Lithium batteries

Safety Aspects In Battery Packs

Are Lithium batteries safe to use?

- Used daily by billions of people in many types of applications
  - Consumer electronic devices
  - Power tools
  - Medical devices
  - Automotive applications
  - Large-scale energy storage
- Statistical failure rate is low - The statistical failure rate of this technology is very low. The risk of failure is comparable to the same risk as getting struck by lightning during a lifetime - it is rare.
- The risk of a battery failure can be minimized by correct handling

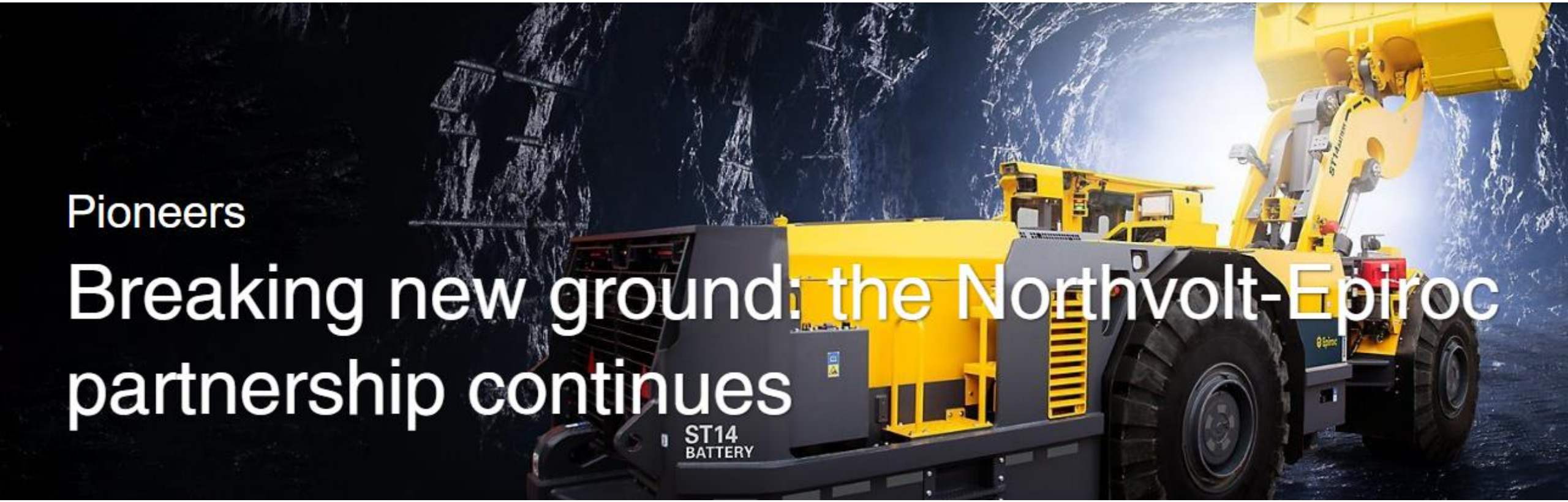
Battery machines & safety

Epiroc

Rocvolt 2020

Northvolt battery system safety

2021-03-31



- Oscar Fors, President for Northvolt Battery Systems, says: “By meeting the highest functional and safety standards required by the demanding environment in an underground mine, we have developed a standard solution that can meet most industrial customer’s needs as well.”

Second Generation

ST14 Battery

Drill Rigs M,E family

Boomer, Simba & Bolterc

MT42 Battery

Epiroc's battery system

Cell

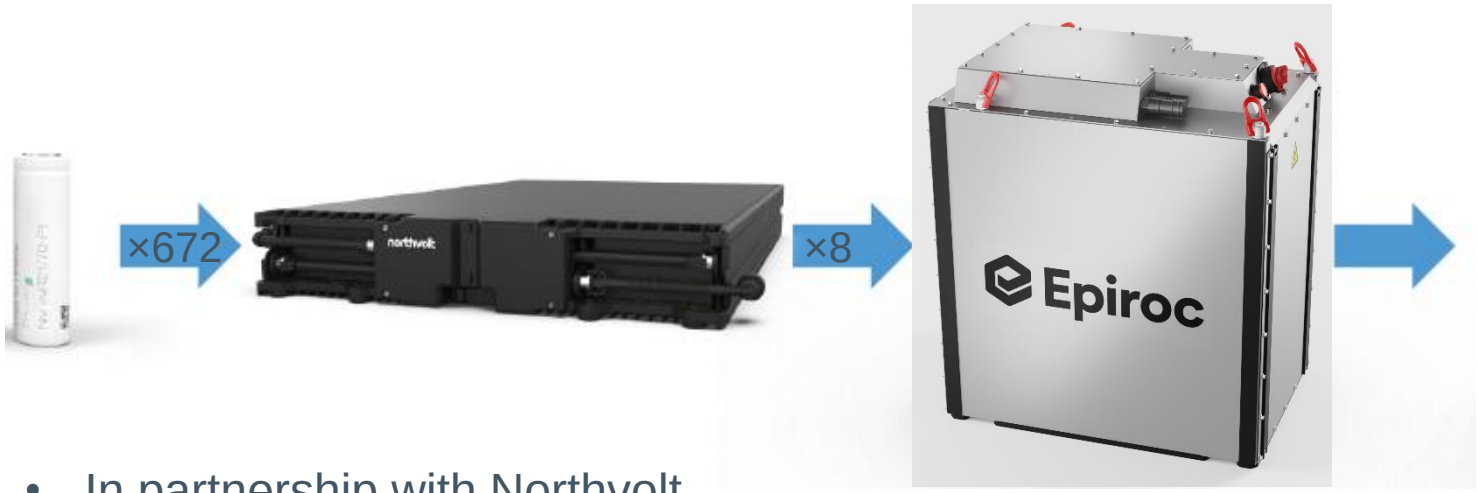
4.2 V
0.0676 kg

Module

100 V
59 kg
672 Cells
24s28p

Sub-pack

800 V
640 kg
5 376 cells



- In partnership with Northvolt
- Designed with safety as the primary focus
- The latest technology
- Economy of scale

Battery packs

MT42

5 Sub-packs

ST14

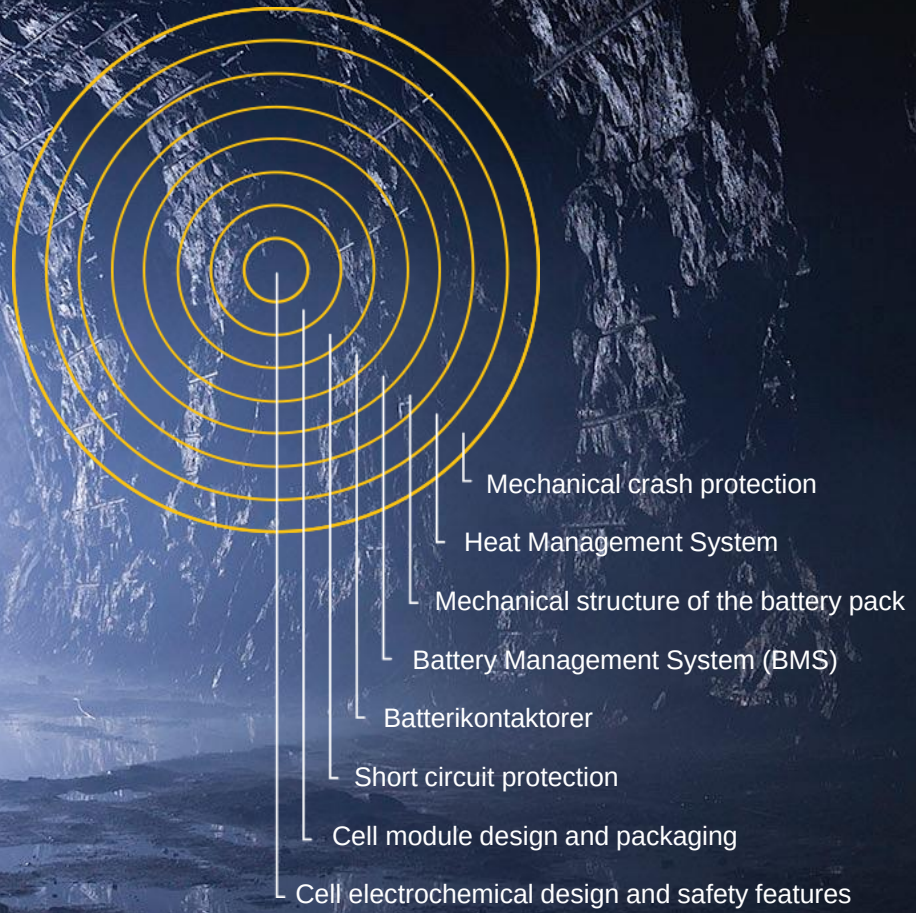
4 Sub-packs

Drill Rigs

2 Sub-packs

Advanced battery safety

Summary



Protection against fire

- Safe cell design to minimize exothermic effects
- Small cylindrical cells
- Fuse (CID) and overpressure ventilation for each cell
- Overload protection on each cell (wire bond)
- All cells are liquid cooled and thermally insulated
- Thermal insulation in several layers
- Three levels of battery management system (BMS)
- Fire retardant ceramic mica layer in modules.

Protection against external fire

- Fire protection on machine for external fire
- Fire extinguishing system in battery pack electronics.

Protection against electric shock)

- REST - Never voltage with open contacts or lids
- Shielded cables
- Insulation monitoring and equipotential bonding
- Automatic and manual contactors with health monitoring
- Manual service disconnect switch (Lock-out / Tag-out).

Protection agains rock fall

- Thick top plate
- Cooling system as demolition protection
- Cables, hydraulics etc. as a demolition buffer..

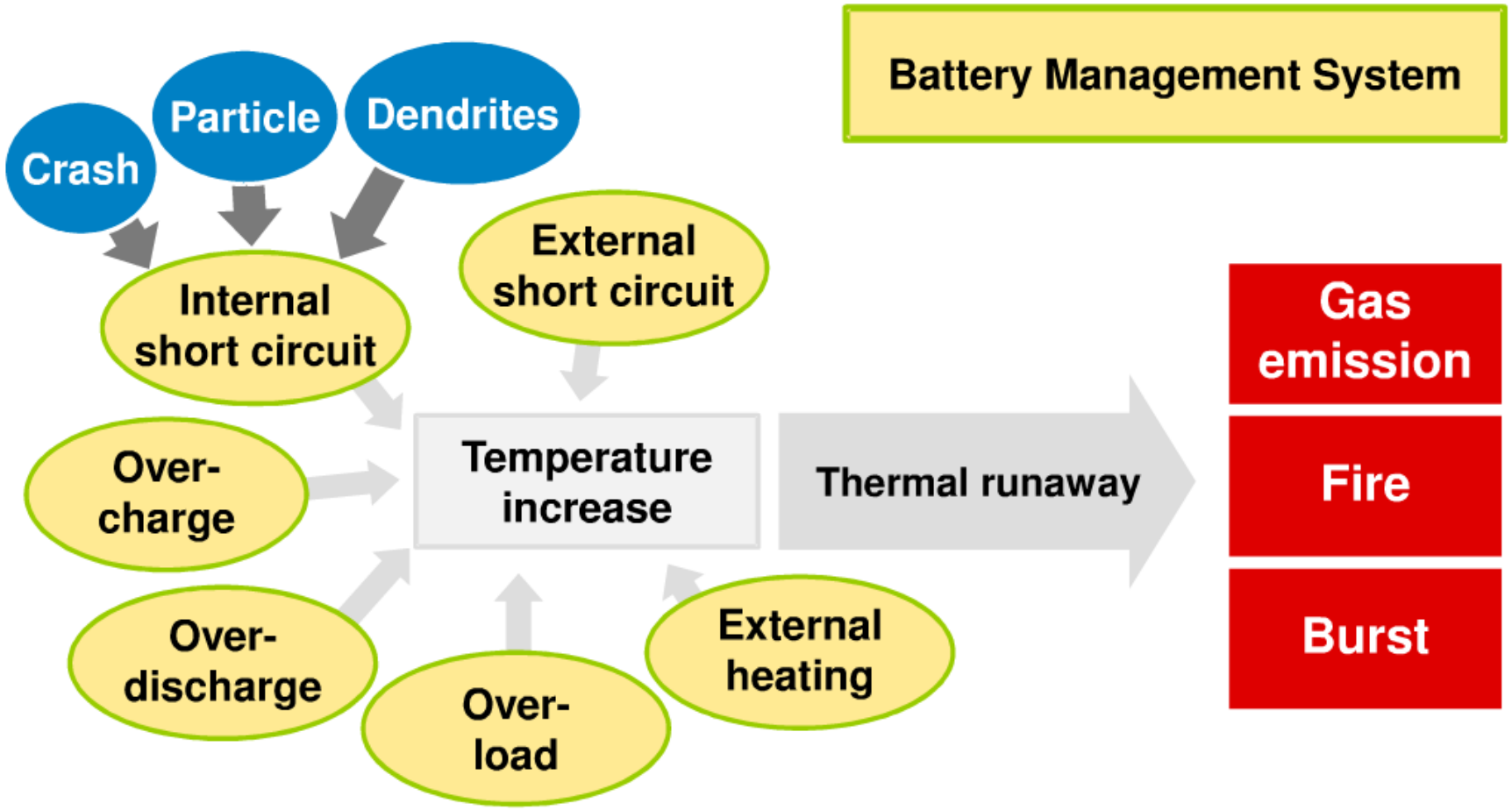
Designed for mining

- Thick steel casing
- Sealed (IP65) sub-pack
- Condensation-adapted
- Designed for the same vibration as machine
- Redundancy in "limp home" battery modules
- Certified for global standards

Epiroc

Lithium batteries

Battery failure mechanism



Li-ion batteries

General design - Cell chemistries

Positive electrode material (cathode)

Comment	Generic name
Less stable than other alternatives	LCO
High rate capability	LMO
Improved stability compared to LCO	NCA
Improved stability compared to LCO	NMC* Epiroc
High stability, but lower cell voltage	LFP

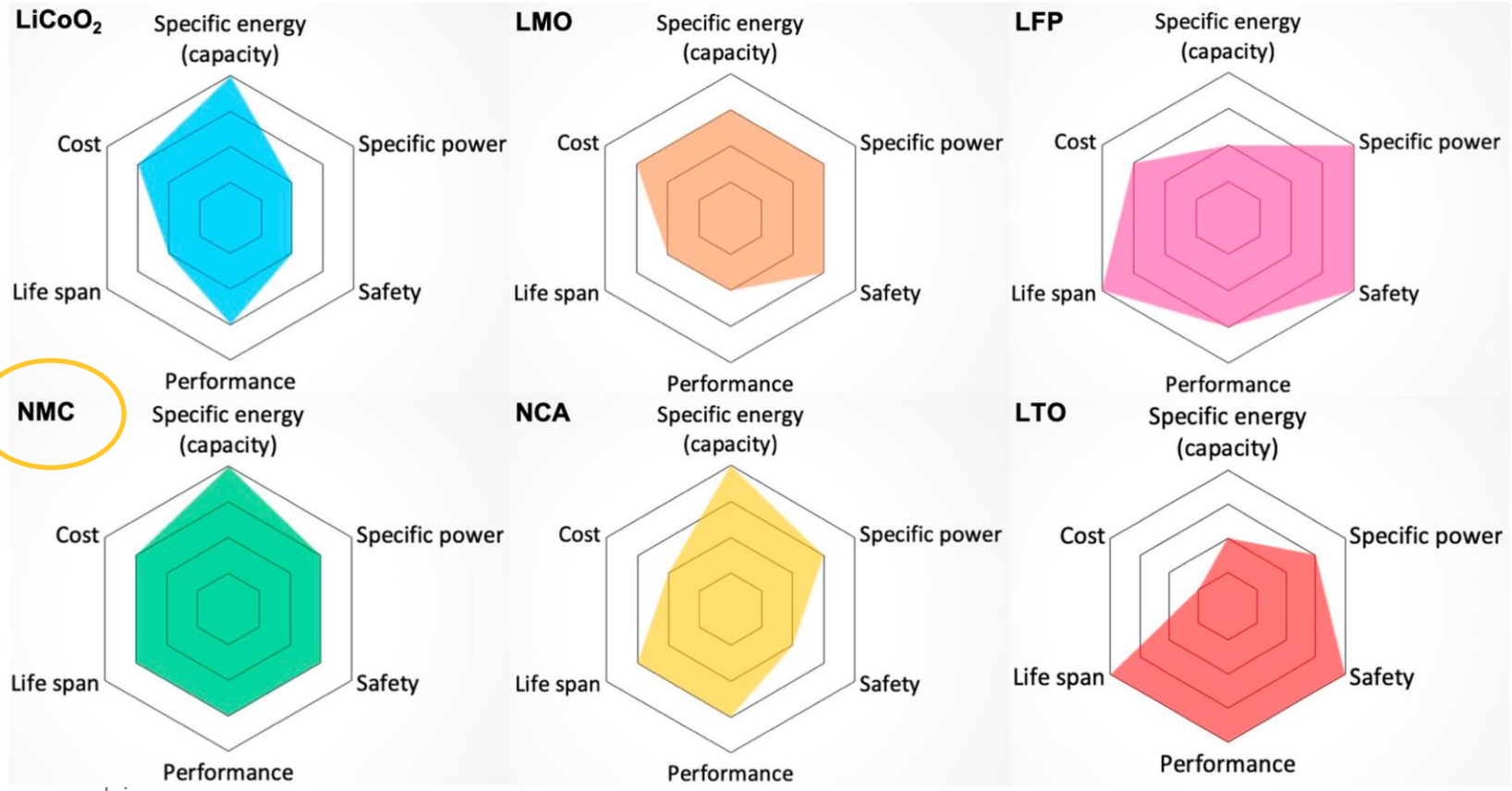
Negative electrode material (anode)

Comment	Generic name
Most common anode material	C* Epiroc
Extremely high capacity, but poor life time	Si
High rate capability, but lower cell voltage	LTO
Extremely high capacity, but safety issues	Li

Typical applications for different chemistries

***NMC** vs. **Graphite** is the increasingly popular combination

Li-ion batteries



www.mdpi.com

- The selection of safe and productive secondary lithium ion batteries is important for mining applications
- The selection of NMC chemistry gives safe operations, high performance and high energy capacity.

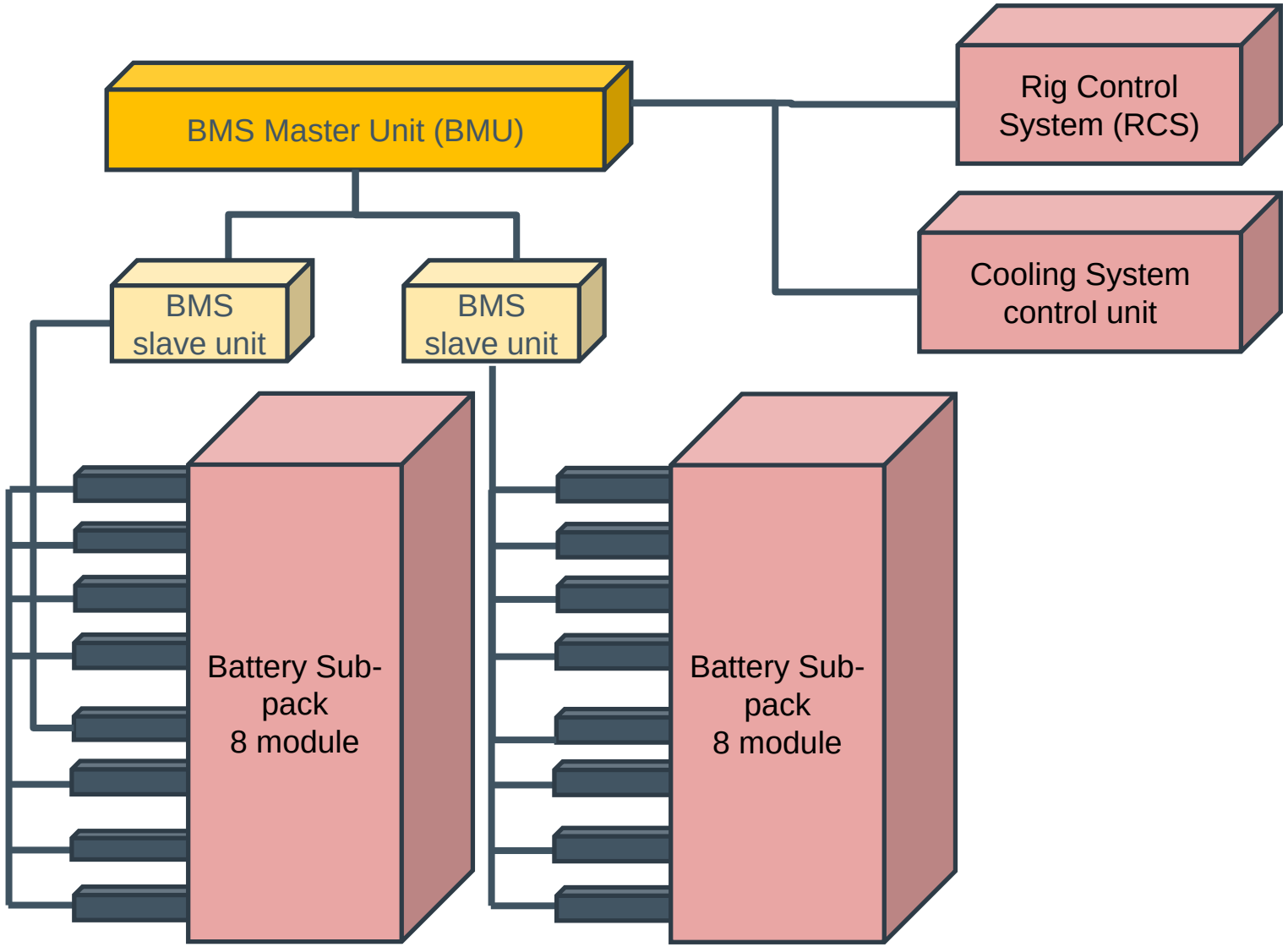
Battery Management System (BMS)

The brain and nerve system of the battery pack

The BMS is an advanced control system that keeps the battery in a safe operation condition.

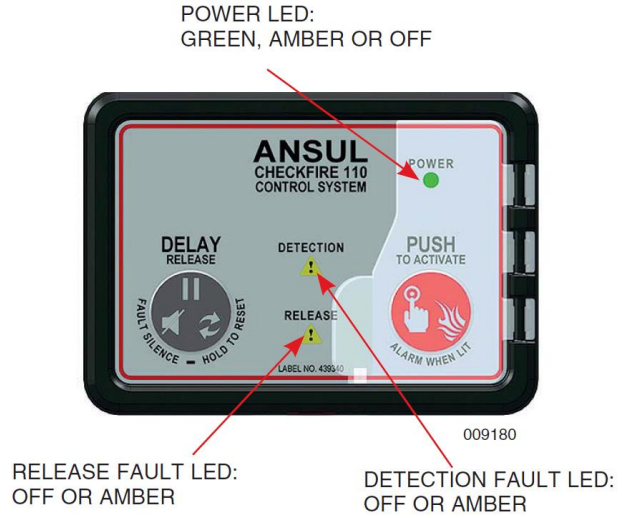
The BMS monitors:

- **Voltage**
- **Current**
- **Temperature**
- **Other electrical safety functions**



Safety

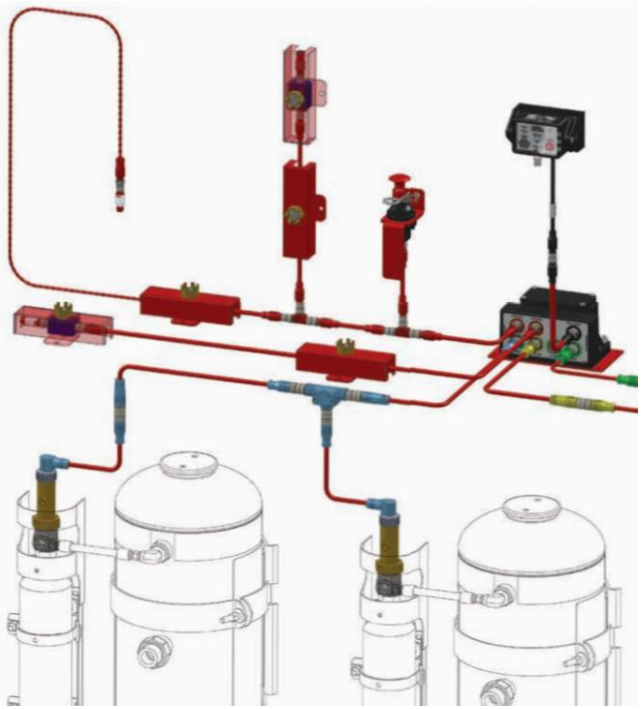
- **Firefighting Equipment for the machine**



➢ Hand Held Fire Extinguisher

➢ ANSUL manually activated fire suppression system, must be activated manually if there is fire.
When triggered, the following occurs:

- ✓ Extinguishing starts
- ✓ The motors are switched off
- ✓ The parking brake is applied
- ✓ Emergency stop circuit broken

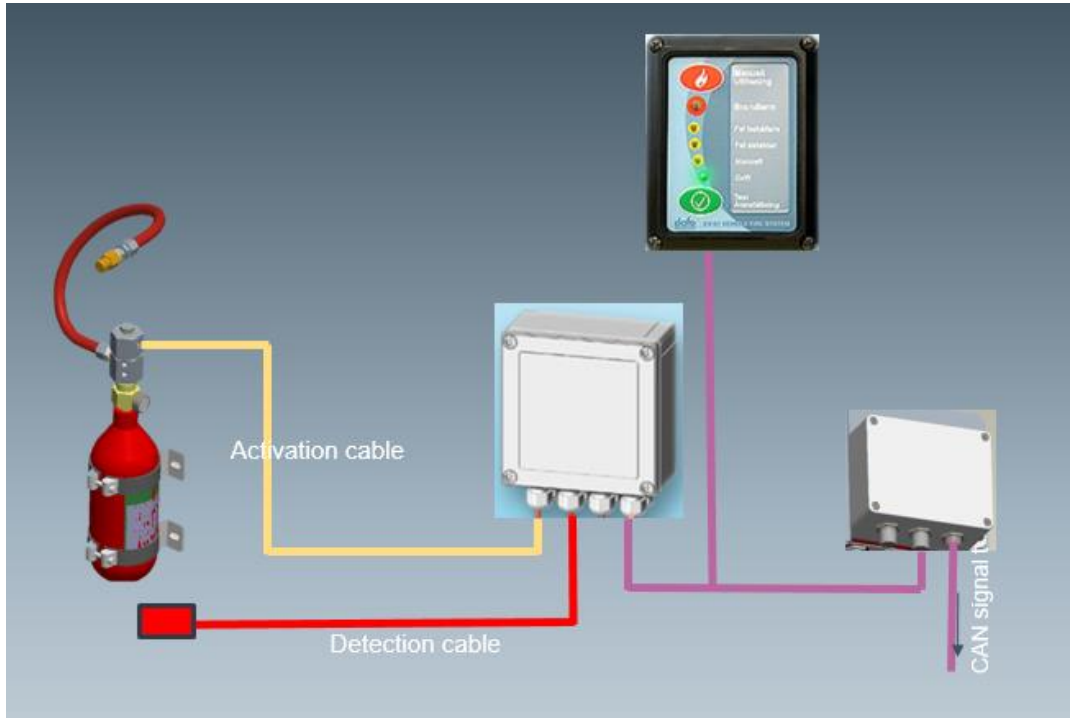


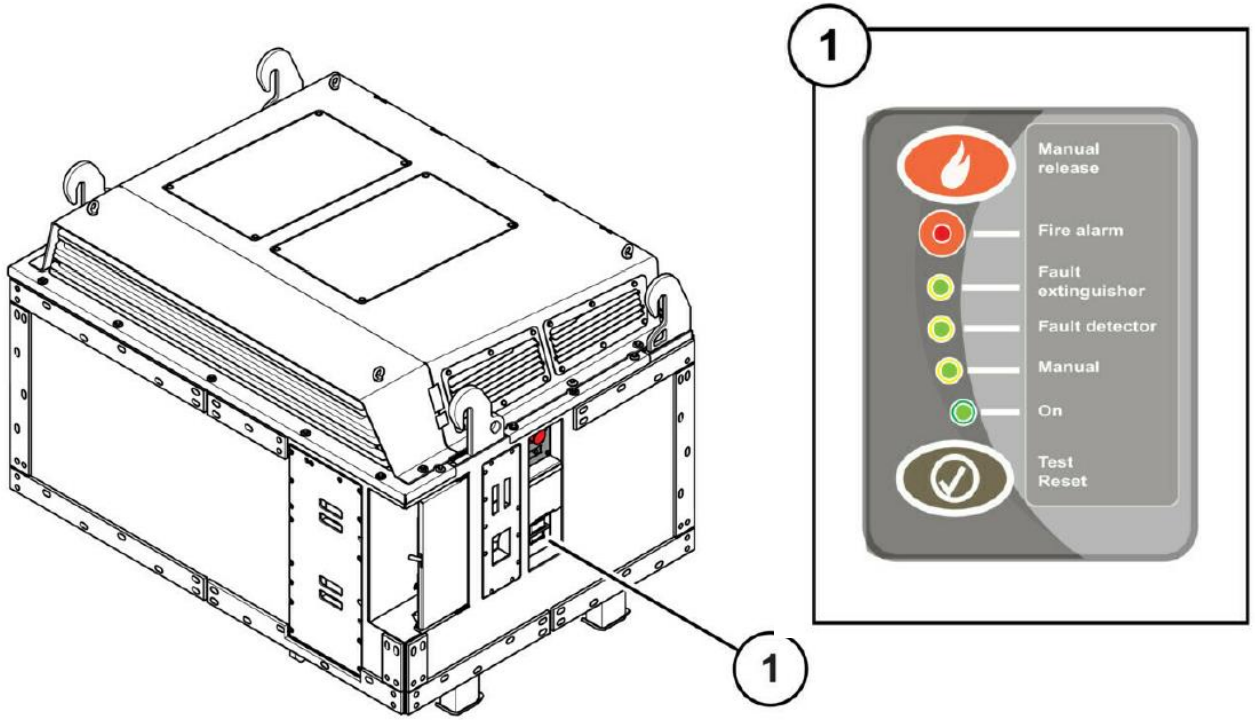
➢ ANSUL Checkfire automatically activated fire suppression system

Safety

Fire Suppression System for the Main Battery

- Stand alone system that detects and **extinguishes fire only on the main battery system (VCB) and does not activate the fire suppression system for the machine**. System has its own extinguisher tank inside the Battery Pack and uses gas as a suppression medium.
- The system triggers automatically when fire is detected in the main battery system and also send a warning signal to the RCS. System can also be activated manually.

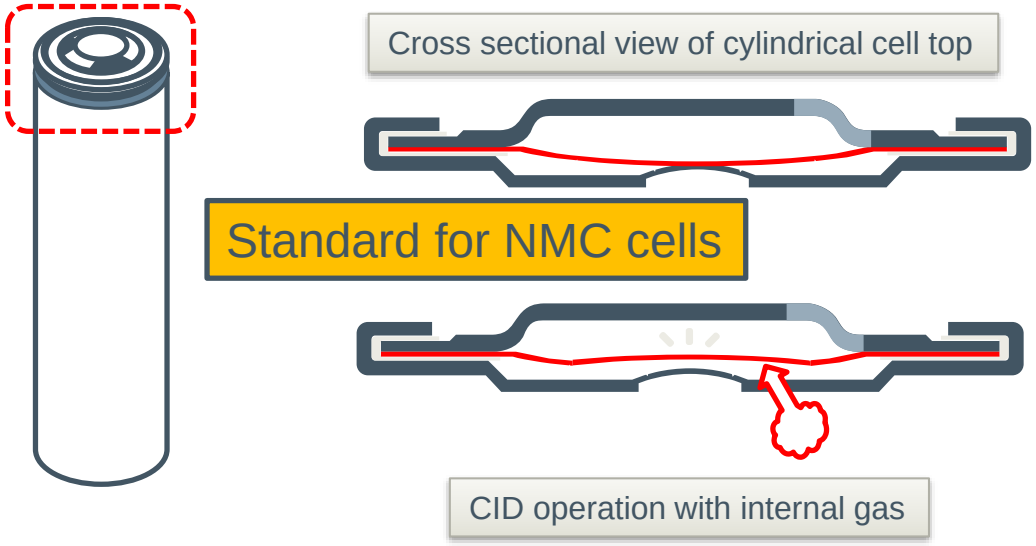




Safety Precautions - Mechanical Part

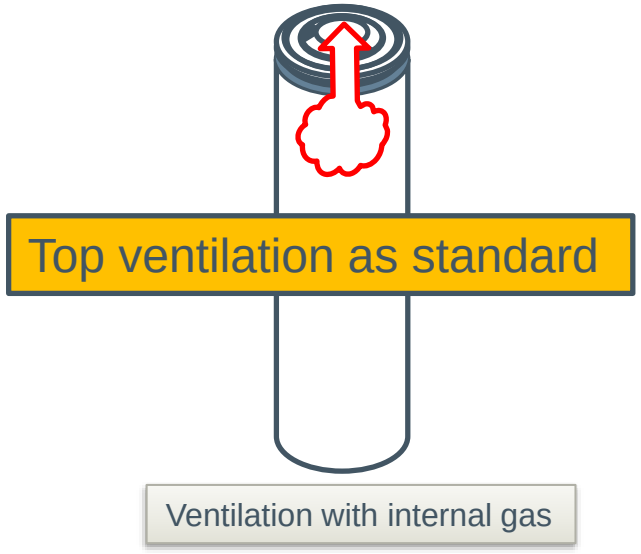
CID

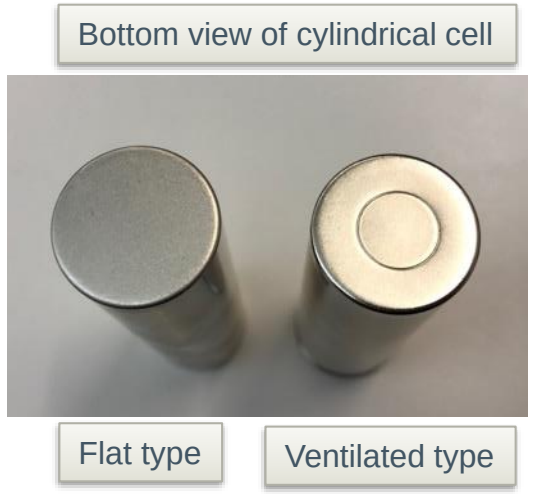
+ “Current Interrupt Device” will work with high internal pressure due to gas production
+ The operating condition is optimized by Northvolt's design



Ventilation Direction Control

+ The direction of gas ventilation can be adjusted based on module and pack design





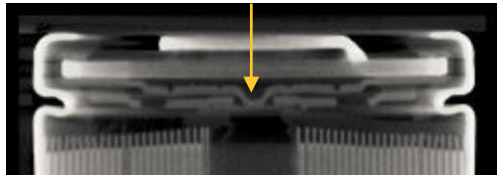
Fuses

Fuses breaks the current when the contactors cannot

Fuses on all system levels:

- Pack Fuses
- Sub-pack fuses
- Wirebond fuses on each cell in the module.
- The current Interrupt Disc inside cell breaks current in case of pressure build up.
- 24 volt control system has fuses.

Sub-pack and pack fuses

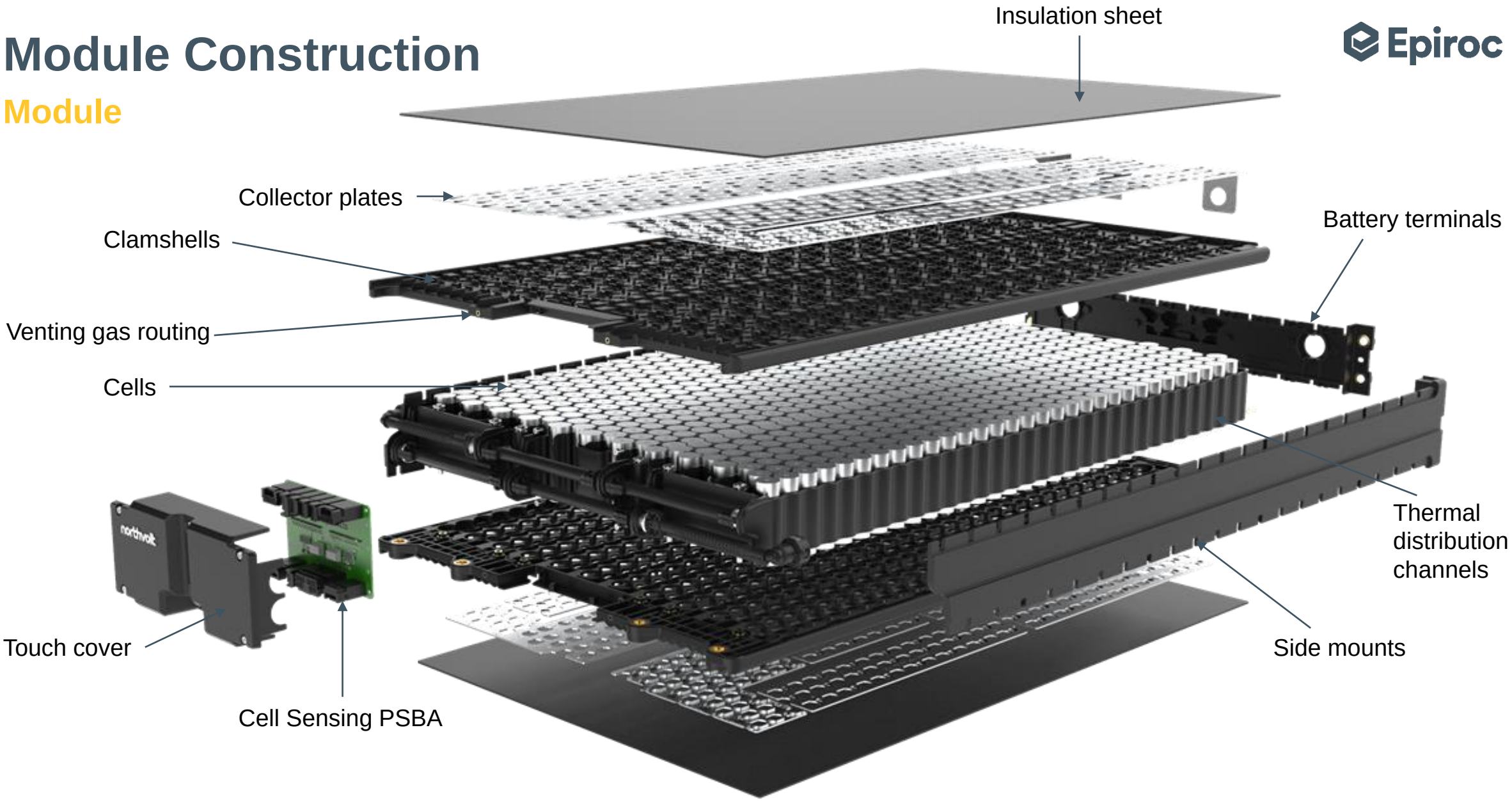


Current interrupted if pressure builds up

Cells connected via wirebonds

Module Construction

Module



Battery validation

+ Batteries are tested against severe abuse conditions in cell/module and pack level.
+ Passing these tests successfully defines battery safety performance. Typical pass criteria is no explosion or catching fire.

Cell level:

+ IEC 62133-2 or IEC 62660
+ UN 38.3, 6th ed. (Transportation tests)
+ UL 1642 (Standard for Safety for Lithium Batteries)

Battery system level:

+ IEC 61619 (Safety requirements for secondary Lithium cells and batteries, for use in industrial applications)
+ UL 2580 (Batteries for use in Electric Vehicles)

Table 1 – Sample size for type tests

	Test	Cell [a, d]	Battery
7.2.1	Continuous charge	5	–
7.2.2	Case stress	–	3
7.3.1	External short-circuit	5 per temperature	–
7.3.2	External short-circuit	–	5
7.3.3	Free fall	3	3
7.3.4	Thermal abuse	5 per temperature	–
7.3.5	Crush	5 per temperature	–
7.3.6	Overcharge	–	5
7.3.7	Forced discharge	5	–
7.3.8	Mechanical – 7.3.8.1 Vibration – 7.3.8.2 Mechanical shock	–	 3 3
7.3.9	Forced internal short [b, c]	5 per temperature	–
D.2	Measurement of the internal AC resistance for coin cells	3	–

[a] Excludes coin cells with an internal resistance greater than 3 Ω.
[b] Country specific test: only required for listed countries.
[c] Not applicable to coin and lithium ion polymer cells.
[d] For tests requiring charge procedure of 7.1.2 (procedure 2): 5 cells per temperature are tested

– TESTS FOR TECHNICIAN-REPLACEABLE AND USER-REPLACEABLE BATTERIES
- ELECTRICAL TESTS
- 10 Short-Circuit Test
- 11 Abnormal Charging Test
- 12 Forced-Discharge Test
- MECHANICAL TESTS
- 13 Crush Test
- 14 Impact Test
- 15 Shock Test
- 16 Vibration Test
- ENVIRONMENTAL TESTS
- 17 Heating Test
- 18 Temperature Cycling Test
- 19 Low Pressure (Altitude Simulation) Test

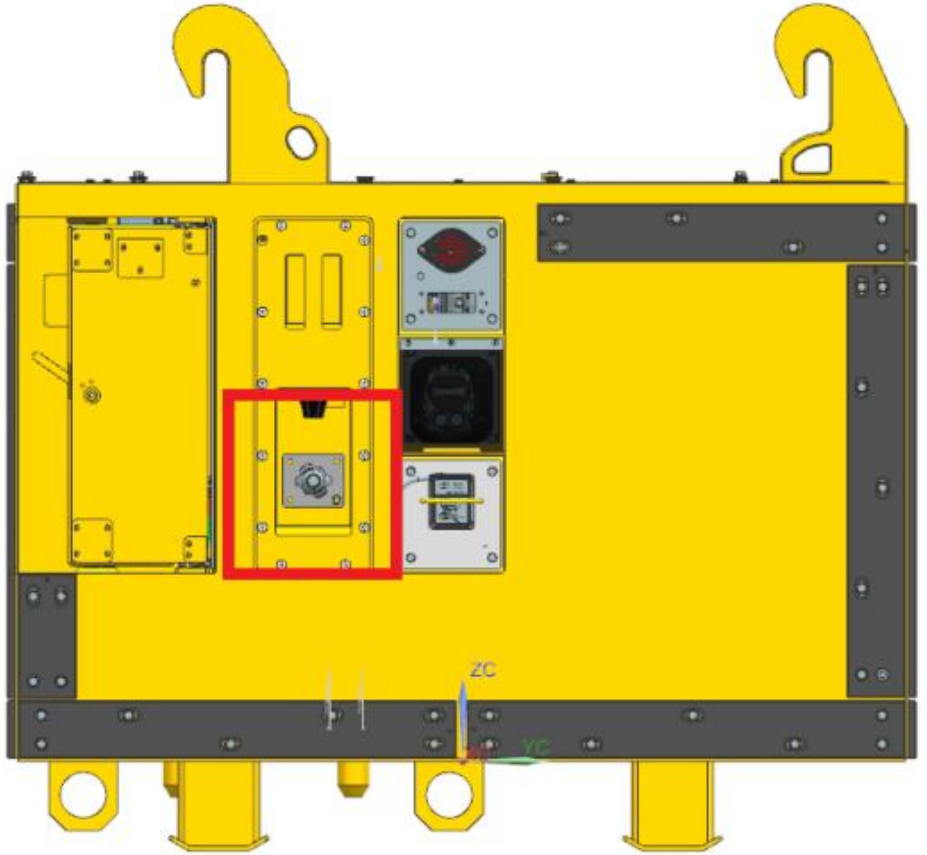
– FIRE EXPOSURE TEST
- 20 Projectile Test

Safety

Flooding of the Battery Pack

Batteries are equipped with a “quick connect” hose couplet outside the main case.

Inside the main case, water is routed directly into each individual subpack.



In case of an accident

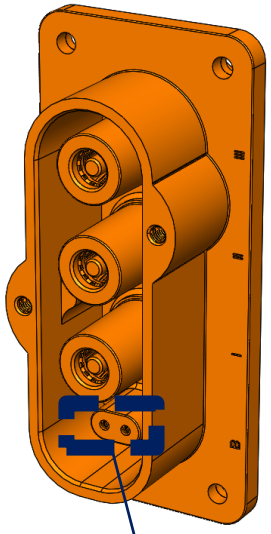
Safety card for lithium batteries

- After risk analysis and advice from safety consultants, DG Epiroc has developed a process for how lithium batteries should be handled at the Epiroc factory AVOS in Örebro.
- This is Epiroc's lithium battery safety card. On this card, we describe how to act in the event of a hazard or in the event of a battery fire.
- The card is placed in several places in the factory, this to make the employees aware that an accident should occur

High Voltage Interlock Loop (HVIL)

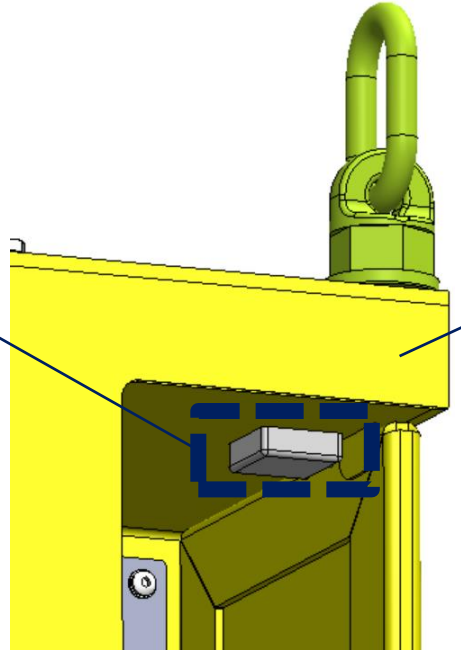
Contactors open when dangerous voltage is accessible

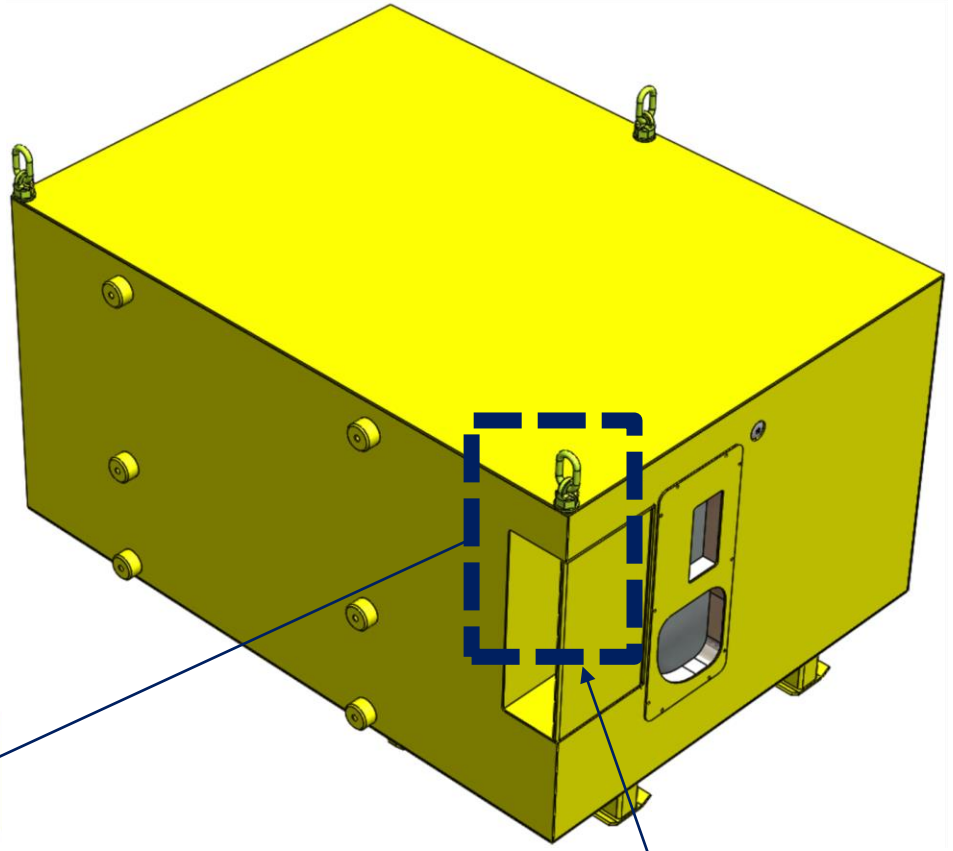
- HVIL is an electric control loop
- Contactors open if the loop is broken.
- Switches that opens the HVIL are located at all interface hatches and panels (see image, and next slide).
- 800 volt contacts also have built in HVIL
- 800 volt contacts are finger proof



HVIL on connections

This switch is pressed out when the hatch is opened, thereby opening the HVIL.





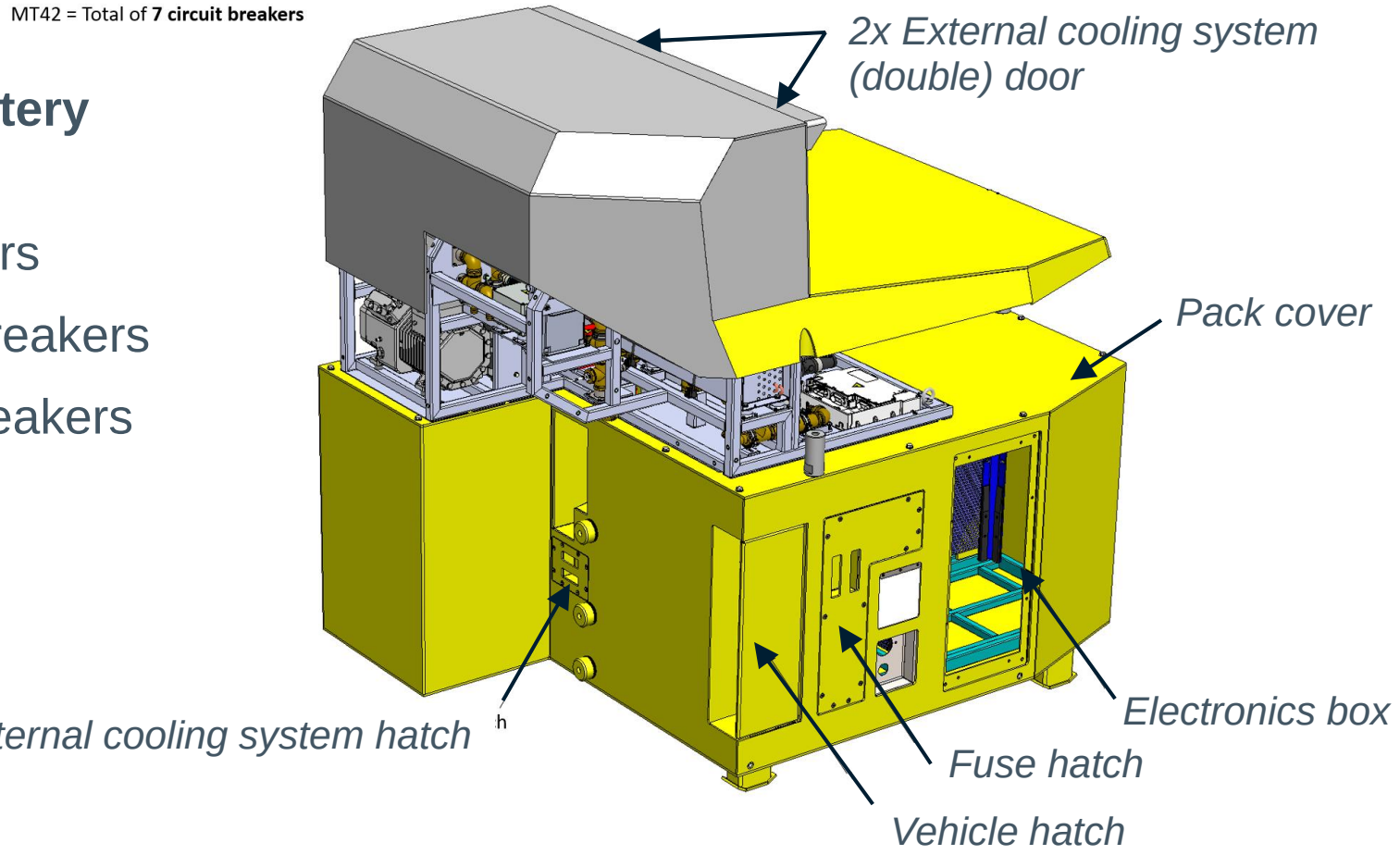
Vehicle Interface Hatch

Hot zones protected by HVIL

Contactors open when dangerous voltage is accessible

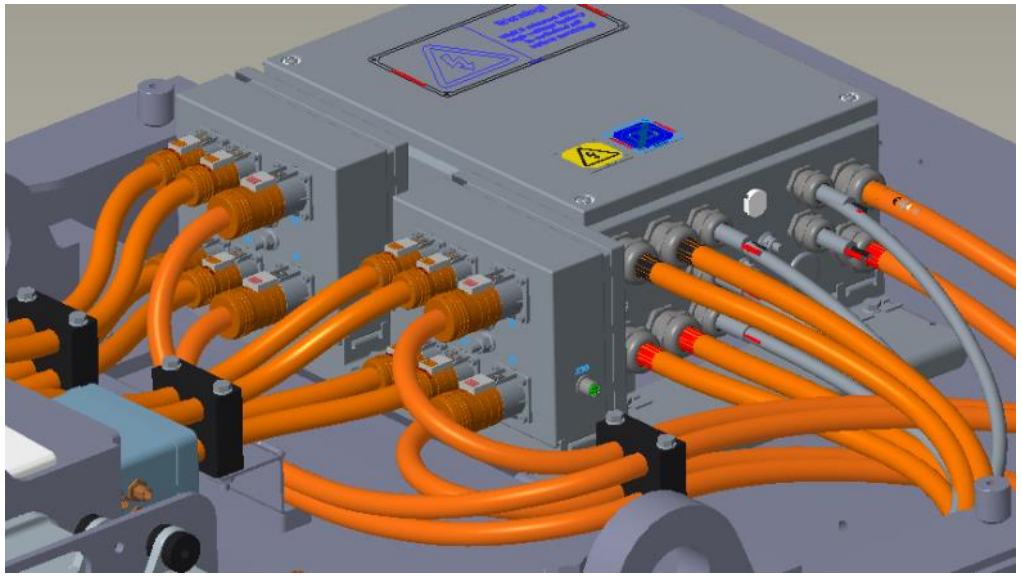
Number of HVIL in the different battery packs:

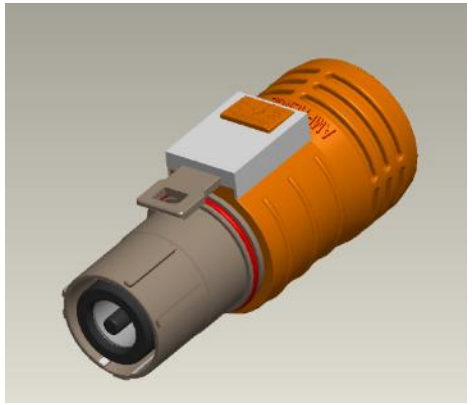
- **MLE Carrier:** 3 HVIL circuit breakers
- **Scooptram ST14:** 6 HVIL circuit breakers
- **Minetruck MT42:** 7 HVIL circuit breakers (highlighted in the image)

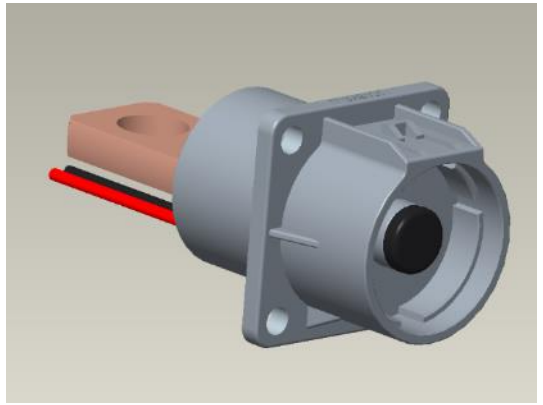


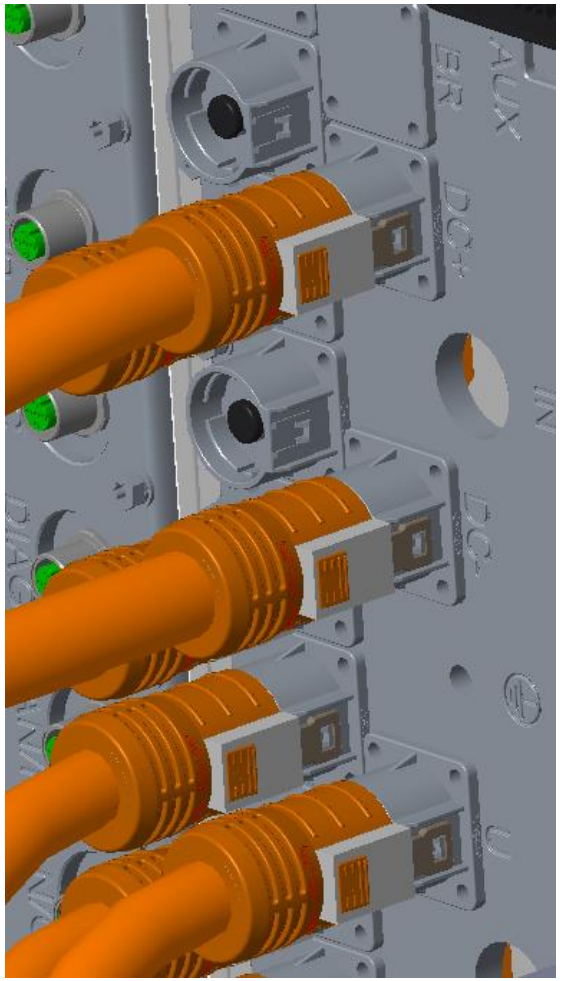
Overview of the HVIL protection in the MT42 battery pack

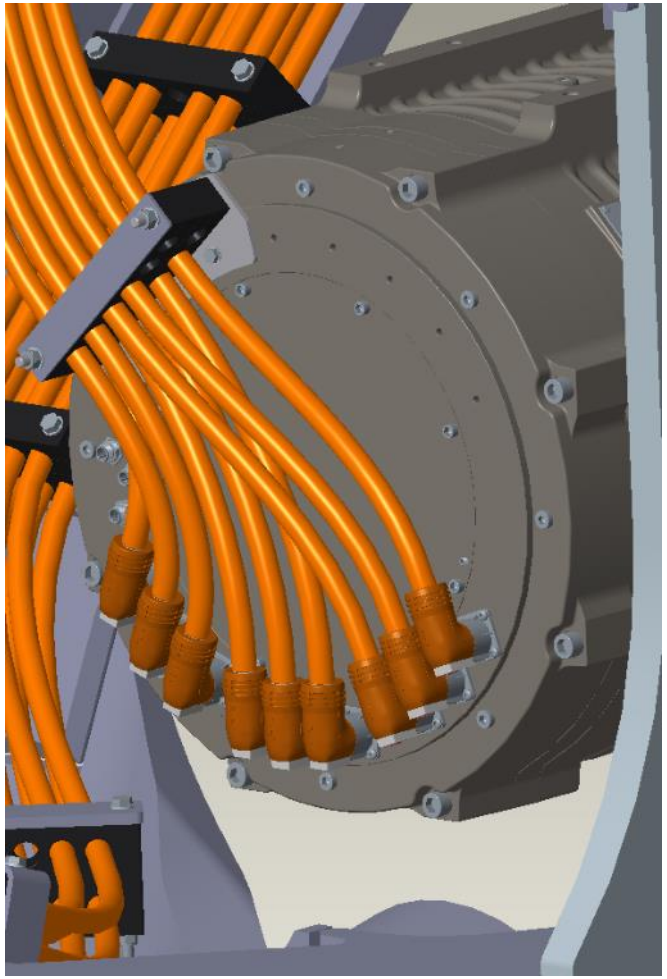
Amphenol power connectors











Contactors

- The 800 volt connections on sub-pack and pack have contactors.
- The contactors open in potentially unsafe scenarios.
- Examples of when contactors opens are:
  - Ground fault.
  - HVIL broken (next page).
  - Operation outside specified voltage, current, or temp. region.

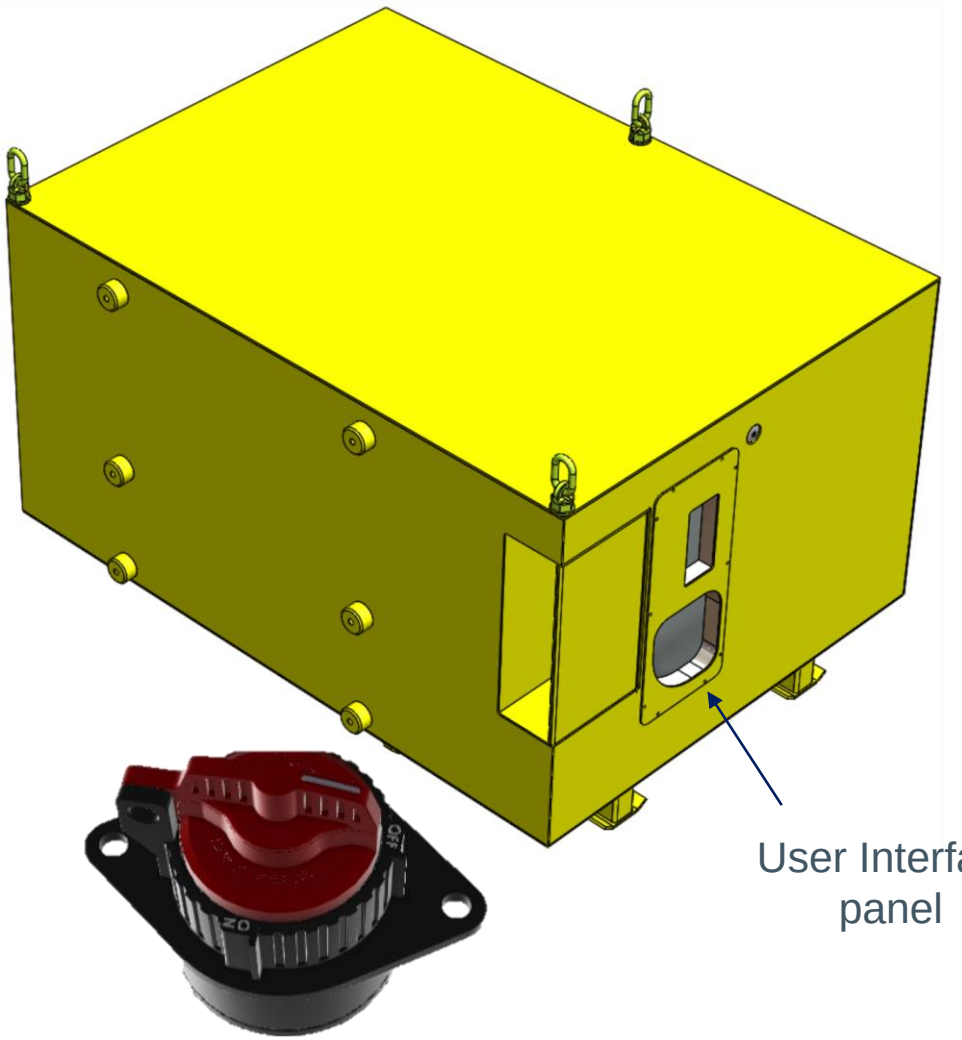
Sub-pack contactor

Pack contactor

Manual Service Disconnect

An extra layer of safety during service

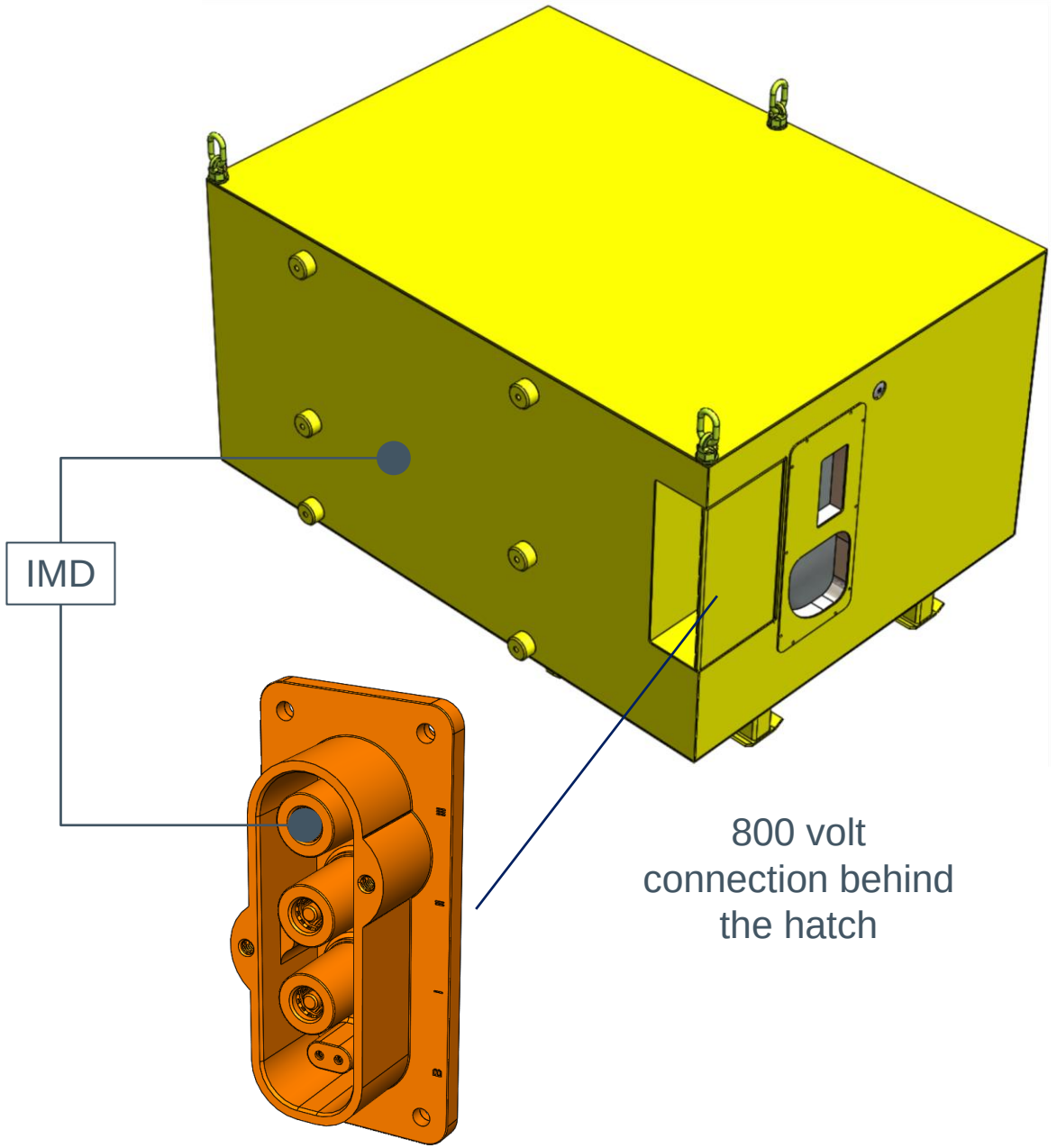
- A manual service disconnect (MSD) is located on the user interface panel (see image)
- Shall be put in its off position during service.
- Contactors are maintained open when MSD is, protecting personnel from dangerous voltages.
- By accessing the service panel, the HVIL is broken and contactors are open. The MSD adds an additional safety layer, making it impossible to accidently close the contactors during service.
- 800 volt machine cables shall be locked on the machine as an additional safety precaution.
- An active discharge circuit discharge any dangerous voltage on the machine side.



Isolation Monitoring Device (IMD)

Protection from ground faults

- The Isolation Monitoring Device (IMD) detects the resistance between:
  - Plus (+) and chassis
  - Minus (-) and chassis
- Ground fault is detected by a low resistance.
- In case of ground fault the contactors opens and operators and service personal are protected from dangerous voltages.



The charging interface

Socket and cable, Scooptram ST14, Minetruck MT42 and MLE Carrier

Charging interface features:

- Charging socket and charging cable are finger proofed
- The socket and cable are energized only when connected
- Charging socket is protected by a temperature sensor monitored by the BMS
- Charing cannot be initiated if the vehicle is still running
- During charging the cooling system will be activated

Batteries as a service

Epiroc

Instant seamless technology leap – pay per use

- Predictable running cost
- Service & connectivity
- Safety and health
- Future tech proof
- Endless warranty

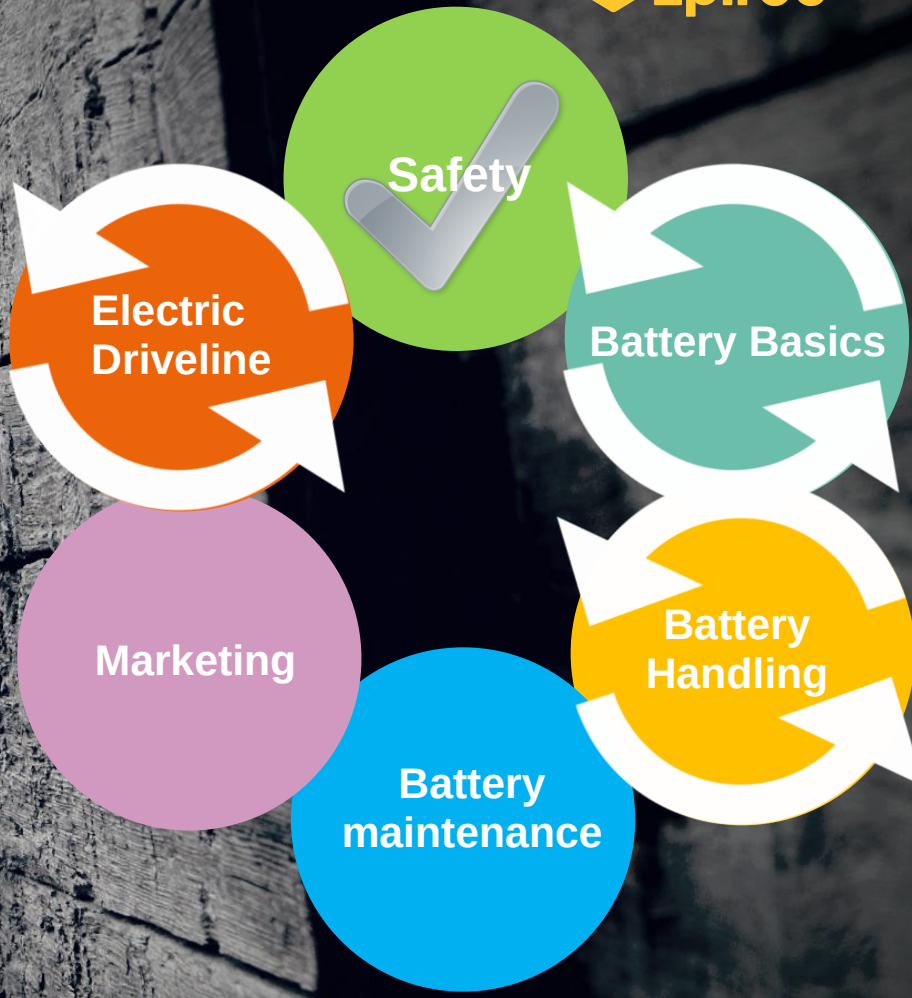
Connectivity

Information

Battery Training Matrix

Epiroc

Prototype Verification	Other R&D	Control System	Mechanic design	Electric design	PC Specialist	PC Analytic	CC Specialist	CC Technician	Machine operator	Storage	Shipping	Production	CC Storage	CC Transport	Sales	
●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	Battery Basics
●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	Safety
●	●	●	●	●	●	●	●	●	●	●	●	●	○	○	○	Handling
●	●	●	●	●	●	●	●	●	○	●	○	●	●	○	○	Maintenance
●	○	●	○	●	●	●	●	●	○	○	○	○	○	○	○	Electrical Driveline
○	○	○	○	○	●	●	●	○	○	○	○	○	○	○	●	Marketing
●	●	●	●	●	●	○	○	○	○	○	○	○	○	○	○	GMG Guideline



●	●	Design for electrical safety
●	●	Electrical safety for workshop Personell

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