighting section of the Model S guide, the company mentions that—because burning lithium-ion batteries release "toxic vapors" including "sulfuric acid, oxides of carbon, nickel, lithium, copper and cobalt"—responders need to wear self contained breathing apparatuses. The section also mentions that, to extinguish a burning battery, responders have to "use large amounts of water to cool the battery." Companies that produce electric mining vehicles should also create similar content.

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Disable the Vehicle and Powertrain

- Determine the status of the vehicle by viewing the dash display, the position of the key in the ignition, and/or the power button to see if it has a lit indicator light. If the vehicle is "on", turn the key to the "off" position. Some new EDVs operate with a proximity key. If the proximity key is within range of the vehicle (usually less than 16 feet), the vehicle is powered "on" by a button on the dash. Turn the vehicle "off" by pressing this button. Then remove the key from the ignition and place it beyond the range of the vehicle (typically greater than 16 feet).
- In addition to the high voltage battery that powers an EDV motor, there is a conventional 12volt battery located somewhere on the vehicle. The 12-volt battery powers many of the vehicle accessories and is used to control high voltage contactors. Severing the 12-volt battery's ground cable will prevent the vehicle from powering up. Cutting the 12-volt battery in a vehicle that is "on", however, will not turn the vehicle "off", as power supplied by the DC/DC convertor may keep the contactor closed. After the vehicle has been powered down by the key/ignition button, firefighters should further disable the vehicle by severing the 12-volt battery's negative ground cable. The officer should refer to NFPA's Electric Vehicle Emergency Field Guide or other appropriate guides for vehicle specific information on the location of the 12-volt battery and fuses that can be pulled to disable the high voltage system.
- If firefighters are unable to gain access to the area housing the 12-volt battery or fuses, they may attempt to isolate the high voltage system by removing or switching off the high voltage main disconnect (or "high voltage service disconnect"). Firefighters will need a guide, such as NFPA's Electric Vehicle Emergency Field Guide, in order to determine the location of the high voltage main disconnect and identify the proper method for de-energizing the system. Firefighters may not be able to complete this step until after the fire is extinguished. Further detail on recommendations for high voltage system disabling can be found in SAE International Recommended Practice J2990.

Image: https://www.pinterest.com/pin/474003929506446066/

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Extrication

- A damaged high voltage battery may emit corrosive, toxic, and flammable fumes. If responders become aware of unusual odors and/or sense irritation of their eyes, nose, or throat, they should don PPE and SCBA. In addition, responders should use ventilation techniques to protect the occupants of the vehicle and prevent the build-up of flammable vapors in the trunk or passenger compartment.
- A charged attack line should be staged in close proximity to the vehicle during extrication. Responders should constantly monitor for indications that a damaged battery may be overheating, such as sparking, smoking or making bubbling sounds.
- Throughout stabilization and extrication, response personnel must avoid inadvertent contact with all high voltage cabling and high voltage components. Response personnel should never cut through any high voltage electrical component. Personnel performing the extrication should visually check for the presence of high voltage electrical cabling and components of the supplemental restraint system prior to initiating every cut or displacement (e.g. pry). The location and routing of high voltage components may prevent some advanced extrication techniques, such as trunk tunneling and gaining access through the underside or floor pan of the vehicle.

Image: https://firestormgroup.com.au/solutions/mining/

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Cut-out Devices

- When barriers protecting electrical equipment operate automatically, mines should provide a circuit breaker to de-energize the equipment immediately the automatic system operates. This should be arranged to provide an indication to a manned control point that the barrier has operated.

- Providing vehicles designed for use below ground with isolators or circuit breakers to the battery circuits, to enable the battery circuit to be isolated when the vehicle is not in use. Vehicles designed for surface use will require such devices fitting before they are taken below ground.

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Fire Types

Class A

Class A fires are fires in **ordinary combustibles** such as **wood, paper, cloth, rubber, and many plastics**.

Class B

Class B fires are fires in **flammable liquids** such as **gasoline, petroleum greases, tars, oils, oil-based pain solvents, alcohols**. Class B fires also include **flammable gases** such as **propane** and **butane**. Class B fires include fires involving cooking oils and grease.

Class C

Class C fires are fires involving **energized electical equipment** such as **computers, servers, motors, transformers, and appliances**. Remove the power and the Class C fire becomes one of the other classes of

Class D

Class D fires are fires in **combustible metals** such as **magnesium, titanium, zirconium, sodium, lithium, a potassium**.

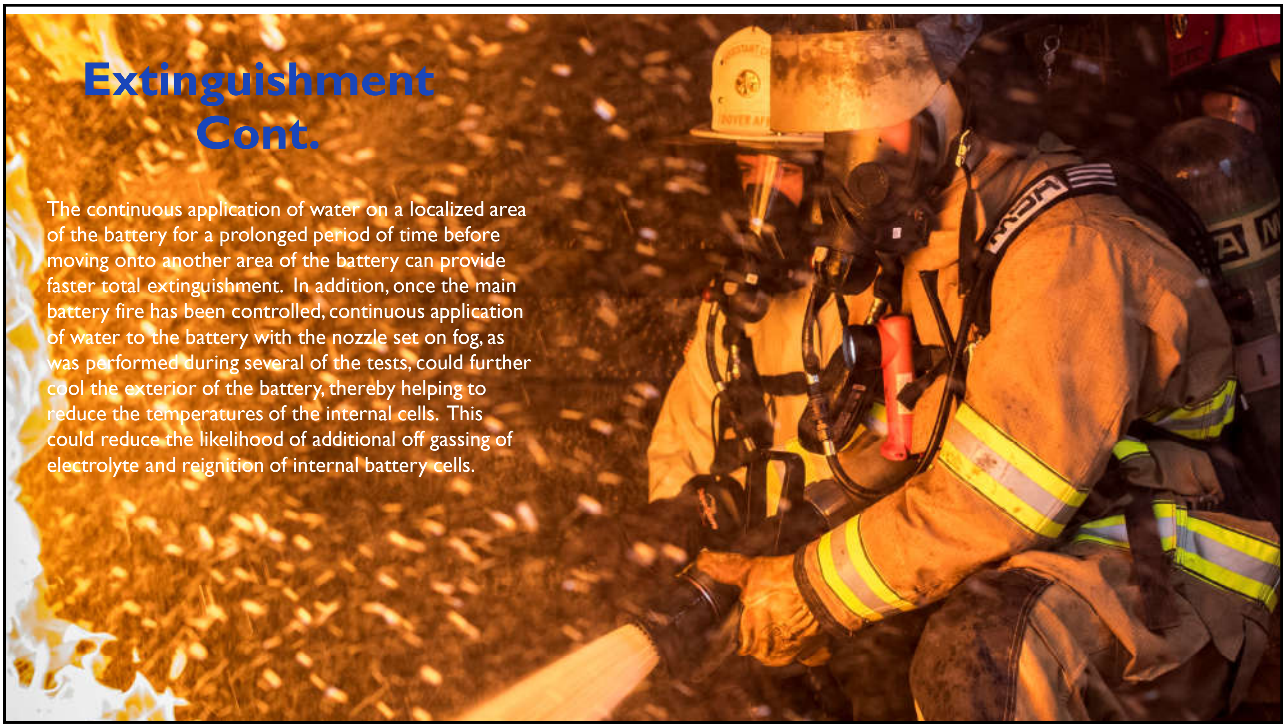
Class K

Class K fires are fires in **cooking oils and greases** such as **animal** and **vegetable fats**.

https://www.femalifesafety.org/types-of-fires.html

Extinguishment

- Fires in the engine compartment of an EDV may require different tactics. Many high voltage components are directly accessible from the engine compartment. Defensively applying a fog stream through existing openings in the wheel-wells and grill can be done safely to knock down the fire. Firefighters should not attempt to force entry into the engine compartment with prying tools, nor should they attempt to spike or cut the hood or fenders with a piercing nozzle, cutting tool, or prying tool. Performing any of these tasks could result in a firefighter being severely shocked or electrocuted.
- It may be the case that firefighters are unable to gain access to the engine compartment. In this instance, defensive fire suppression tactics should be employed until the fire is completely extinguished.
- If there are no exposures and the fire involves the high voltage battery, currently defensive tactics are recommended. Because of the potential difficulty of applying a sufficient amount of extinguishing agent to a burning high voltage battery, the incident commander may allow the vehicle to burn itself out. If the high voltage battery is involved in the fire, an offensive attack may be recommended if there are exposures (other vehicles, buildings, etc.). If the high voltage battery is not involved in the fire, an offensive attack may be mounted regardless of whether there are exposures.



Extinguishment Cont.

The continuous application of water on a localized area of the battery for a prolonged period of time before moving onto another area of the battery can provide faster total extinguishment. In addition, once the main battery fire has been controlled, continuous application of water to the battery with the nozzle set on fog, as was performed during several of the tests, could further cool the exterior of the battery, thereby helping to reduce the temperatures of the internal cells. This could reduce the likelihood of additional off gassing of electrolyte and reignition of internal battery cells.

Water Supply

- Given the large quantities of water necessary to sufficiently cool the batteries and the long duration to achieve reduced temperatures, water supplies may be an issue. Long term suppression operations will likely require a sufficiently large water supply. In remote areas or where no hydrant is available, offensive suppression strategies will likely require a water shuttle, drafting arrangement, water rotation, or additional fire department companies equipped with additional water supplies.
- A clear trend in the water volume data indicated that as the total battery size increased and/or when the battery was less accessible due to vehicle configurations, there was a significant increase in the total volume of water necessary to extinguish the fire.

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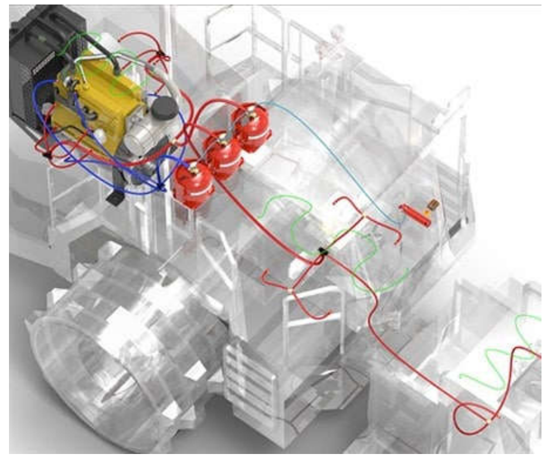
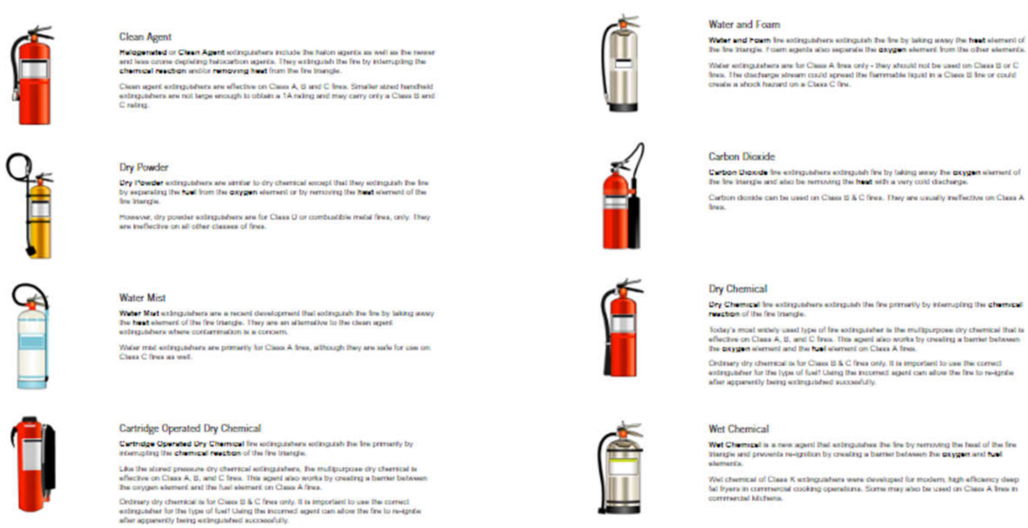
On Board Fire Suppression

Fire suppression system should be on board and placed in strategic areas around any driveline source of power. For EVs, this would be the electrical component system, as there are risks for fire all along it. For a hybrid, additional fire suppression should be placed around the engine and turbocharger. This system should only activate if the vehicle is truly on fire, and should act in such a way that it does not leave permanent damage from the extinguisher itself after the fire is extinguished.



Fire Extinguisher Types



https://www.femalifesafety.org/types-of-fires.html

Fire Extinguishers

- Mines should site fire extinguishers:
  - In conspicuous positions close to any machinery or equipment that gives rise to the fire risks. Below ground it should be sited on the intake side of the fire risk and in buildings it should be sited close to fresh air
  - On electrically powered mobile plant and equipment
  - At places where flammable materials are stored
  - In other locations indicated by the outcome of the fire risk assessment.
- Fire extinguishers should be provided near electric motors (other than those that are part of portable apparatus), transformers or switchgear (including electrical sub-stations, transformer houses, motor rooms and panel trains), workshops below ground, and battery charging and transfer stations
- Firefighters unanimously reported that access to the "hot spots" or "heat" was a significant barrier to extinguishing efforts.

Image: https://www.omegasonics.com/uncategorized/ultrasonic-cleaners-meeting-nfpa-standards/

Allowed burn

Total water volumes were significantly greater in some tests than traditional ICE vehicle fires. In areas where a suitable water source is not present and there are no threats to life safety or to nearby structures, vehicles, or other combustibles, allowing the battery pack to burn to self-extinguishment may be a viable alternative to suppression. However, this may require extended periods of monitoring and observation for any reignitions. In the free burn test, the battery continued to visibly flame for approximately 90 minutes. Once it self-extinguished, it never reignited, although it did continue to off gas and was at elevated temperatures for hours afterwards.

Conclusions

- The following aspects of safety were reviewed
  - Electric powertrains topologies
  - Ground vehicle safety standards
  - Gaps between non-mining and mining vehicles
  - Fire handling

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