# E-Dumper: Battery cell characterization and risk assessment

The E-Dumper Project supports the electrification of mobility. The project is supported financially by the SFOE through its pilot and demonstration programme.

The cells have been passed by UN 38.3 tests (test items: altitude, thermal, vibration, shock, external circuit, impact, forced discharge).

Empa is responsible for following tasks:

- Tests and development of battery cells and module configuration: CT images, short-circuit behaviour
- Safety and risk analysis of cells and battery management system

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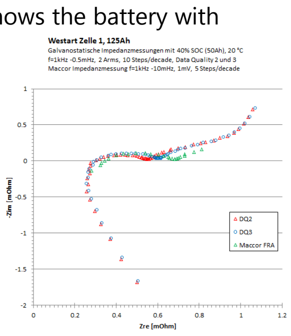
## Data of battery system

- 700 kWh Lithium Ion Battery capacity (one downhill trip result in 40 kWh energy; of which 10 kWh is the amount of stored excess energy)
- 1440 nickel manganese cobalt oxide (NMC) cells; brand Shenzen Westart, System 4 x 180s2p
- Currents up to 3000 A (max. decline of 12%)
- IP67 protected battery system

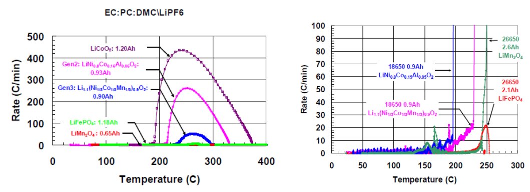
Cell specifications

- X-ray computer tomography shows the battery with 125 Ah capacity consisting of 5 pouch cells of 25 Ah each with nominal voltage of 3.7 V.
- Operation Temperature Range: 0°C up to 45 °C Charging / -20°C up to 55°C Discharging
- Stainless Steel Shell
- Internal Resistance: ≤0.6mΩ




## Safety of NMC batteries

- NMC ($LiNi_{1/3}Mn_{1/3}Co_{1/3}O_2$, used in E-mobility) are safer than LCO ($LiCoO_2$, used in mobile devices) or NCA ($LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$; used for electric powertrain)




Safety of Cathode materials depends on two major factors: maximal self-heating (left plot) and onset temperature of a thermal runaway (right plot). The blue circle (NMC; Gen3) shows a smaller maximal self-heating rate than NCA or LCO. In the right plot, NMC shows a higher onset temperature than NCA.

- Because of its high safety standard and energy-density NMC cells are widely used in E-Mobility applications.
- Electric Safety Devices: Battery Management System protects against over-or under-voltage conditions as well as excessive current or temperature.

## Procedure of a risk assessment

In a risk assessment first of all the system boundary has to be defined. Thereafter the risks to material goods and persons have to be identified and estimated (risk analysis). The risk can be displayed in a qualitative risk matrix:

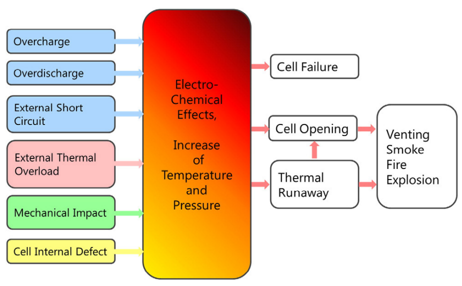
| Probability | Low | Moderate | High |
|---|---|---|---|
| Very Likely | Acceptable Risk (medium – 2) | Unacceptable Risk (high – 3) | Unacceptable Risk (extreme – 5) |
| Likely | Acceptable Risk (low – 1) | Acceptable Risk (medium – 2) | Unacceptable Risk (high – 3) |
| Unlikely | Acceptable Risk (low – 1) | Acceptable Risk (low – 1) | Acceptable Risk (medium – 2) |
| Ocurrence / Impact | Low | Moderate | High |

Probability x Impact = Risk
Impact (how serious is the risk?)

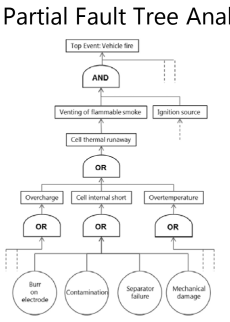
The risks will be evaluated. If needed the system is adapted and the risk assessment is done again until the risk is acceptable. A risk assessment is a continuous process.

## FTA approach (top-down)

Basic battery cell failure mechanisms and effects:

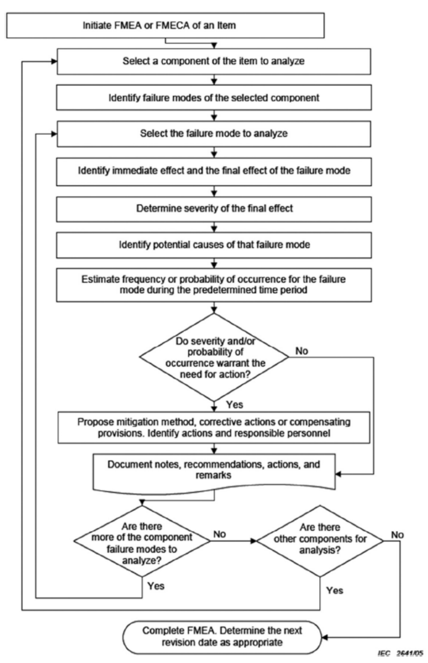



Partial Fault Tree Analysis (FTA):



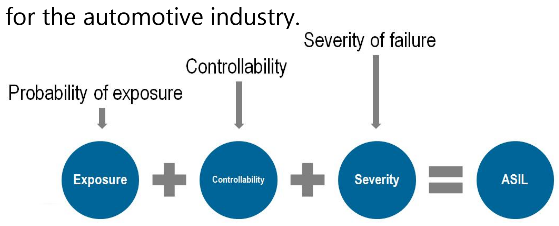

## FMEA approach (bottom-up)

Failure Mode Effect Analysis (FMEA) :




## Risk classification scheme ASIL

Hazards have been classified using the automotive safety integrity level (ASIL) defined by the ISO 26262 standard for the automotive industry.




Different operating states have been evaluated.

| no. | Operating state |
|---|---|
| B1 | Driving flatland or uphill |
| B2 | Driving downhill |
| B3 | Vehicle is being loaded |
| B4 | Vehicle is being unloaded |
| B5 | Vehicle is feeding energy into grid |
| B6 | Vehicle is being charged from grid |
| B7 | Vehicle is parked |
| B8 | Vehicle is maintained |
| B9 | Vehicle is decommissioned |
| B10 | Vehicle crash while driving |

| no. | source of danger | threat |
|---|---|---|
| GS1 | BMS x Vent/Gas | Contamination BMS Vehicle |
| GS2 | BMS x Vent/Gas | Contamination Environment (other vehicles) |
| GS3 | BMS x Vent/Gas | Contamination Environment (buildings) |
| GS4 | BMS x deflagration | Pressure to Vehicle |
| GS5 | BMS x deflagration | Pressure to Environment (other vehicles) |
| GS6 | BMS x deflagration | Pressure to Environment (buildings) |
| GS7 | BMS x fire | Contamination Vehicle |
| GS8 | BMS x fire | Contamination Environment (other vehicles) |
| GS9 | BMS x fire | Contamination Environment (buildings) |
| GS10 | BMS x fire | Fire Vehicle |
| GS11 | BMS x fire | Fire to Environment (other vehicles) |
| GS12 | BMS x fire | Fire to Environment (buildings) |

Hazard to physical property:

| Nr. | B1 | B2 | B3 | B4 | B5 | B6 | B7 | B8 | B9 | B10 | B11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| GS1 | ASIL B | ASIL B | ASIL B | ASIL B | ASIL B | ASIL B | ASIL B | ASIL B | ASIL B | ASIL B | ASIL B |
| GS2 | QM | QM | QM | QM | QM | QM | QM | ASIL B | ASIL B | QM | QM |
| GS3 | QM | QM | QM | QM | QM | QM | QM | ASIL C | ASIL C | QM | QM |
| GS4 | ASIL B | ASIL B | ASIL B | ASIL B | ASIL B | ASIL B | ASIL B | ASIL B | ASIL B | ASIL B | ASIL B |
| GS5 | QM | QM | ASIL B | ASIL B | QM | QM | QM | ASIL B | ASIL B | QM | QM |
| GS6 | QM | QM | QM | QM | QM | QM | QM | ASIL C | ASIL C | QM | QM |
| GS7 | ASIL B | ASIL B | ASIL B | ASIL B | ASIL B | ASIL B | ASIL B | ASIL B | ASIL B | ASIL B | ASIL B |
| GS8 | QM | QM | QM | QM | QM | QM | QM | ASIL B | ASIL B | QM | QM |
| GS9 | QM | QM | QM | QM | QM | QM | QM | ASIL C | ASIL C | QM | QM |
| GS10 | ASIL C | ASIL C | ASIL C | ASIL C | ASIL C | ASIL C | ASIL C | ASIL C | ASIL C | ASIL C | ASIL C |
| GS11 | QM | QM | ASIL A | ASIL A | ASIL A | ASIL A | ASIL A | ASIL C | ASIL C | QM | QM |
| GS12 | QM | QM | QM | QM | QM | QM | QM | ASIL D | ASIL D | QM | QM |

| | | |
|---|---|---|
| ASIL A | proposed failure rate: | $\lambda_F < 10^{-6}/h$ |
| ASIL B | proposed failure rate: | $\lambda_F < 10^{-7}/h$ |
| ASIL C | required failure rate: | $\lambda_F < 10^{-7}/h$ |
| ASIL D | required failure rate: | $\lambda_F < 10^{-8}/h$ |

## References

[1] Picture: Xray CT through battery WS-NCM125AH, Roman Furrer
[2] Graph: EIS Analysis of Battery, Marcel Held
[3] Plots: D. Doughty, E. P. Roth, "A general discussion of li ion battery safety," Electrochemical Society Interface, vol. 21, no. 2, pp. 37–44, 2012.
[4] Figure: https://www.researchgate.net/figure/275155519_fig3_Figure-4-Qualitative-Risk-Matrix-Probability-x-Impact
[5] Scheme: http://www.specialistsafety.co.uk/services/risk-assessment-method-statements/
[6] Scheme Cell failures and Partial fault tree: Marcel Held
[7] IEC 60812, Analysis Techniques for System Reliability - Procedure for Failure Mode and Effects Analysis (FMEA), 2006.

## Partners

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