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Electronic Engineering

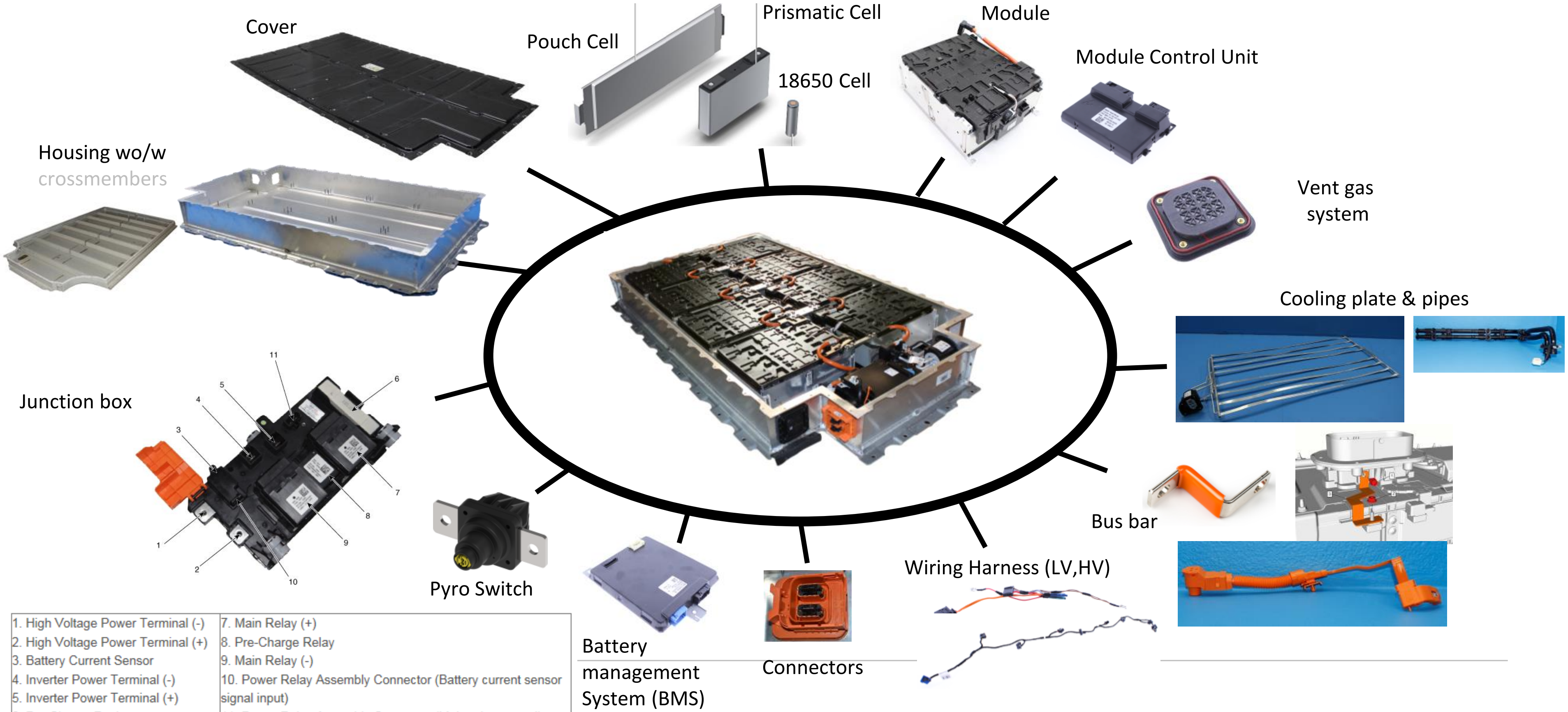
Testing of Automotive Systems (Part I)

Module 6 - HV Battery and Testing

David Ludwig , Magna Steyr

HV Battery - BASICS

Overview HV Battery



1. High Voltage Power Terminal (-)	7. Main Relay (+)
2. High Voltage Power Terminal (+)	8. Pre-Charge Relay
3. Battery Current Sensor	9. Main Relay (-)
4. Inverter Power Terminal (-)	10. Power Relay Assembly Connector (Battery current sensor signal input)
5. Inverter Power Terminal (+)	
6. Pre-Charge Resistor	11. Power Relay Assembly Connector (Main relay control)

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HV Battery Components

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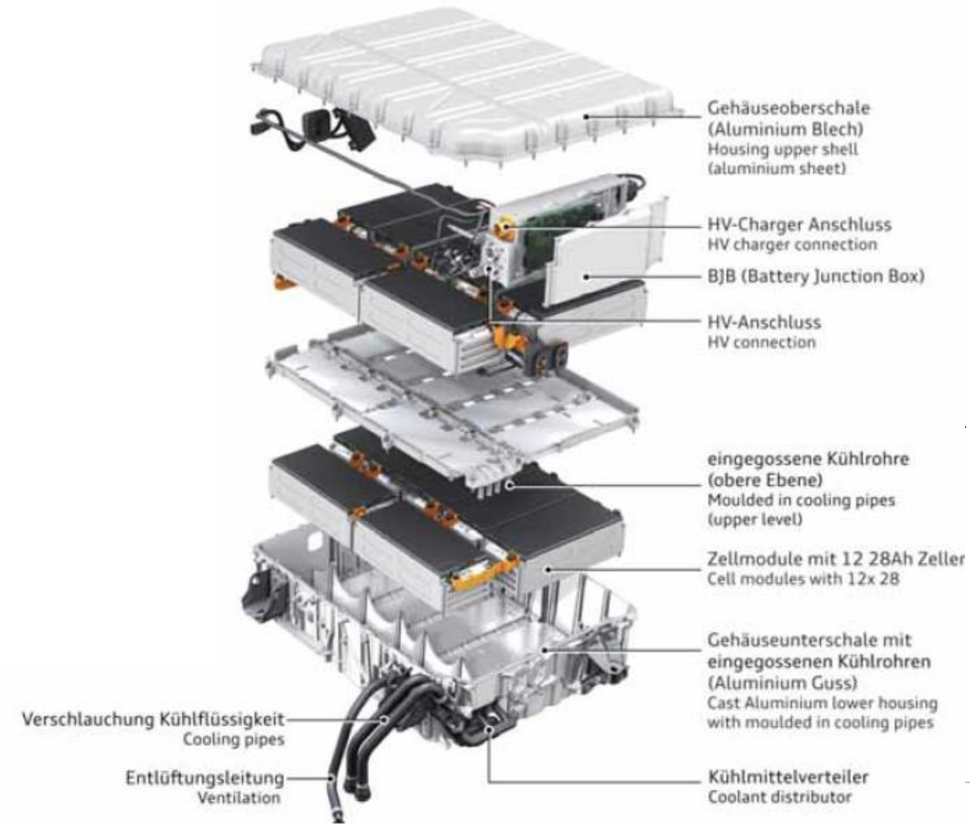
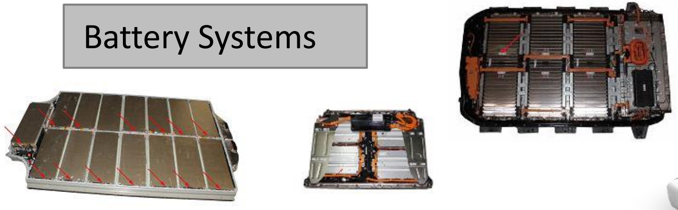
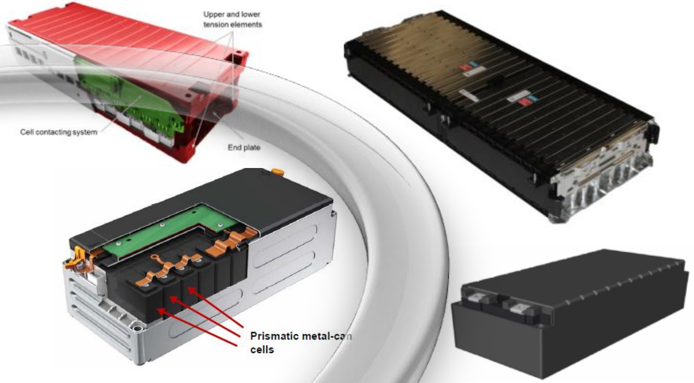


Universal Setup of Battery Systems

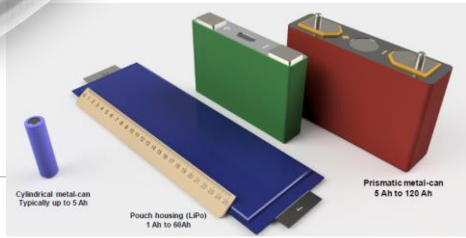
Battery Systems



Battery Modules



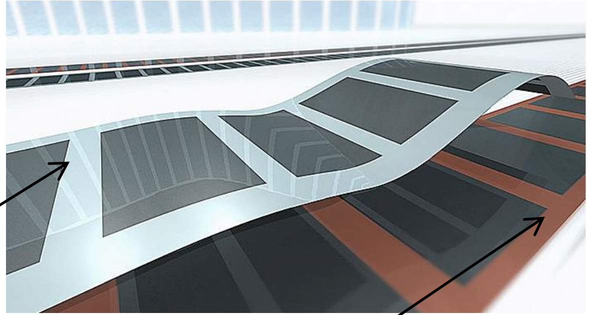
Battery Cells



Vehicle	Hybrid or Electric Vehicle				
System	Battery System				
Subsystem	Battery module	Cooling system (air or liquid)	Electronic components	Battery housing	Connectors + wires
Components	Cell	Fan	Battery control board	Housing	High voltage wires
	Cell sensors	Heat exchanger	System sensors	Overpressure valve	HV-connector to vehicle
	Cell connector	Pipe/ channels/ manifolds	Insulation monitoring	Pressure balance device	Module connectors (busbar)
	Module housing	Sensors	Fuse(s)	Electrical insulation	Service disconnect
	Module sensors	Gaskets	Interlock system	Thermal insulation	Main contactor and precharge relay
	Gaskets			Gaskets	Signal wires
					Signal-connectors to vehicle

Important Terms and Parameters I

- (Galvanic) cell: Smallest unit
- Module: Connection of cells into (geometrically standardized) modules
- Battery pack: Connection of two or more module
- Electrodes:
  - Anode: positive Electrode
  - Cathode: negative Electrode
- Location of chemical reaction; consisting of current collector foil and coated active material



Example of a cathode:

Dark grey areas: coated active material

Light grey areas: current collector foil (Aluminium)

Example of an anode:

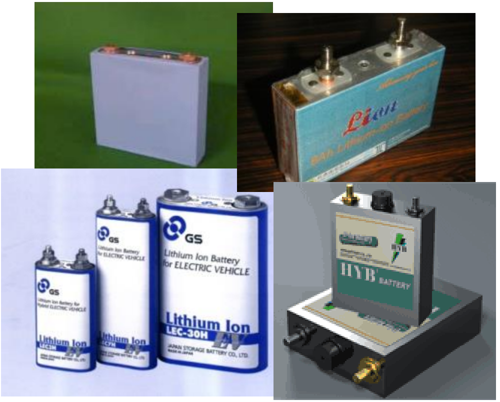
Dark grey areas: coated active material

Red/brown areas: current collector foil (Copper)

Mechanical Cell Designs – Housing Possibilities

Cylindric Cells

Prismatic Cells



Pouch Bag Cells

Different Cells for Different Applications

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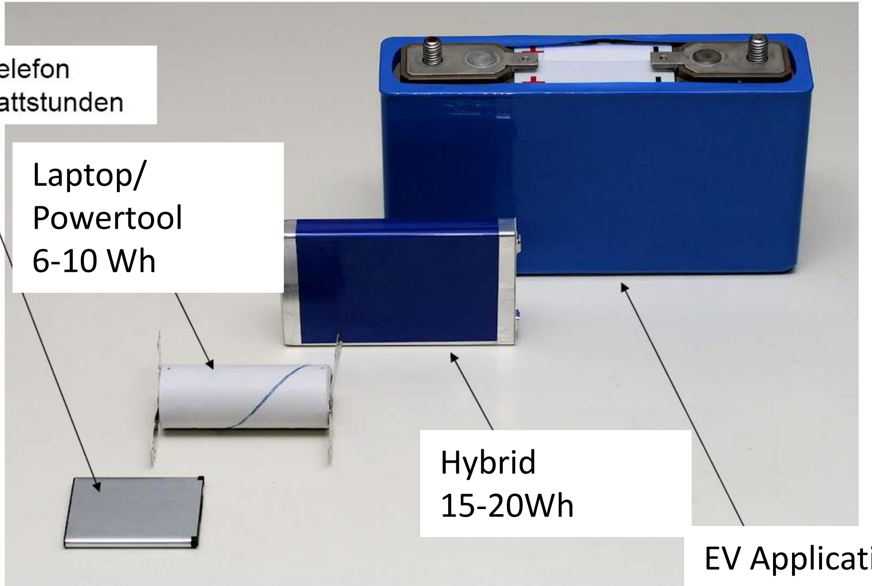


Mobiltelefon
2-3 Wattstunden

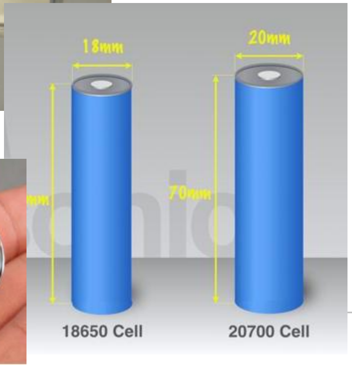
Laptop/
Powertool
6-10 Wh

Hybrid
15-20Wh

EV Application
100 – 250 Wh

CCC Market

Automotive Application



Source: https://gas2.org/2015/03/18/lighter-batteries-may-prove-tipping-point-electric-vehicles/

Cell Designs – Housing Possibilities

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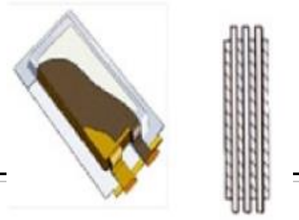
Type		Pro	Con
Cylindrical Cell		✓ High energy density ✓ Fast standard process production ✓ Possibility of integrated safety features (pressure relief valve, circuit breaker,…)	– Poor cooling behavior – High volume when integrated into modules – Limited cell size (Ah)
Prismatic Cell		✓ Good cooling behavior via can ✓ Low volume and weight when integrated into modules ✓ Possibility of integrated safety features (pressure relief valve,circuit breaker,…)	– More expensive cell housing – Bracing with endplates necessary – Different stress at flat and bent areas of jelly roll
Pouch Cell		✓ High energy density ✓ High flexibility in design ✓ Good cooling behavior ✓ Lower cost	– Rather complex module design – Integration of safety features not possible – No defined exhaust relief position

Important Terms and Parameters II

- **Capacity [Ah]:**
  - Withdrawable **charge** of the battery

    $$Q = I*t$$

  - [Attention: it is a charge - not mix it up with the term capacity in the proper sense (capacitor; C=Q/U)]
  - C-Rate: Rate of electric current related to the cell capacity

    Examples: 1C: battery with 100 Ah → 1 hour with 100A for full charge or discharge of the battery
    C/5: Battery with 100 Ah → 5 hours with 20A for full charge or discharge of the battery
    2C: Battery with 100 Ah → ½ h at 200A for full charge or discharge of the battery

  - Charge Efficiency (Coulombic Efficiency; [%]):

    $$q_{Ah} = (Q_{disch}/Q_{ch})*100$$

- **Open Circuit Voltage (OCV) [V]:**
  - Difference of electrical potential between two terminals of a device when they are disconnected from any circuit
- **Nominal Voltage [V]:**
  - Voltage at defined current (1C-Rate)
  - e.g.: lead acid: 2V; Lithium-Ion: 3,6V; Nickel-Metallhydride: 1,2V; …

Important Terms and Parameters III

- **Energy [Wh]:**
  - The **specific energy** [Wh/kg] respectively the **energy density** [Wh/l] maintain the stored energy content of a battery.
  - This parameter depends on the specific charge/discharge density of the active materials as well as on the redox-potentials of the electrochemical reactions.
  - The stored energy is reduced by charge and discharge losses:
    - Current-heat losses at the internal resistance* (heating of the cell): $P_v = I^2 \times R_i$
    - Charge losses due to side reactions: gas generation
    - Self discharge (electrochemical accelerated by high T)

$$E = U*I*t$$

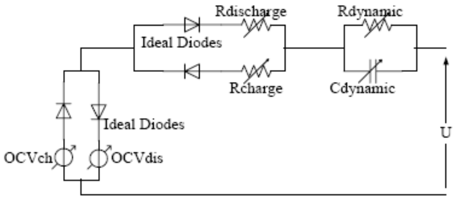
  - Energy Efficiency:

$$q_{Wh} = q_{Ah}*(U_{disch}/U_{ch})$$

$$P = E/t = U*I$$

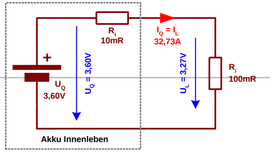
- **Power [W]:**
  - The power related to the battery weight or volume is denoted as **specific power** [W/kg] or **power density** [W/l].
  - This parameter describes the maximum current carrying capacity.

Equivalent circuit



- **Internal Resistance (Impedance) [Ohm]**

Modell



Important Terms and Parameters IV

→ From vehicle to battery – which battery property is important for which vehicle function?

Vehicle data	Battery data
Range (one refueling)	specific Energy (Wh/kg) Energy density (Wh/l) Self discharge (%/month)
Refueling	Charging time (Ah/h)
Overall range of car	number of cycles till EOL
Acceleration	specific Power (W/kg) Power density (W/l)
Reliability	Reaction to Shock/ Vibration
Safety	influence of temperature OverCharge, Short circuit Charge after Deep discharge

Battery requirements for future automotive applications
EG BEV&FCEV
July 2019

Table 1. - Battery requirements for future Battery Electric Vehicle (BEV) applications

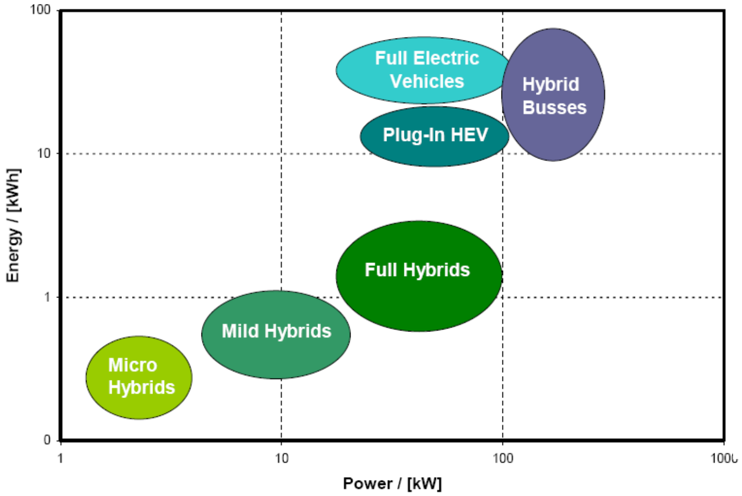
BEV - Parameter at CELL level	Unit	Condition	State of the art 2019 (approximated average values)	Target 2030 Mass market PC low range ~400km	Target 2030 Mass Market PC high range >600km	Target 2030 Mass market Commercial HDV
Specific energy	Wh/kg	@ 1/3C charge and discharge at 25°C (charging with CC and CV step)	~250	450	450	450
Energy density	Wh/l	@ 1/3C charge and discharge at 25°C (charging with CC and CV step)	~500	1000	1000	1000
Continuous specific power - discharge	W/kg	180s, SOC100%-10%, 25°C	750	1000	1000	1000
Continuous power density - discharge	W/l	180s, SOC100%-10%, 25°C	1500	2200	2200	2200
Peak specific power PC - discharge Peak specific power CV - discharge	W/kg	10s, SOC50%, 25°C / -25°C (PC) 60s, SOC50%, 25°C / -25°C (HDV)	1500/500	1800 / 600	1800 / 600	1350 / - due to performance
Peak power density PC - discharge Peak power density CV - dischqrge	W/l	10s, SOC50%, 25°C / -25°C 60s, SOC50%, 25°C / -25°C	3000/1000	4000 / 1300	4000 / 1300	3000 / -
Charging rate	C (1/h)	SOC 0%-80%	3	3.5	3.5	3
Self discharge	%	SOC100%, 25°C, 30 days	1	1	1	1
Cycle lifetime WLTP for cars Cycle lifetime for truck / bus	Energy throughput MWh	25°C, DOD90% until SOH80%	~20	22 to 24	22 to 24	N/A
Hazard level	EUCAR safety levels		<=4	<=4	<=4	<=4
Cost	€ / kWh		220	70	70	70
BEV - Parameter at PACK level	**Unit**	**Condition**	**State of the art 2019 (approximated average**	**Target 2030 Mass market PC low range ~400km**	**Target 2030 Mass Market PC high range >600km**	**Target 2030 Mass market Commercial HDV**
Cell volume per battery pack	%		60	75	75	75
Cell weight per battery pack	%		70	80	80	80
Lifetime expectation	Years & km	DOD90%	lifetime of a car 150.000km	lifetime of a car 150.000km	lifetime of a car 150.000km	N/A
Cost	€ / kWh		*+30% of cell cost	*+20% of cell cost	*+15% of cell cost	N/A

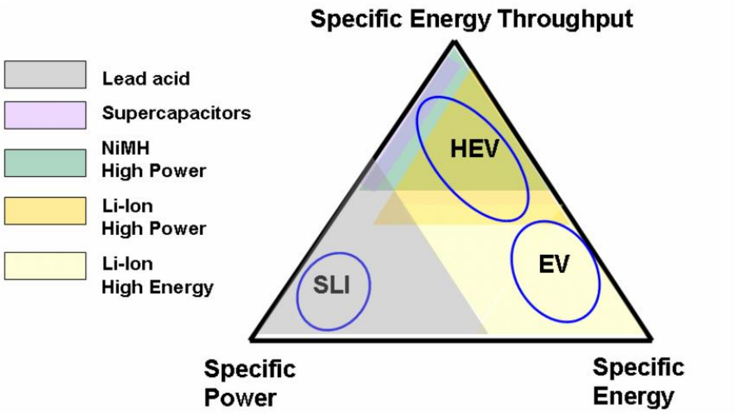
PHEV - Parameter at CELL level

State of the art 2019 (approximated average values)	Target 2030 Mass Market PC PHEV e-mode ~100km
~200	350
~500	800
750	1750
1500	3850
1500/500	3500 / -
3000/1000	7700 / -
4	5
1	1
~20	15 to 24
<=4	<=4
220	100
State of the art 2019 (approximated average values)	**Target 2030 Mass Market PC PHEV e-mode ~100km**
60	70
70	75
lifetime of a car 150.000km	lifetime of a car 150.000km
*+30% of cell cost	*+20% of cell cost

https://eucar.be/wp-content/uploads/2019/08/20190710-EG-BEV-FCEV-Battery-requirements-FINAL.pdf

Battery Dimensioning





SLI: Start light and ignition batteries for cars…

The challenge is to select the correct:

- ✓cell technology (chemistry)
- ✓cell size and
- ✓cell design!

Pack Requirements for 3 Automotive Applications

HEV

Requirements on pack level

- Very high peak power
- dynamic duty profile
- Low useable energy (150Wh)
- High relative energy throughput

Cell Characteristic

- Low capacity (5-7 Ah)
- Small cell dimensions
- High C-rates (20-30)
- Small thermal capacity
- high thermal gradients
- Energy throughput limiting

PHEV

Requirements on pack level

- Depending on application
- HEV Mode <==> EV Mode

Cell Characteristic

- Medium capacity (20-30 Ah)
- Medium cell dimensions
- Moderate C-rates (10-15)
- Medium thermal capacity

EV

Requirements on pack level

- Low peak power
- "Continuous" load
- High useable energy (15-35 kWh)
- Low relative energy throughput

Cell Characteristic

- Large capacity (50-70 Ah)
- Large cell dimensions
- Low C-rates (3-5)
- High thermal capacity
- Calendar life limiting

The specific demands on vehicle & system level require specific cell technologies

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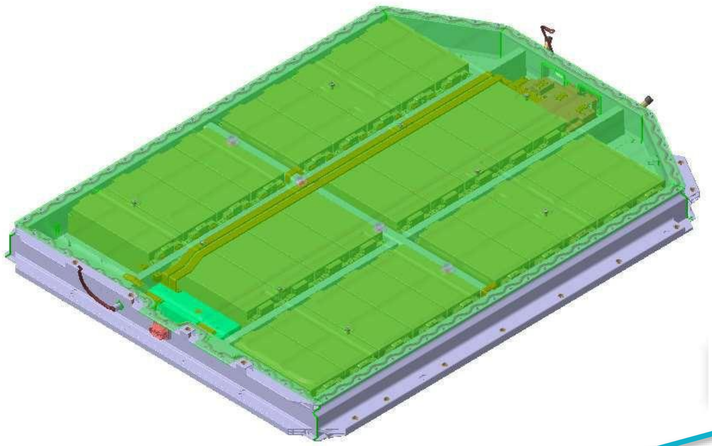
Data sheet example



Project		Scheme
Information	Capacity (KWh)	86.7
	Cell type and system	811
	Nominal capacity (Ah), 1/3C capacity (Ah)	68.9/71
	Nominal voltage (V), 1/3C voltage (V)	3.54/3.64
	Cell size (mm)	342×11.5×102
Module information	Module type	3P4S
	Number of modules (pcs)	28
	Module size	390×152×108
System information	Connection method	3P112S
	System nominal voltage (V)	396.5， 1C
	System voltage range (V)	280-470.4
	System nominal energy (kWh)	81.9， 1C
	NEDC available energy (kWh)	79.8(92% 1/3C)
	Type of thermal management	Liquid cooling
	Battery pack weight (kg)/size (mm)	weight: 490
	Energy density (Wh/kg)	~182

3,54V*4S*28 Modules

68.9Ah*3*396.5V

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Battery Management System (BMS)

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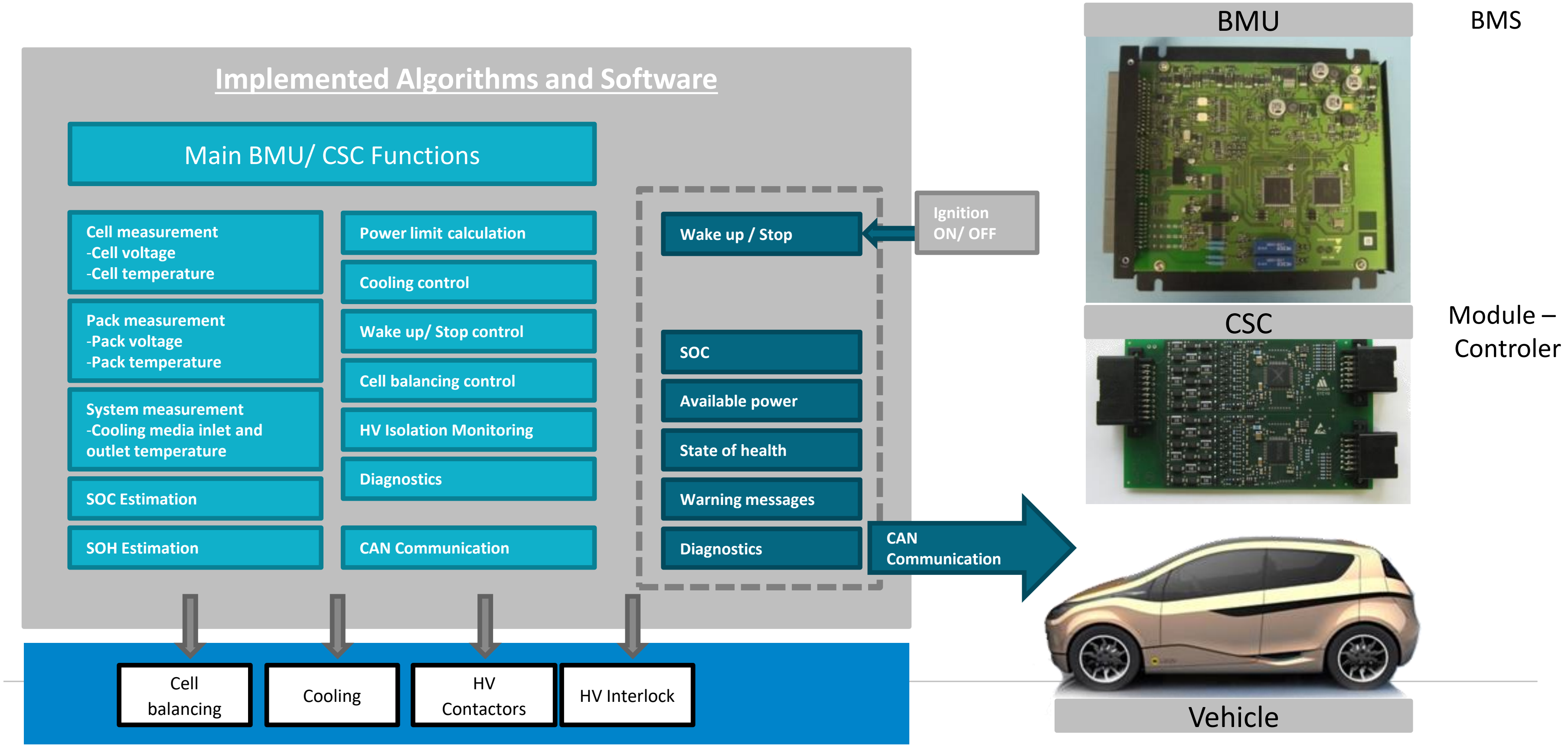

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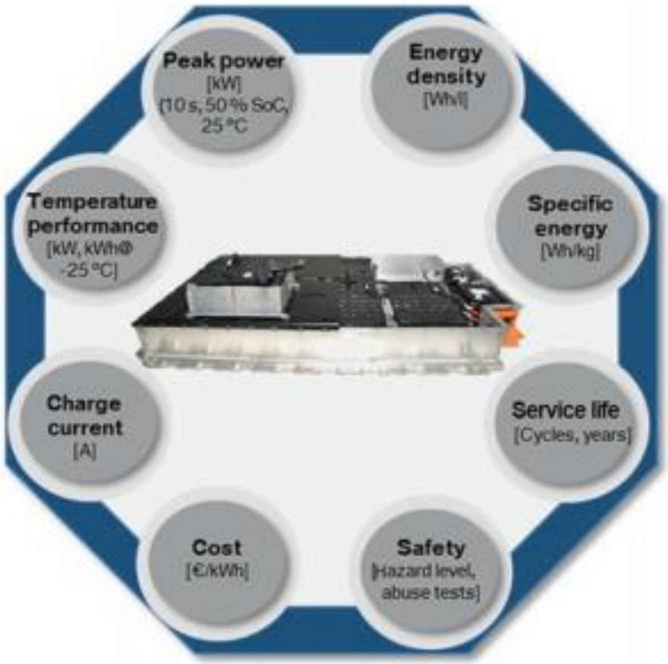
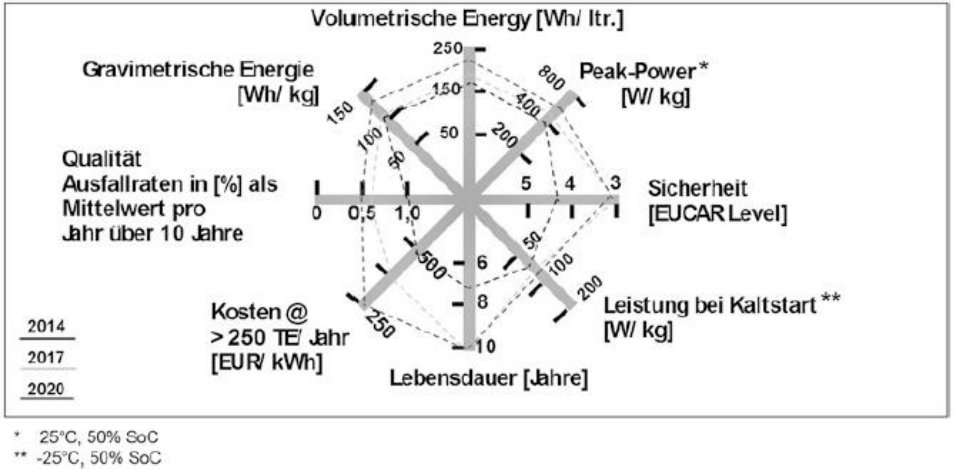
Key-Performance Parameters



Key performance parameters for electric vehicle batteries (targets for 2014 to 2020)



* 25°C, 50% SoC
** -25°C, 50% SoC

Source: Peter Lamp in
R. Korthauer (Hrsg.), Handbuch
Lithium-Ionen-Batterien, 2013 / resp. 2018

eDrive Systems: BMW i3

Technical Data	BMW i3
Nominal voltage	360 V
Max. current	409 A
Energy content	22 kWh
Discharge Power peak	147 kW
Total number of cells	96 (1p, 96s)
Weight (with connections)	233 kg
Charging time	<0,5 h for 80% (DC charge)
Cooling	Refrigerant

Electric motor			
Type		BMW eDrive technology: Hybrid synchronous motor with integrated power electronics, charger and generator mode for recuperation	
Peak-Output	kW (hp)	125 (170)	125 (170)
Permanent Output	kW (hp) / min^{-1}	75 (102) / 4800	75 (102) / 4800
Torque	Nm/ min^{-1}	250 / 0	250 / 0
Recuperation	kW	up to 50	up to 50
High-voltage battery			
Rated voltage	V	360	353
Energy capacity (gross/net)	kWh	21,6/18,8	33,2/27,2
Storage technology		Lithium-ion	Lithium-ion

[BMW i3]

Fahrzeugdaten	BMW i3s
Motor	Synchron-Elektromotor
Batterietyp	Lithium-Ionen
Batteriekapazität (netto/brutto)	27,2/33,2 kWh
Spitzenleistung kW (PS)	135 (184)
Nennleistung kW (PS)	75 (102)

[BMW i3s]

Source: Schoewel & Hockgeiger (BMW) @ AABC 2015
[BMW i3] Technical Specifications 07/2016 Media Information
[BMW i3s] http://www.autobild.de/artikel/bmw-i3s-test-13410337.html

HV Battery Safety

Thermal Runaway / Propagation

Safety of Lithium-Ion Batteries - Setscrews

Level 1	Level 2	Level 3	Level 4
Cell Materials	Cells	Pack	Vehicle
Safe Materials e.g. usage of shut down separator…	Design & Manufacturing e.g. integrated safety devices (overpressure valve…)	Safety Functions e.g.battery state detection and prediction	Safety Functions e.g. thermal management

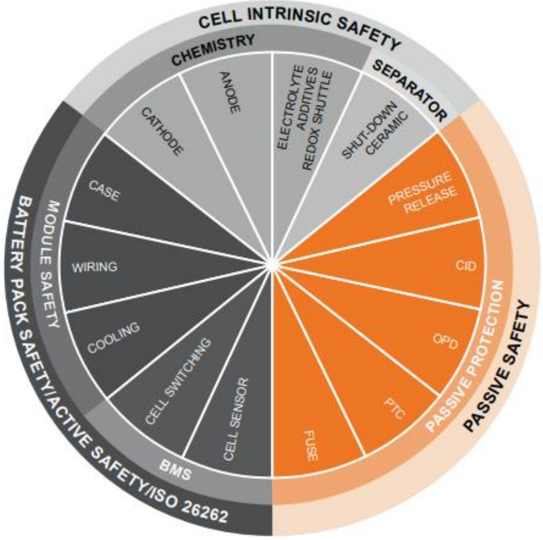


Fig. 24.4 Battery system safety

Source: M. Vogt in
R. Korthauer (Ed.), Lithium-Ion Batteries: Basics and Applications, 2018

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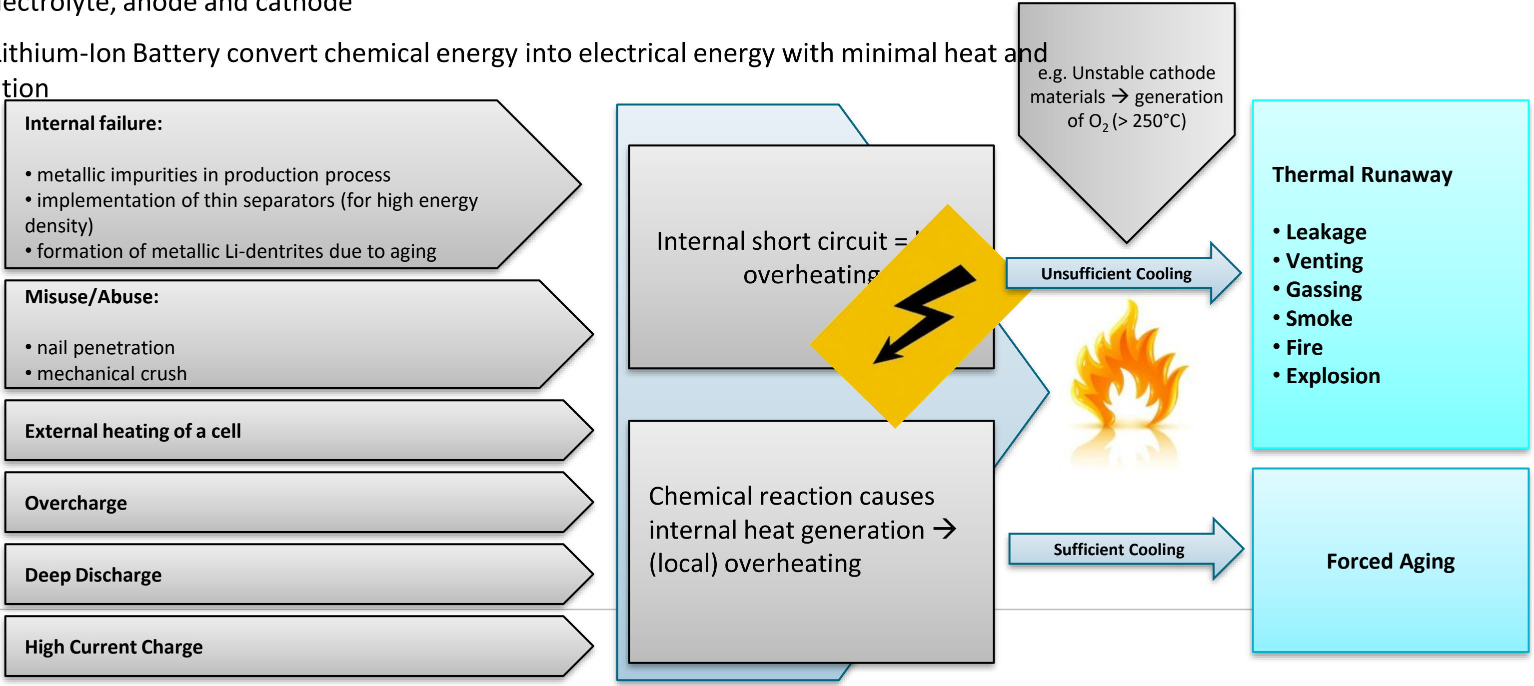
Thermal Runaway

- Thermal runaway is one of the failure modes in lithium-ion batteries with enormous impact on safety
- Thermal runaway occurs when an exothermic (energy release) reaction goes out of control → exothermic reactions between electrolyte, anode and cathode
- Normal Conditions: Lithium-Ion Battery convert chemical energy into electrical energy with minimal heat and negligible gas generation



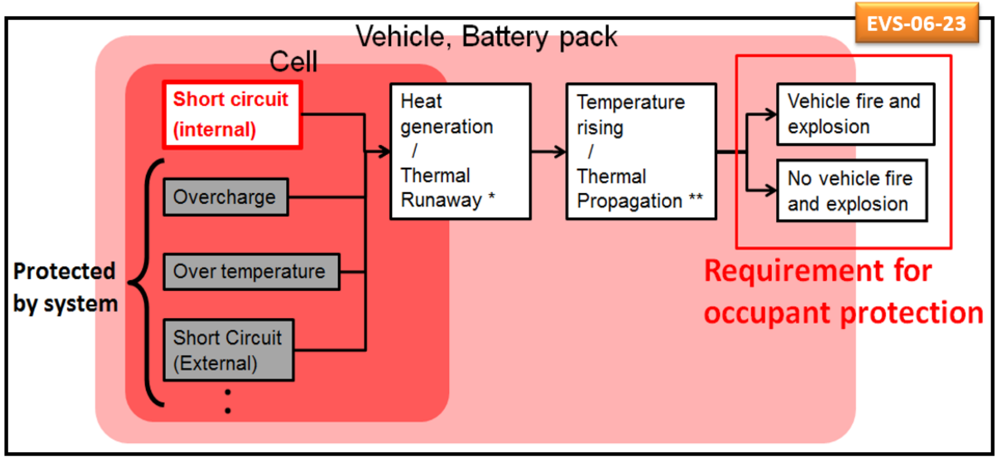
Definitions

*Thermal Runaway

“Thermal runaway” means the phenomena of uncontrollable heat generation with continuous temperature rise caused by exothermal chain reaction in the cell.

**Thermal Propagation

“Thermal propagation” means the sequential occurrence of thermal runaway within a battery system triggered by thermal runaway of a cell in that battery system.



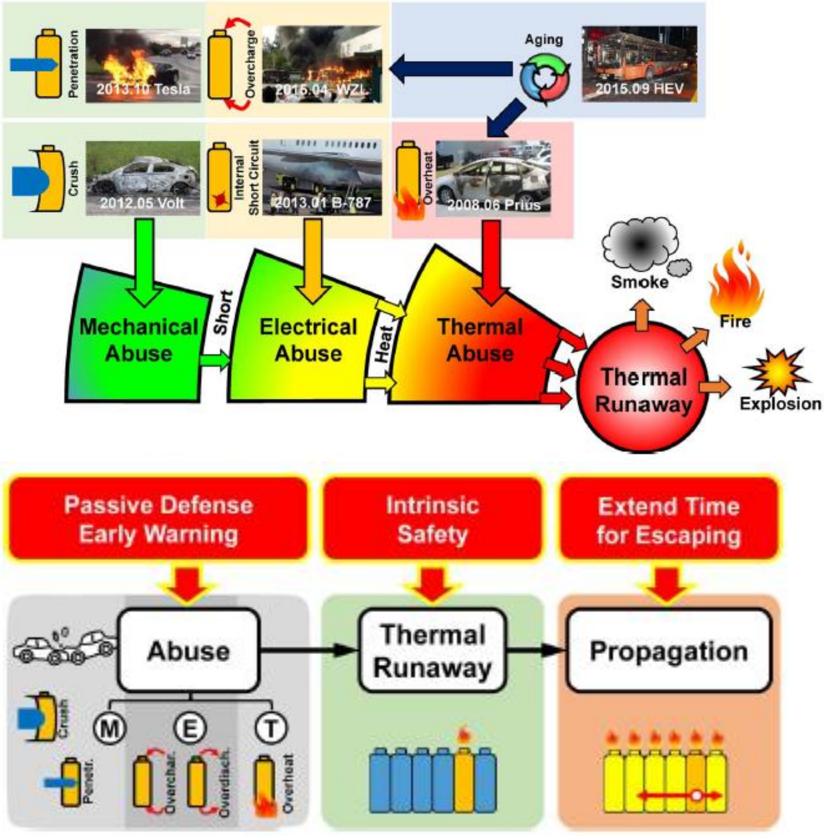


Fig. 14. The three-level strategy of reducing the hazard caused by thermal runaway.

Source: Japanese Research for Thermal Propagation
EVS-GTR IWG #9 in China 14th-18th Sep, 2015

Thermal Events at Vehicle Level

- Development tests are usually highest strictly confidential level
- Test authorities have published a few results of vehicles already longer in the market (Leaf, i-MiEV)
- The few accidents of electric vehicles in the field lead to videos going viral in social networks, but no technical information

Source: https://www.youtube.com/watch?v=p4Qhr_LLoJ0

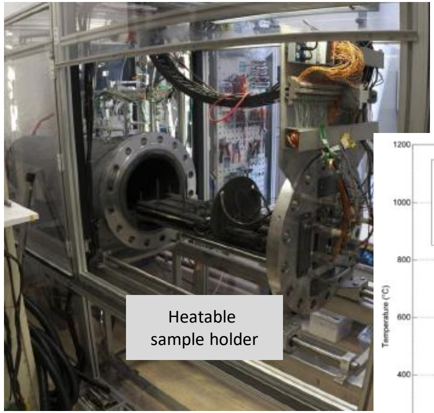
Figure 103 - Top left: 7:07, beginning of first runaway. Top right: 8:16, fourth cell runaway in the first module. Bottom left: 14:47, second module begins after lull. Bottom right: 22:10, several modules into event, ignition coming soon. Between runaways, the smoke cleared and resembled the top left image.

Figure 104 - Top left: 23:41, ignition has occurred. Top right: 26:44, rear flames continue. Bottom left: 28:22, flames inside cabin. Bottom right: 30:53, many internal flames.

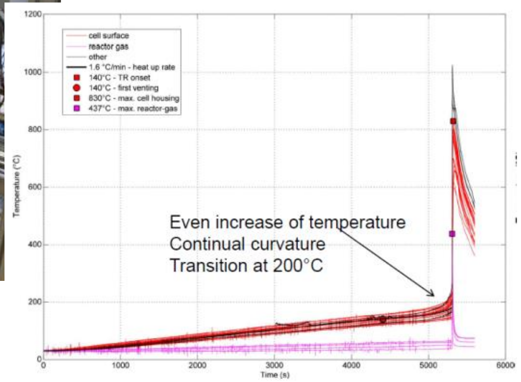
Source: National Highway Traffic Safety Administration. (2019, May). *Safety performance of rechargeable energy storage systems* (Report No. DOT HS 812 717). Washington, DC:

Practical Implementation

Cell Test



Closed chamber with analysis



The bigger the cell capacity is, the more gas is generated at thermal runaway

Pack test

Closed pack with valves

Initiate e.g. with heat plates at one cell

Source: Golubkov at Workshop: Safer Li-Ion Batteries by Preventing Thermal Propagation? Petten Mar 2018

Public example: Vimeo

Classification of Results – Abuse/Misuse Test

Hazard Level Definition – EUCAR:

Hazard Level	Description	Classification Criteria & Effect
0	No effect	No effect, no loss of functionality.
1	Passive Protection activated	No defect, no leakage, no venting, no fire or flame, no rupture, no explosion, no exothermic reaction or thermal runaway. Cell reversibly damaged. Repair of protection device needed.
2	Defect / Damage	No leakage, no venting, no fire or flame, no rupture, no explosion, no exothermic reaction or thermal runaway. Cell irreversibly damaged, repair needed
3	Leakage $\Delta m < 50\%$	No venting, no fire or flame, no rupture, no explosion, Weight loss < 50% of electrolyte weight. (electrolyte = solvent + salt)
4	Venting $\Delta m \geq 50\%$	No fire or flame, no rupture, no explosion, Weight loss ≥ 50% of electrolyte weight.
5	Fire or Flame	No rupture, no explosion, i.e., no flying parts.
6	Rupture	No explosion, but flying parts, ejection of parts of the active mass.
7	Explosion	Explosion, i.e., disintegration of the cell.

Examples - Testing Results:

Abuse/ Missuse Test	GS Yuasa	A123 - 32113	
	LEV 50	Gen1	Gen2
	hazard level	hazard level	hazard level
Crush	4	4	4
Nail penetration	4	3	3
Heat	2	2	2
Overcharge	5	4	4
External short circuit	2	2 - 3	2 - 3
Overdischarge	2	2	2
Average	**3**	**2,5**	**2,5**

Regulation

UN ECE-R100

Uniform provisions concerning the approval of vehicles with regard to specific requirements for the electric power train

UN-R 100-02

E/ECE/324-TRANS/505/Rev.2/Add.99 Basic version In force: 23.08.1996
E/ECE/324-TRANS/505/Rev.2/Add.99 Basic version, Corr. 1 In force: 12.02.1997
E/ECE/324-TRANS/505/Rev.2/Add.99/Amend.1 Basic version, Supplement 1 In force: 21.02.2002
E/ECE/324-TRANS/505/Rev.2/Add.99/01 series of amendments In force: 04.12.2010
E/ECE/324-TRANS/505/Rev.2/Add.99/Rev.1/Amend.1/Suppl.1 to 01 In force: 26.07.2012
E/ECE/324-TRANS/505/Rev.2/Add.99/Rev.1/Amend.2/Suppl.2 to 01 In force: 15.07.2013
E/ECE/324-TRANS/505/Rev.2/Add.99/Revision 2/02 series In force: 15.07.2013
E/ECE/324-TRANS/505/Rev.2/Add.99/Rev.2/Amend.1/Suppl.1 to 02 In force: 10.06.2014
E/ECE/324-TRANS/505/Rev.2/Add.99/Rev.2/Amend.1/Suppl.2 to 02 In force: 29.01.2016
E/ECE/324-TRANS/505/Rev.2/Add.99/Rev.2/Amend.1/Suppl.3 to 02 In force: 18.06.2016
Supplement 4 to the 02 series of amendments – Date of entry into force: 28.05.2019

- Battery drop tests
- Battery corrosion tests
- Battery nail penetration tests
- Immersion tests
- Fire resistance tests
- Over-discharge tests
- Over-charge tests
- Over-temperature tests
- Short circuit tests
- Thermal propagation tests
- Thermal shock and cycling tests
- Battery mechanical crush, impact and shock tests
- Altitude tests
- Vibration tests

UN T 38.3
UN ECE R 100

UN 38.3
Transport of Lithium Batteries

~~UNITED NATIONS
New York and Geneva, 2015~~

Manual of Tests and Criteria

Seventh revised edition

UNITED NATIONS
New York and Geneva, 2019

Recommendations on the

TRANSPORT OF DANGEROUS GOODS

Manual of Tests and Criteria

Gefahrzettel Nr. 9A (10 x 10 cm)

ADR:
UN 3480

IMDG Code:
UN 3480 LITHIUM ION BATTERIES

Testreihe	Inhalt	Lithium-Ionen-	
		Zellen	Batterien
T.1	Höhen-simulation	X	X
T.2	Thermische Prüfung	X	X
T.3	Schwingung	X	X
T.4	Schlag	X	X
T.5	Äußerer Kurzschluss	X	X
T.6	Aufprall oder Quetschtest	X	
T.7	Überladung		X
T.8	Erzwungene Entladung	X	

Source: https://www.lithium-batterie-service.de/de/un-38.3-test-reihe

China Regulations

GB/T 31467.3

Lithium-ion traction battery pack and system for electric vehicles –
Part 3: Safety requirements and test methods

GB/T 18384.3

Lithium-ion traction battery pack and system for electric vehicles –
Part 3: Safety requirements and test methods

GB/T 31484

Cycle Life Requirements and Test Methods for Traction Battery of Electric Vehicle

GB/T 31485

Safety Requirements and Test Methods for Traction Battery of Electric Vehicle

GB/T 31486

Electrical Performance Requirements and Test Methods for Traction Battery of Electric Vehicle

GB/T 31498

The Post-crash Safety Requirement of Electric Vehicles

GB/T 18384.1

Electrically propelled road vehicles – Safety specifications –
Part 1: On-board rechargeable energy storage system (REESS)

GB/T 18384.2

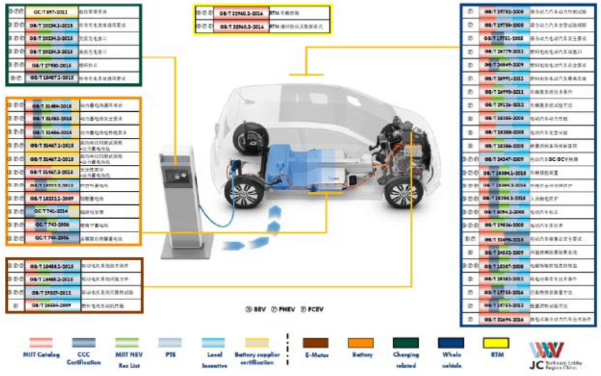
Electrically propelled road vehicles – Safety specifications –
Part 2: Vehicle operational safety means and protection against failures

GB/T 38031-2020

Replaces GB/T 31485-2015, GB/T 31467.3-2015

Source: Wilhelmy AABE 2018

International standards and regulations e.g. China



> 80 NEV related Standards

changing quickly

China Regulation GB/T 31467.3

GB/T 31467.3 (May 2015)-> Amendment 1 of June 6, 2017
This Part applies to the lithium-ion traction battery packs and systems..

7. Test of Safety

7.1	Vibration (battery pack/system) ->
7.2	Mechanical shock
7.3	Drop
7.4	Turn-over
7.5	Simulated collision ->
7.6	Crush
7.7	Temperature shock
7.8	Damp heat cycle
7.9	Seawater immersion
7.10	External bonfire
7.11	Salt mist
7.12	High altitude
7.13	Over-temperature protection
7.14	Short-circuit protection
7.15	Over-charge protection
7.16	Over-discharge protection

Table 2 Frequency and Acceleration

Frequency (Hz)	Acceleration (m/s2)
7–18	10
18–30	Gradually decrease from 10 to 2
30–50	2

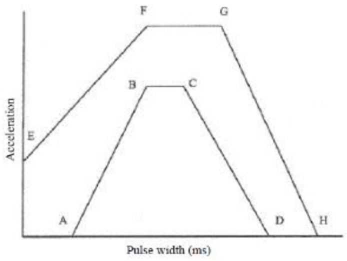


Figure 3 Illustration of acceleration pulse

GB 38031—2020

Electric vehicles traction battery safety requirements

Issued on: May 12, 2020 **Implemented on: January 1, 2021**

C.1 Purpose

An advance warning (intended for warning of thermal events of the whole vehicle) shall be sent to occupants to evacuate within 5 minutes before the occurrence of any danger within the occupant compartment resulting from thermal propagation within battery pack or system caused by thermal runway of a single cell. It shall be deemed satisfactory if the thermal propagation does not leave the occupants in danger.

HV Battery DVP EXAMPLE

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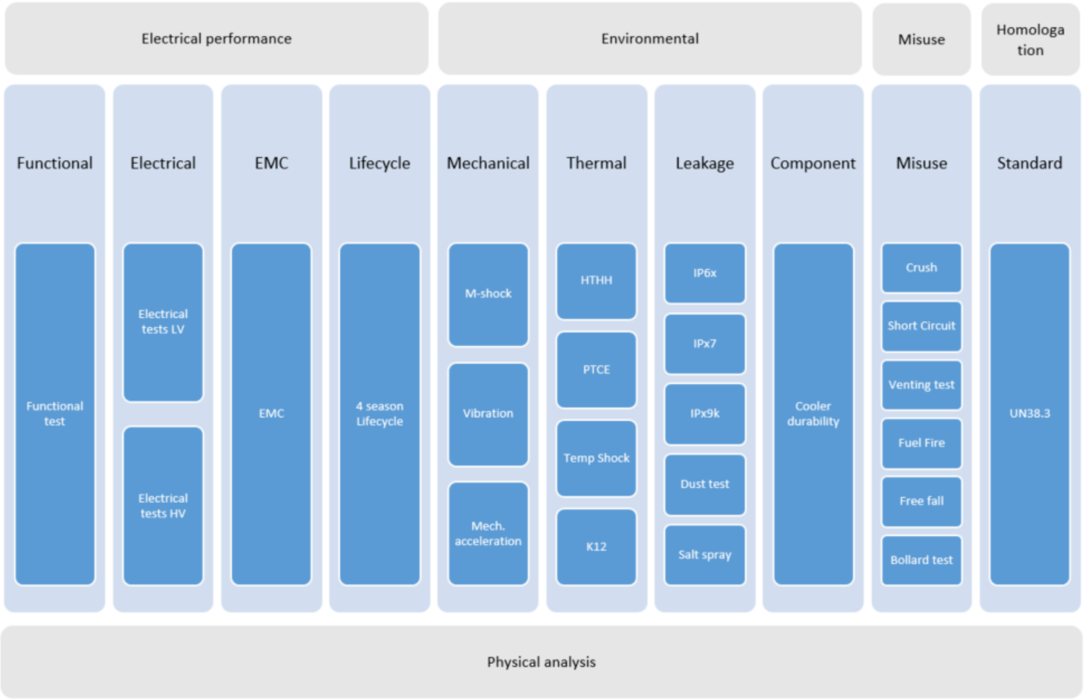
B-Sample Plan HV Battery



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Functional Test

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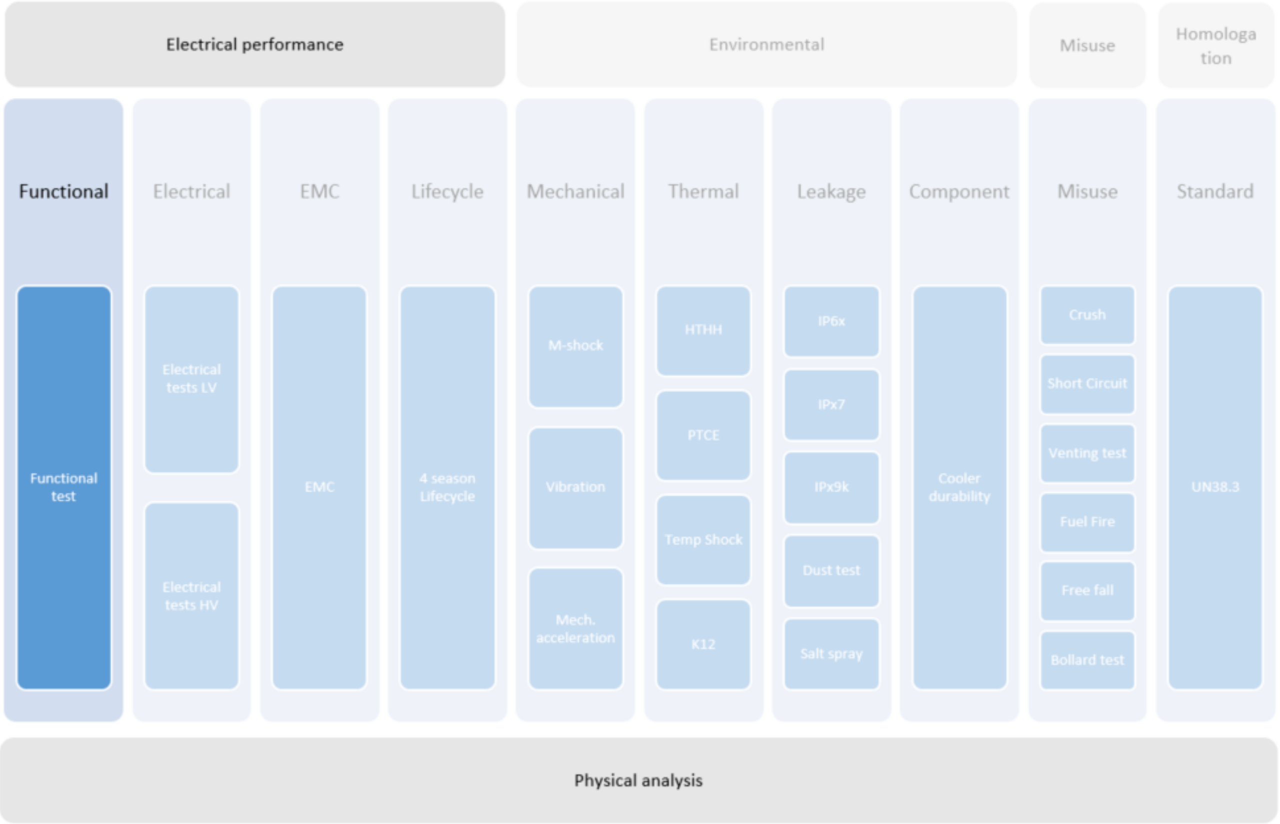

Component function test

Basis functions OK?
- optical inspection
- tightness
- isolation resistance
- interlock working
- withstand voltage
  (test equipment below)
- power delivery
- capacity
- ...

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Electrical Performance: Electrical - 01

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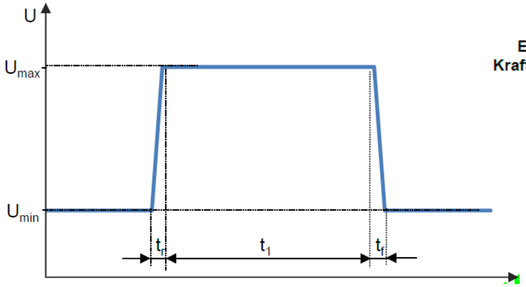
Version 1.3 LV 124 Erstelldatum 20.01.2010

LV124

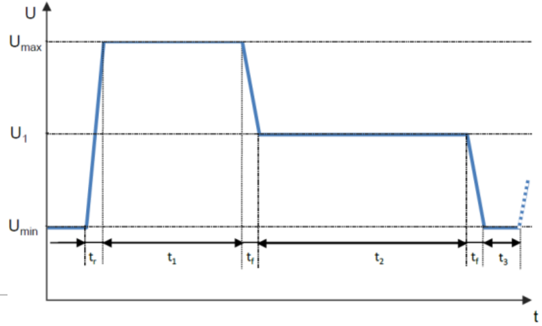
Elektrische und elektronische Komponenten in Kraftfahrzeugen bis 3,5t - Allgemeine Anforderungen, Prüfbedingungen und Prüfungen

LV124

- Long time overvoltage:

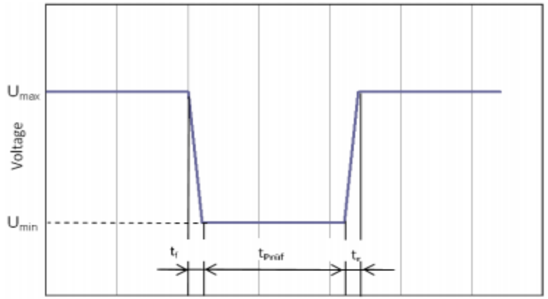


- Transient overvoltage

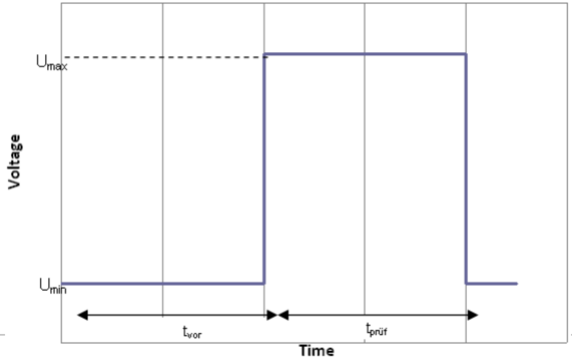


Electrical Performance: Electrical - 02

- Transient undervoltage

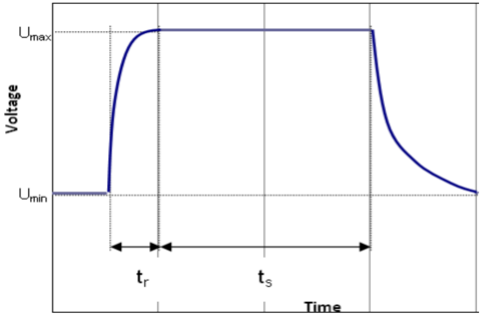


- Jump start

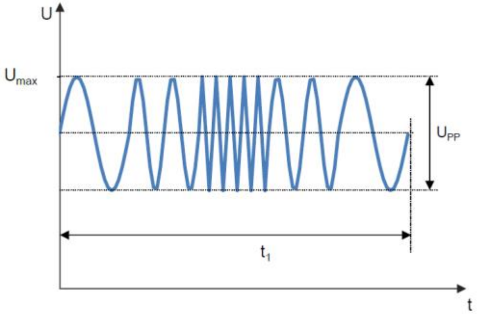


Electrical Performance: Electrical - 03

- Load dump

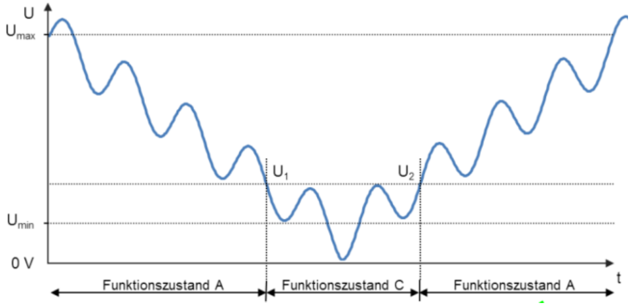


- Superimposed alternating voltage

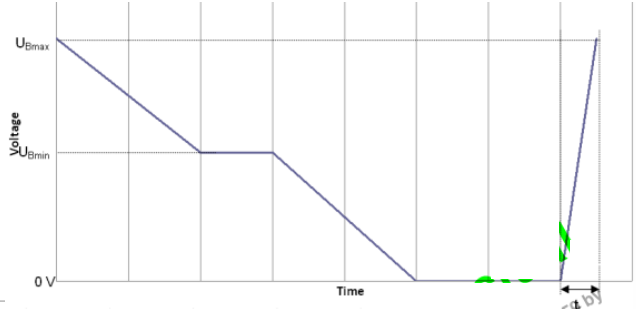


Electrical Performance: Electrical - 04

- Slow decrease and increase of the supply voltage

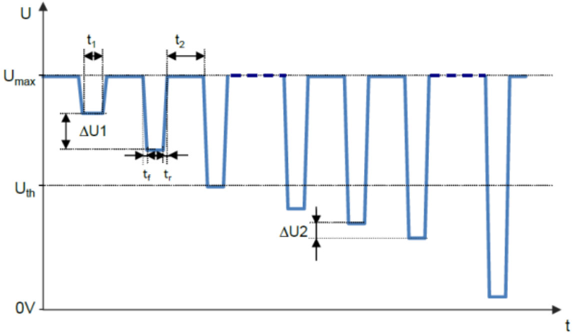


- Slow decrease, quick increase of the supply voltage

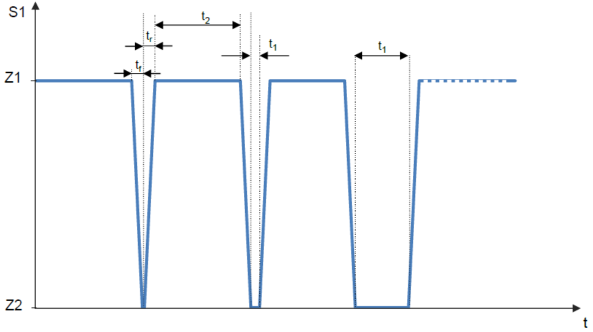


Electrical Performance: Electrical - 05

- Reset behavior

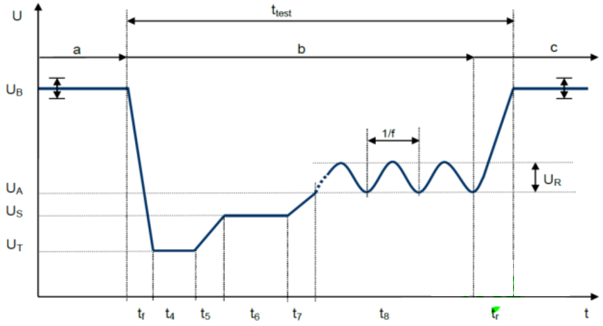


- Short interruptions

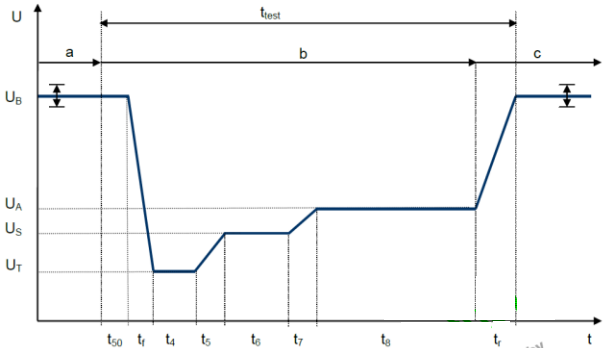


Electrical Performance: Electrical - 06

- Cold start



- Warm start



Electrical Performance: Electrical - 07

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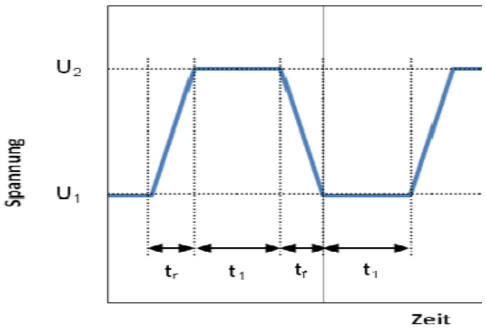
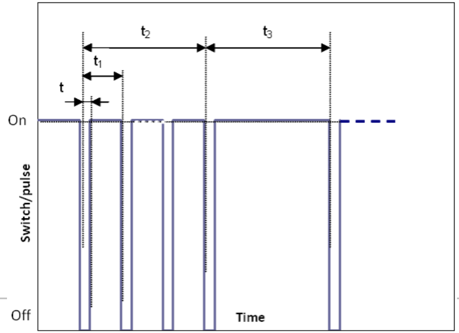
- Voltage curve with intelligent generator control



- Pin interruption



Electrical Performance: Electrical - 08

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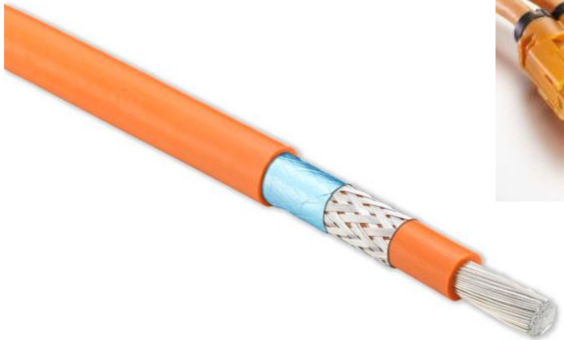
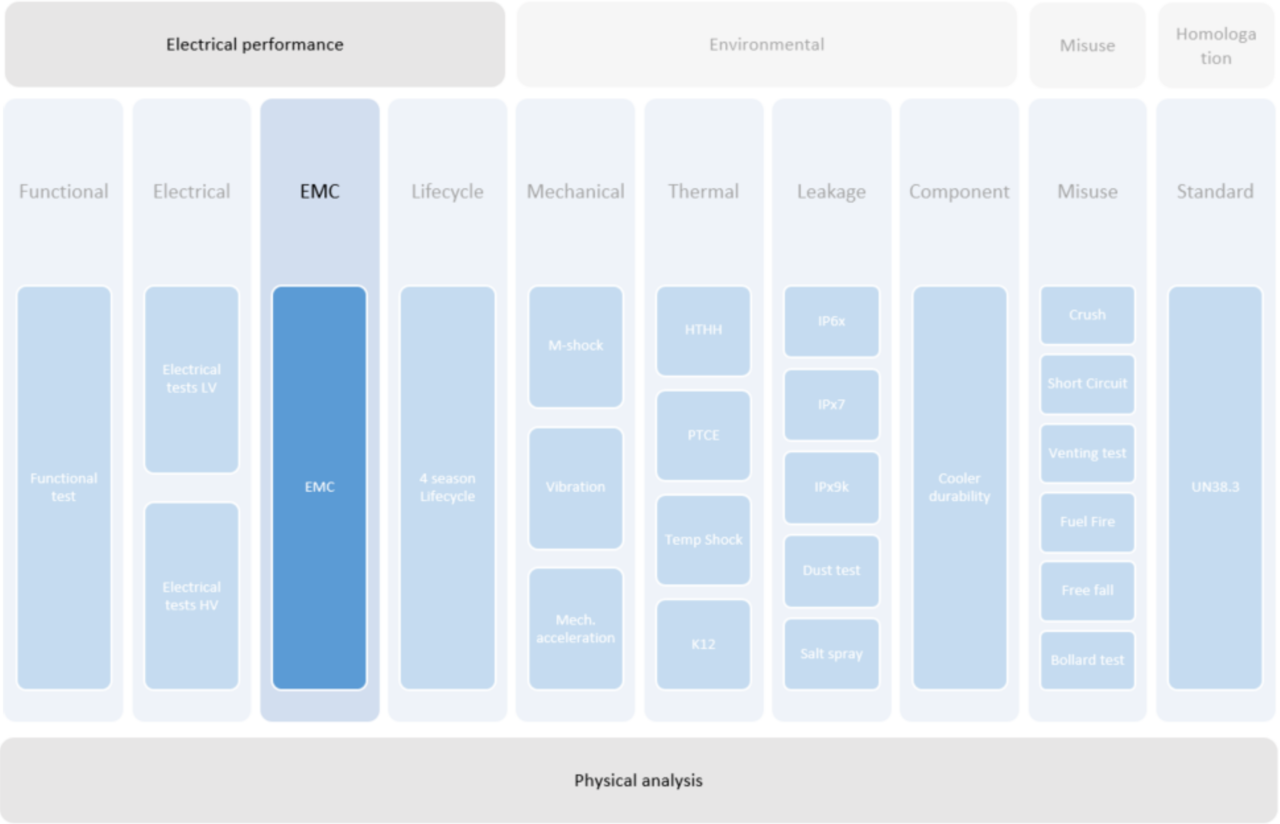
- Equalization bonding
- Dielectric strength
- HV shielding
- Etc…

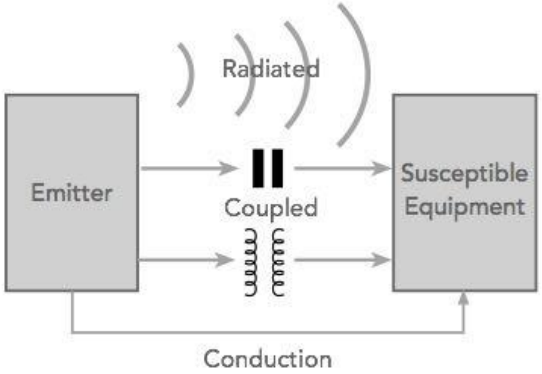


Sources : Gebauer & Griller; Rosenberger Hochfrequenztechnik GmbH & Co. KG

Electrical Performance: EMC



- Electromagnetic compability



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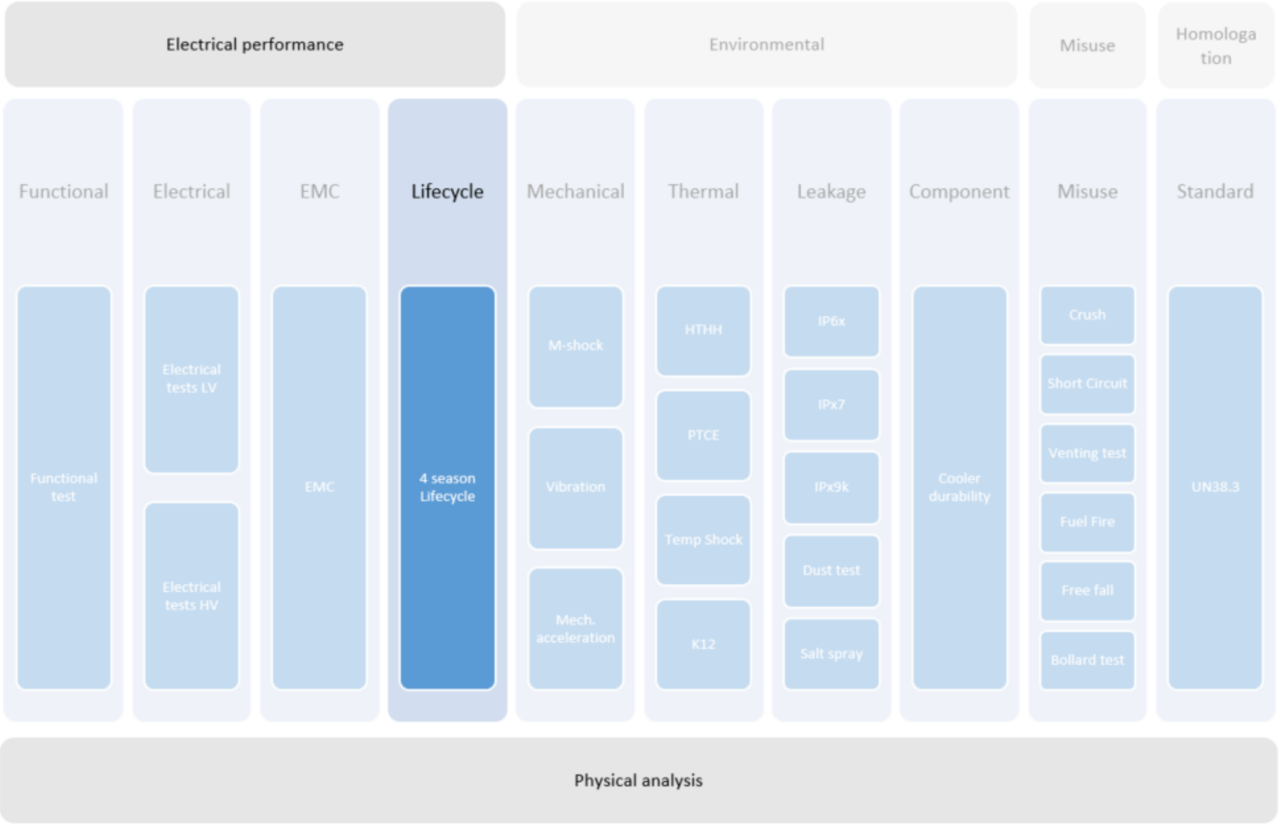
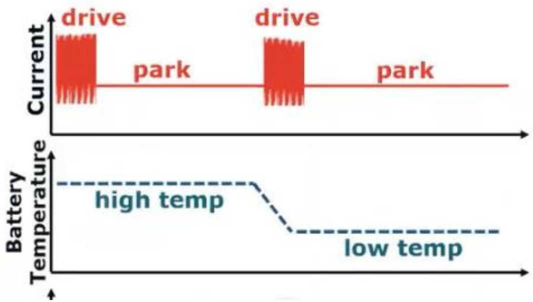
Electrical Performance: Lifecycle



- 4 season lifecycle test
  - Spring
  - Summer
  - Fall
  - Winter



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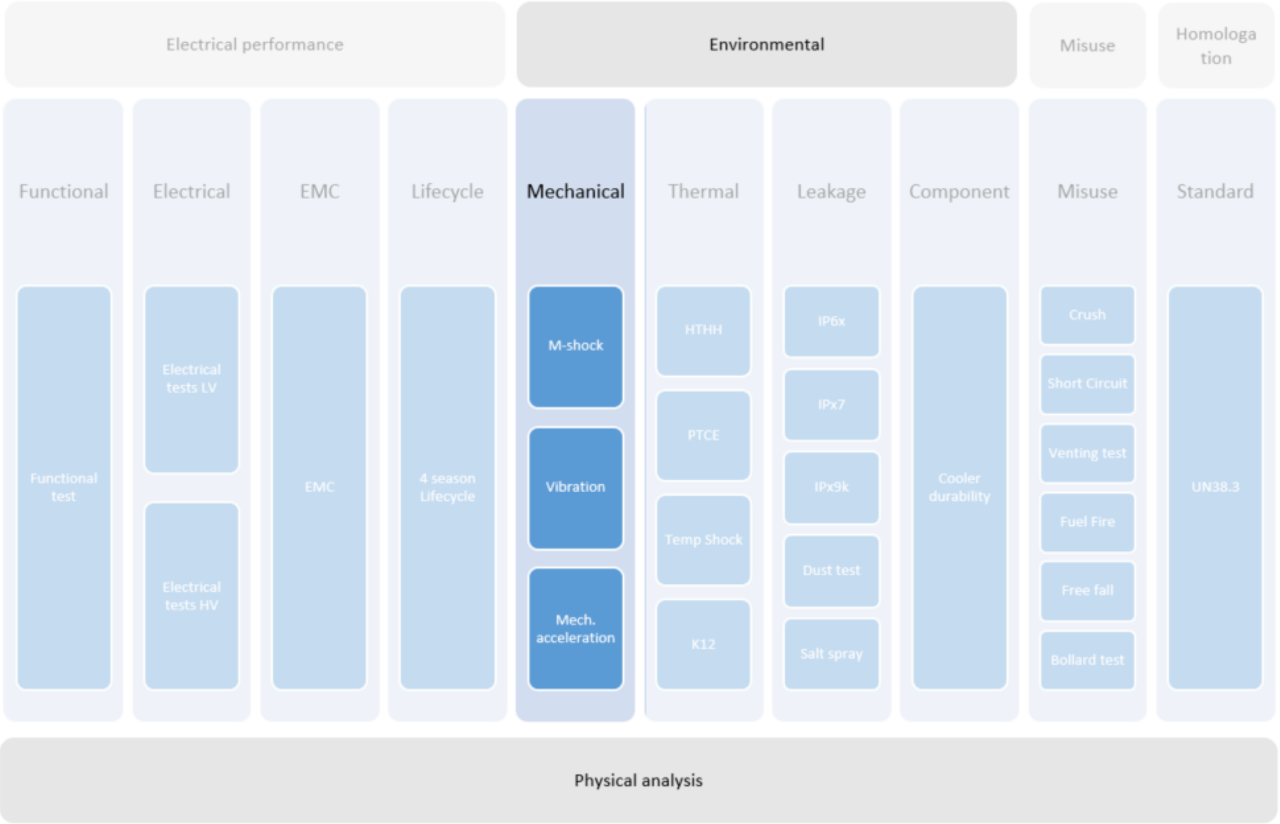
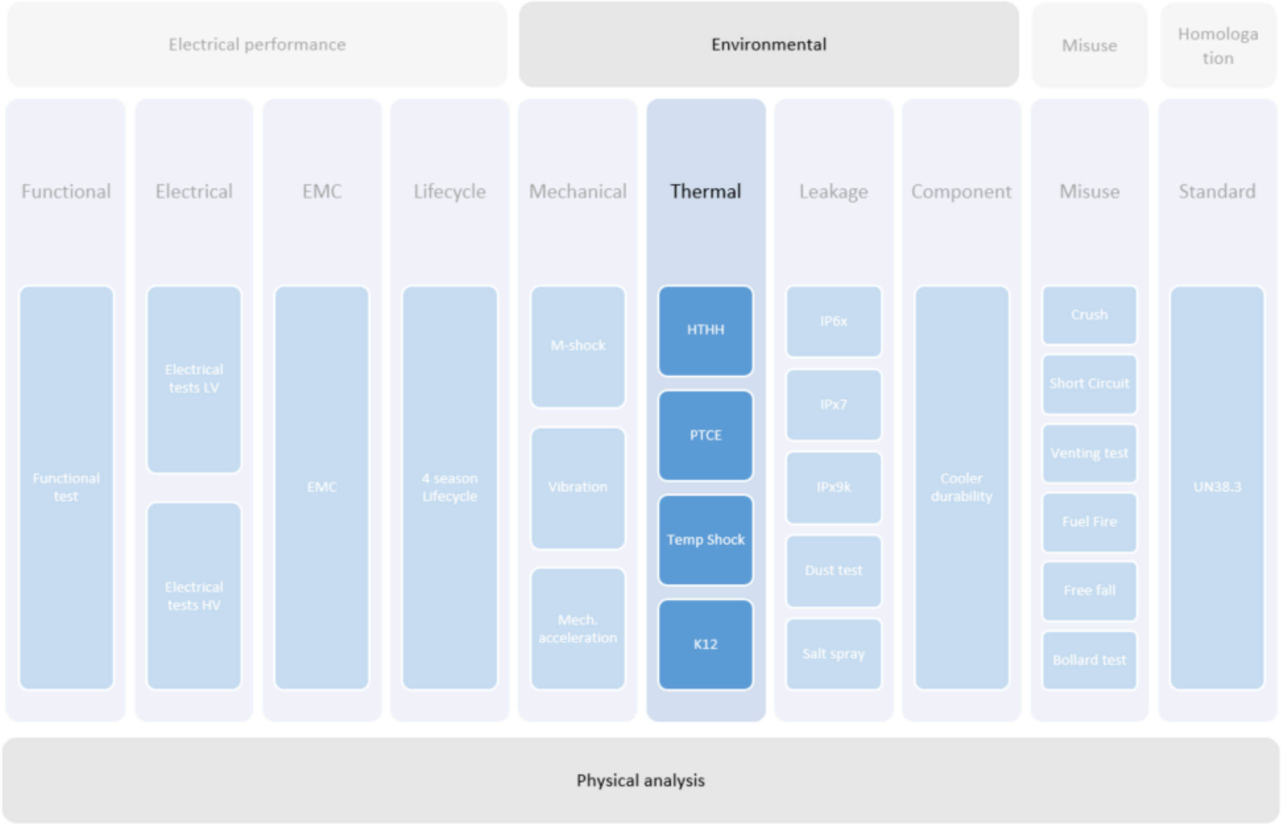
Environmental Tests: Mechanical



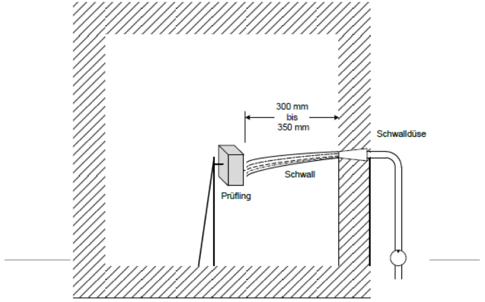
- M-shock
  - Shocks from the road
- Vibration
  - Vibration during driving
- Mech acceleration
  - Verify safety performance

Source: https://www.sgs-cqe.de/

Environmental Tests: Thermal



- HTHH
  - High temperature High humidity
- PTCE
  - Power thermal cycling endurance
- Temp shock
  - Temperature shock
- K12
  - Thermal Shock with splash water



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Environmental Tests: Leakage

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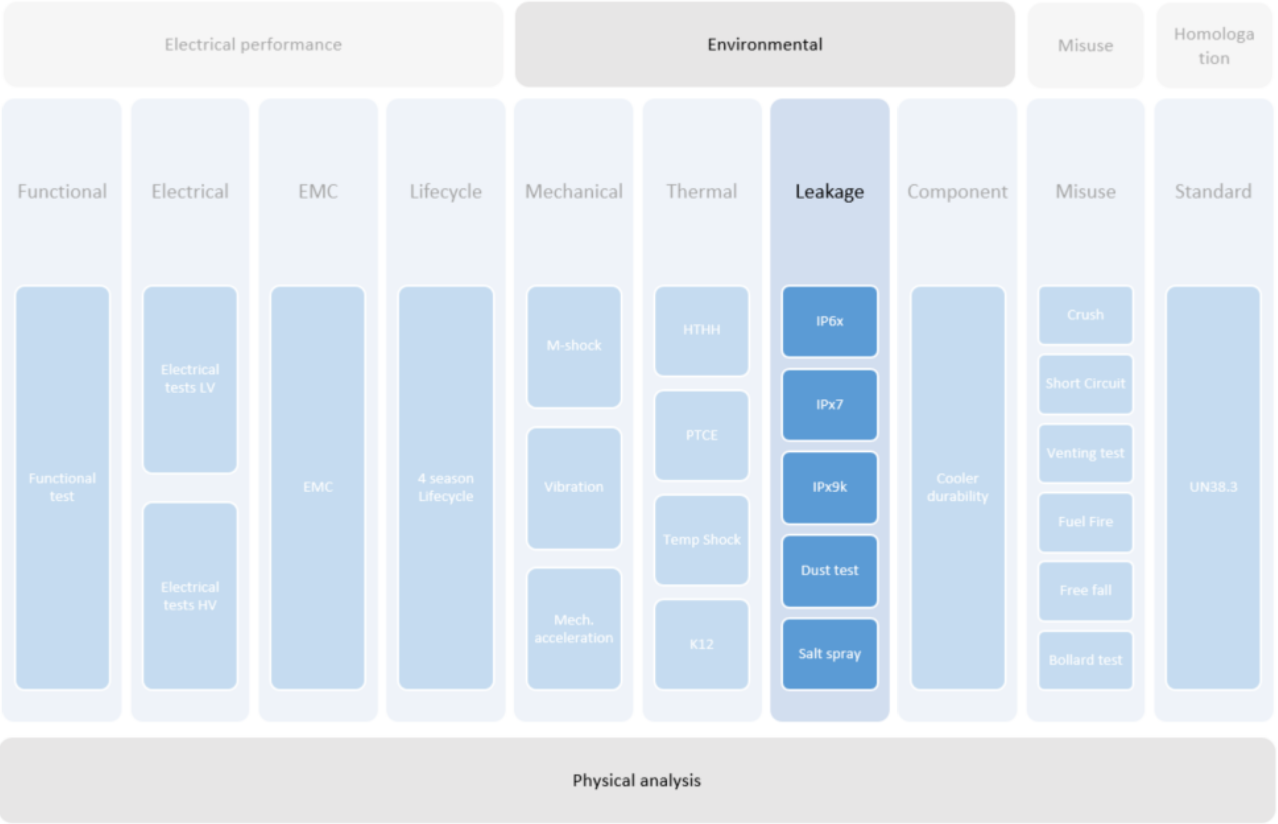
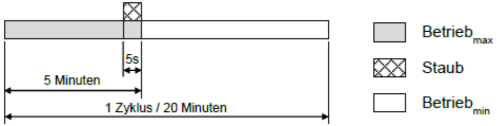


- IP6x
  - Dust testing



- IPx7
  - Immersion
- IPx9k
  - High pressure
- Dust test
  - Arizona dust
- Salt spray
  - Resistance to corrosion

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Environmental Tests: Component

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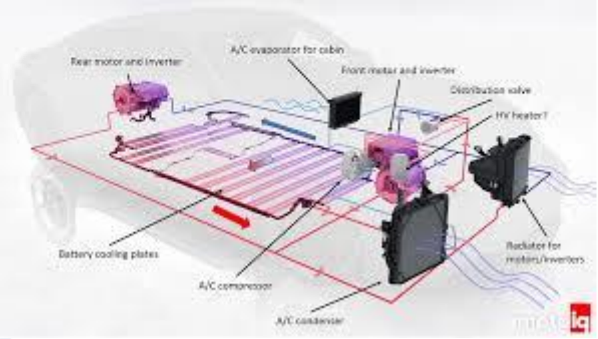
Electrical performance				Environmental				Misuse	Homologation
Functional	Electrical	EMC	Lifecycle	Mechanical	Thermal	Leakage	**Component**	Misuse	Standard
Functional test	Electrical tests LV	EMC	4 season Lifecycle	M-shock	HTHH	IP6x	**Cooler durability**	Crush	UN38.3
	Electrical tests HV			Vibration	PTCE	IPx7		Short Circuit	
				Mech. acceleration	Temp Shock	IPx9k		Venting test	
					K12	Dust test		Fuel Fire	
						Salt spray		Free fall	
								Bollard test	

Physical analysis

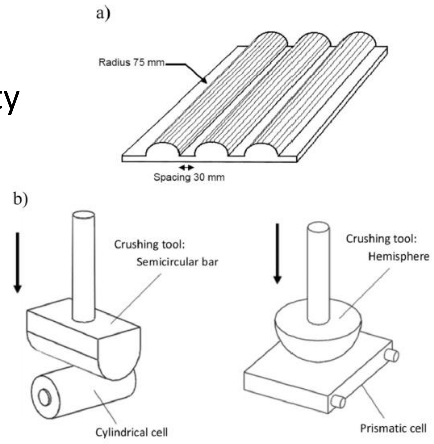
- Cooler durability
  - Pressure variation test



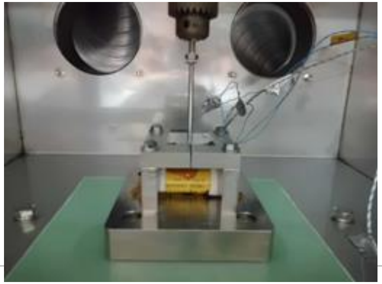
Source: motoi1q.com

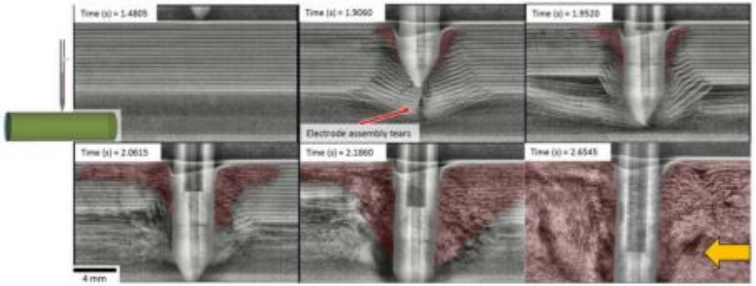
Misuse Test - 01

- Crush
    - Mechanical integrity



- Venting test
    - Nail penetration





Source: Journal Electrochem Soc,164(13) A3285 (2017)

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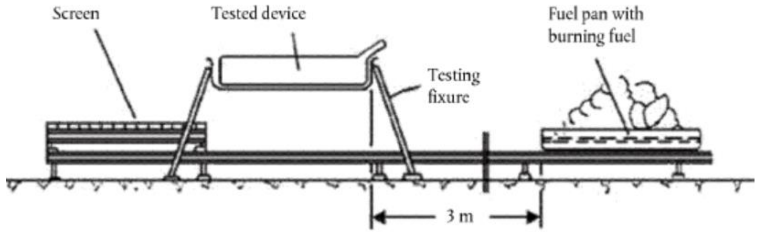
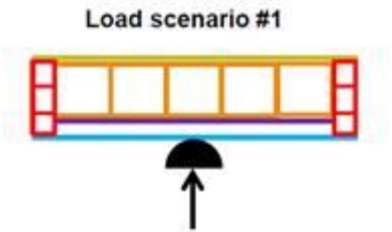
Misuse Test - 02

- Fuel fire
  - According ECE-R100

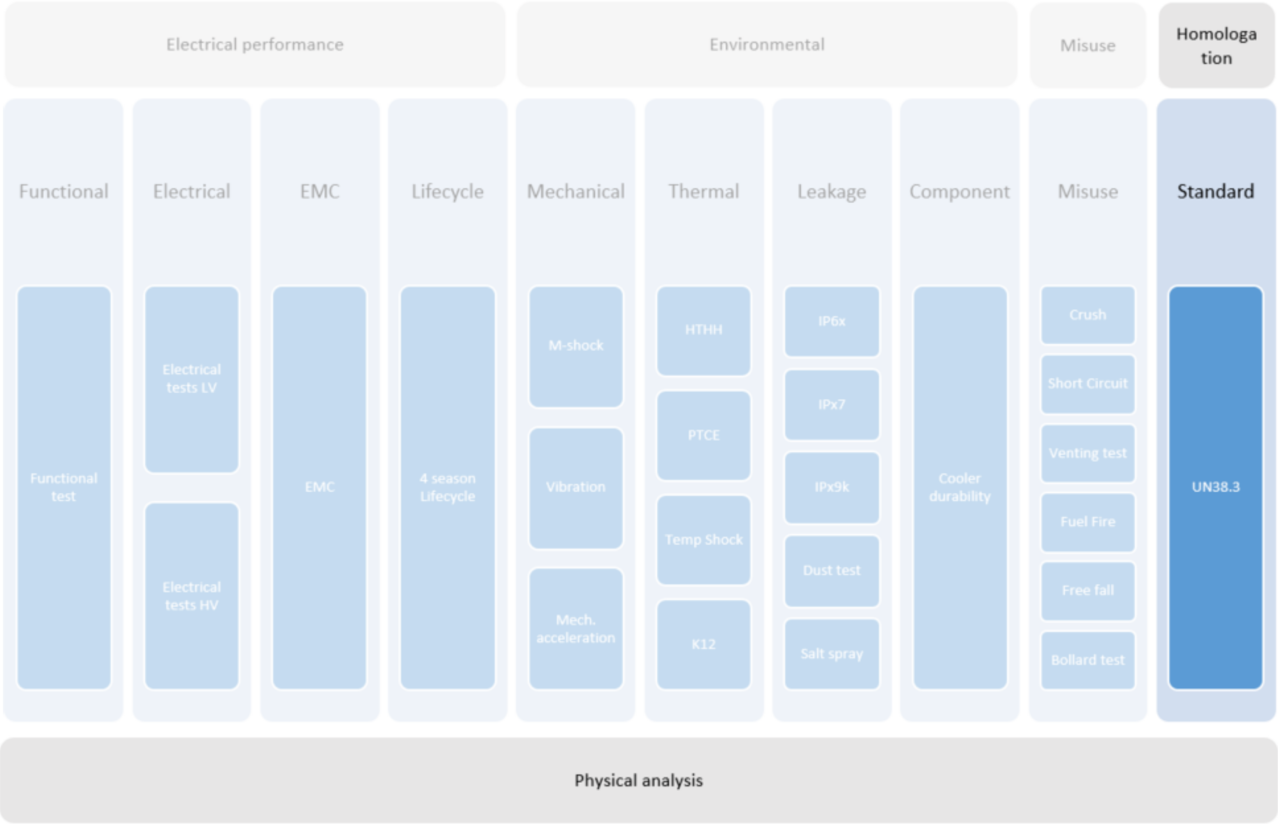


- Free fall
  - Checks malfunctions caused by free fall
- Bollard test
  - Mechanical test



- Short Circuit

Homologation

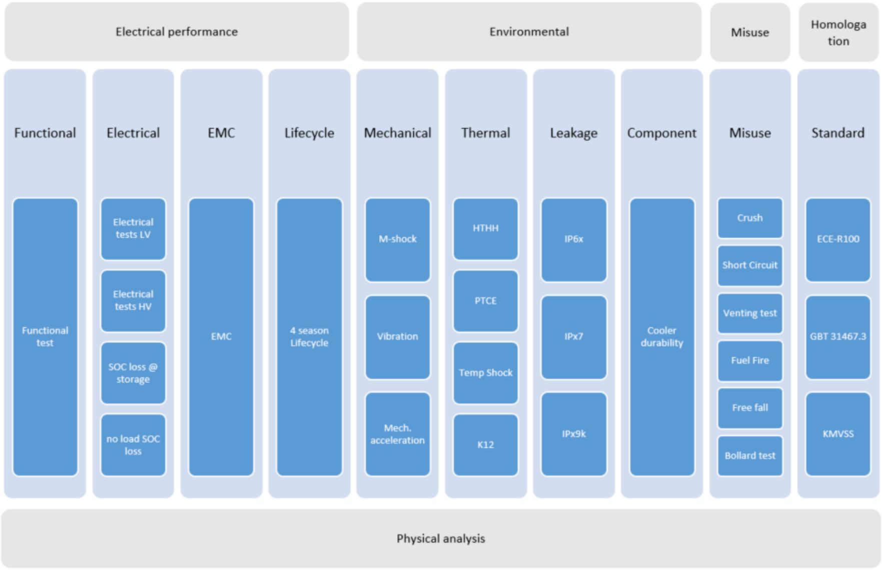


- UN38.3
    - Transportation

C-Sample Plan

- C-Sample Test plan pretty the same like B-Sample but some Homologation tests were included
- C-Samples must be produced with serial parts on serial prodution line

C-Sample Plan HV Battery



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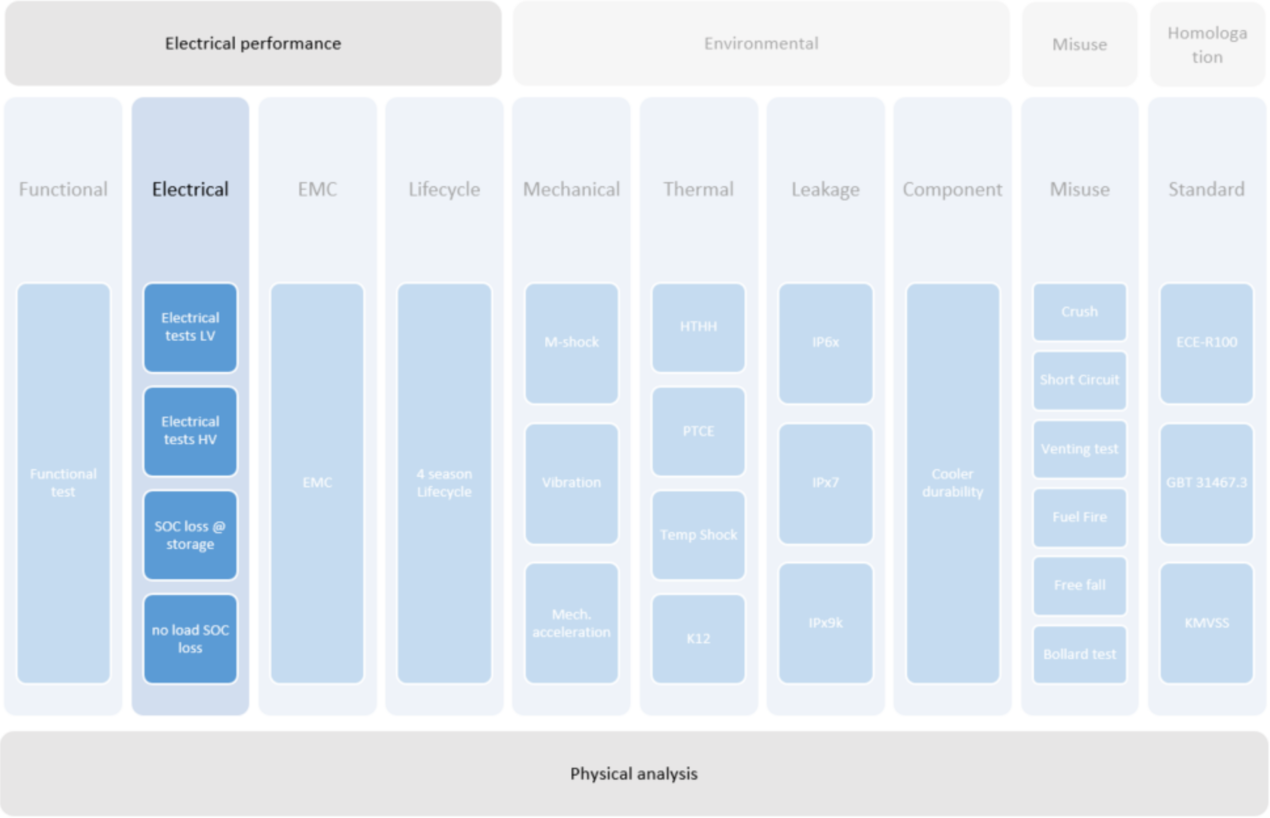
Electrical



- SOC loss @ storage
  - Measure SOC loss is not in use
- No load SOC loss
  - Measure SOC loss @ different Temperatures

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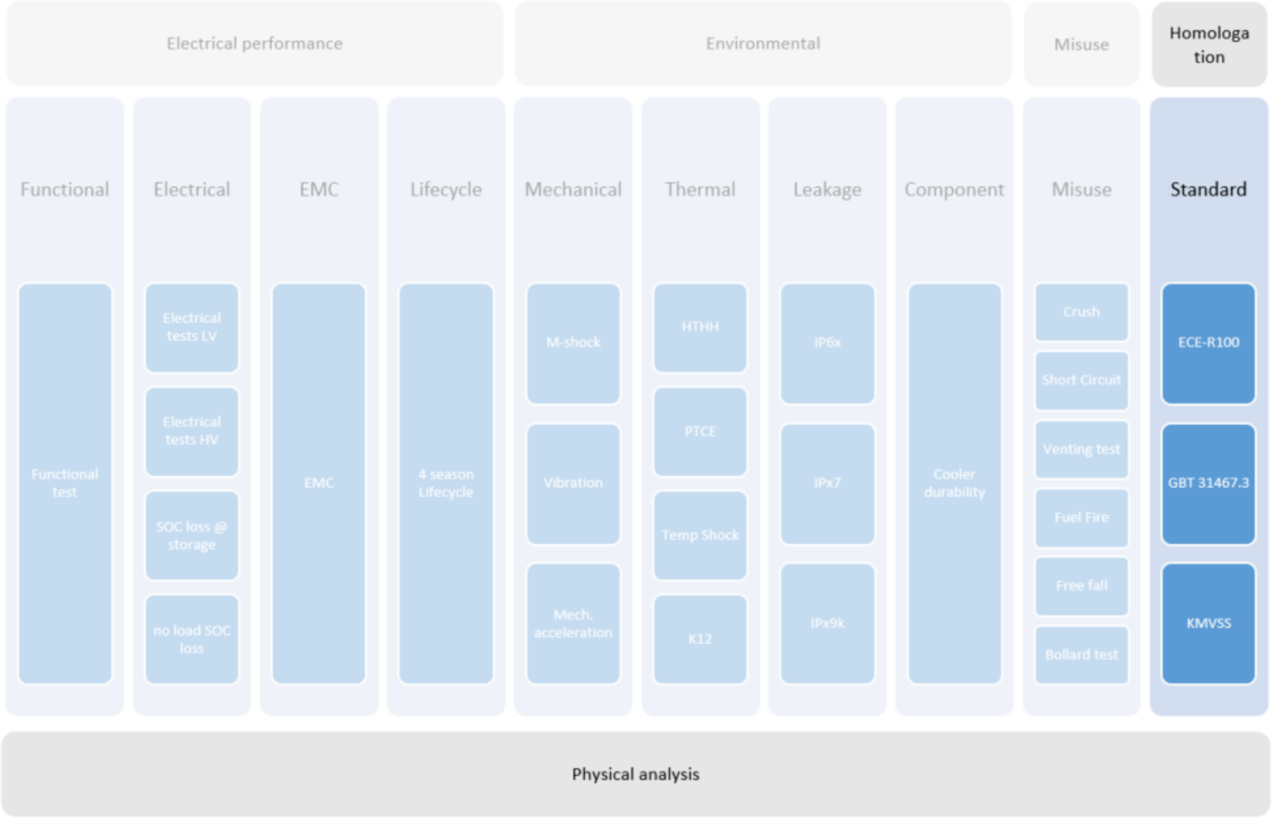
Homologation



- ECE – R100
  - European market
- GBT 31467.3
  - China market
- KMVSS
  - Korean market