LIBERTY

Ageing, performance and safety – developed test procedures, gained test results and the way of reporting them

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Lightweight Battery System for Extended Range at Improved Safety

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Agenda

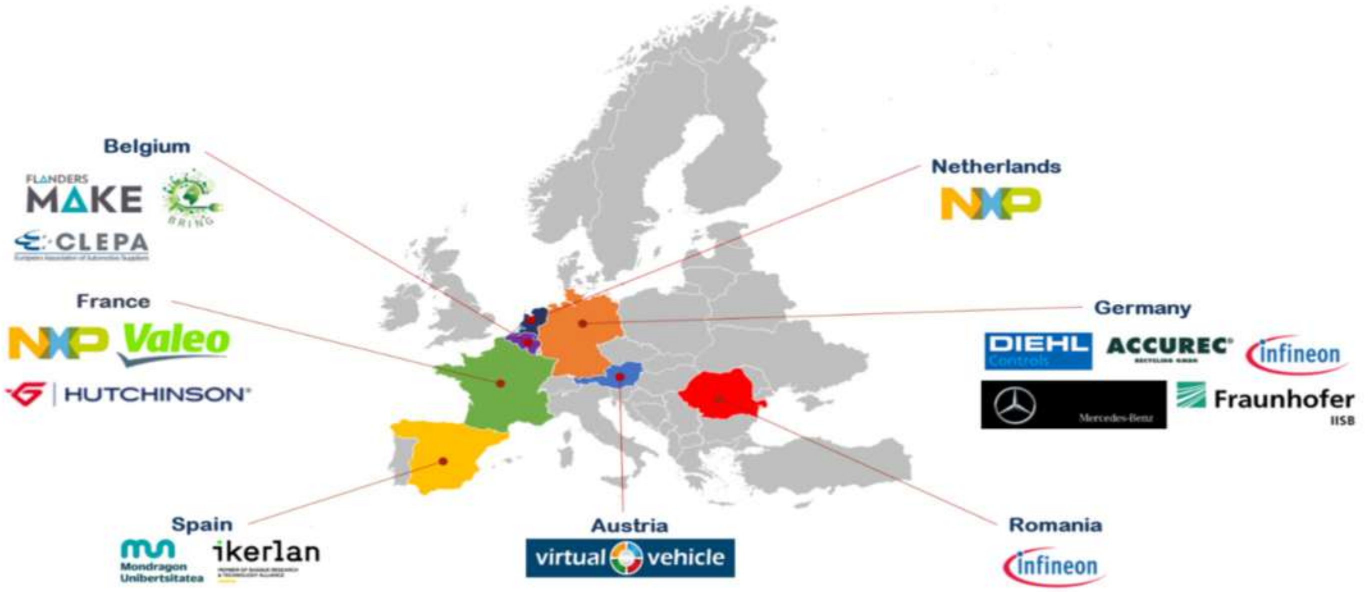
- Overview on LIBERTY project
- Safety Testing
- Aging and Performance Testing

Overview on LIBERTY project

Overview on LIBERTY project

LIBERTY - Lightweight Battery System for Extended Range and Improved Safety

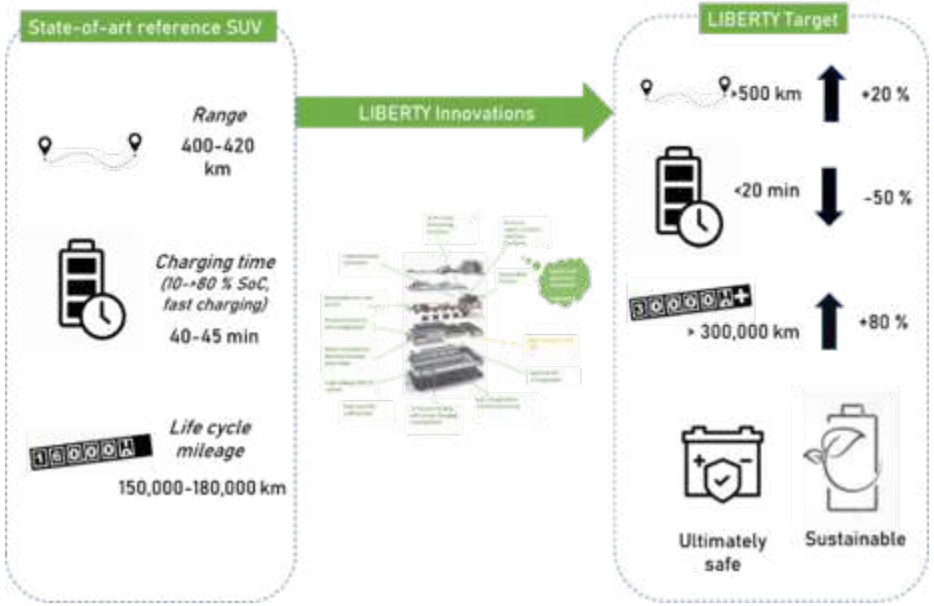
- Overall target: upgrading EV battery performance, safety and lifetime from a lifecycle and sustainability point of view
- 16 Partners from 7 countries
- Website: www.libertyproject.eu
- Start date: January 2021
- Duration: 42 months



Overview Liberty

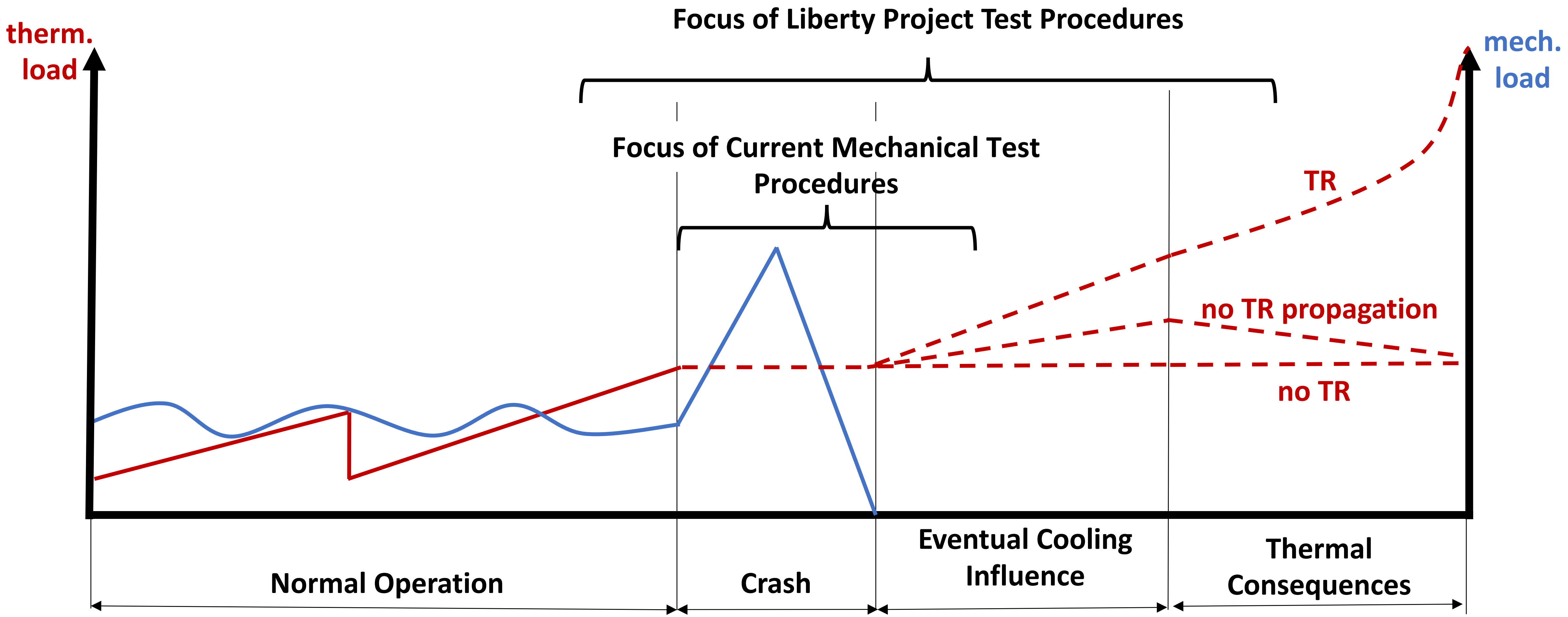
- Lightweight Battery System for Extended Range at Improved Safety
  - ☐ Objective 1: To achieve a range of 500 km on a fully charged battery pack
  - ☐ Objective 2: To achieve a short charging time
  - ☐ Objective 3: To achieve an ultimately safe battery system
  - ☐ Objective 4: To achieve a long battery lifetime
  - ☐ Objective 5: To achieve sustainability over the battery pack's entire life cycle

Parameter	Benchmark: EQC 2019	Target: LIBERTY EQC
Battery system capacity [kWh]	80	96
Battery system weight based on 80 kWh battery capacity [kg]	650	520
Max. charging power [kW]	110	350
Charging window 10-80% SoC [min]	40	18
Range (WLTP) [km]	417	500
Battery life (no. of cycles to 80% DoD)	500	1000
Mileage [km]	160,000	>300,000

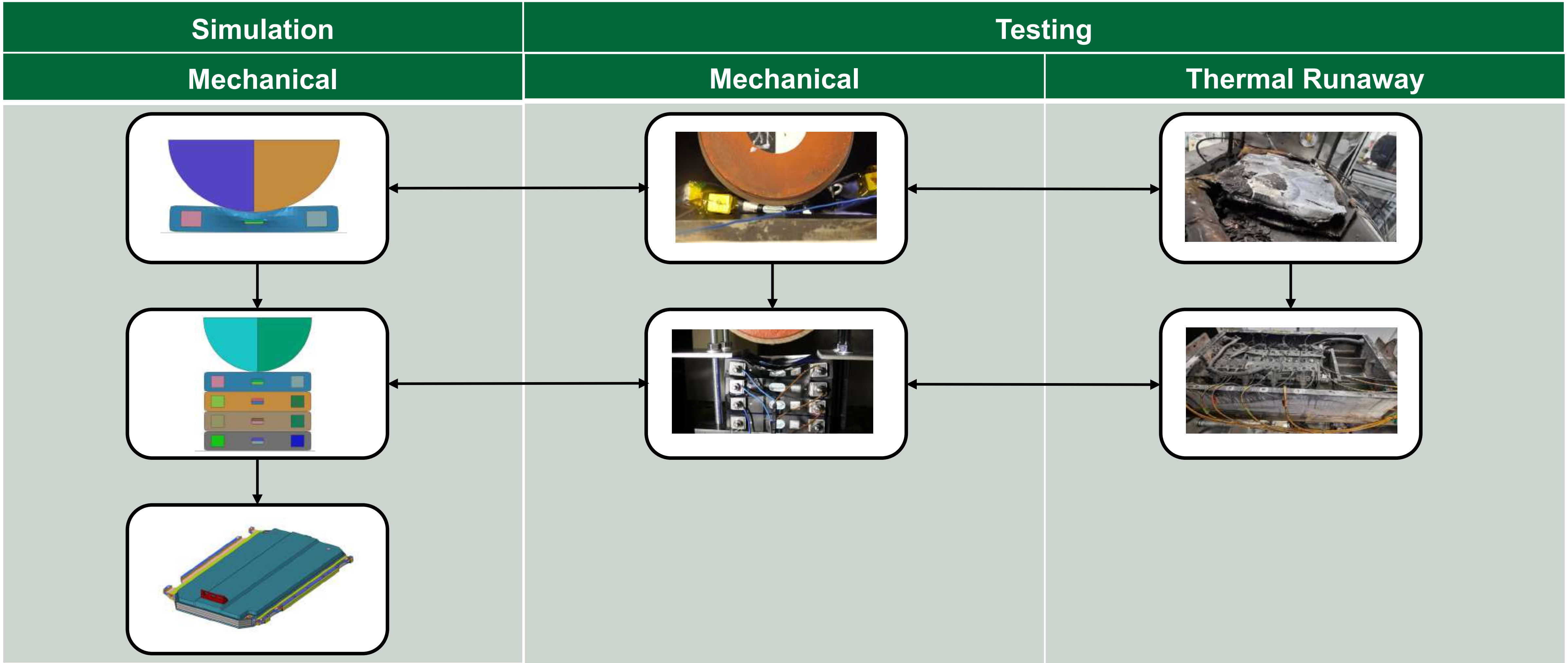


Safety Testing

Safety Testing



Safety Testing



Mechanical Cell Testing

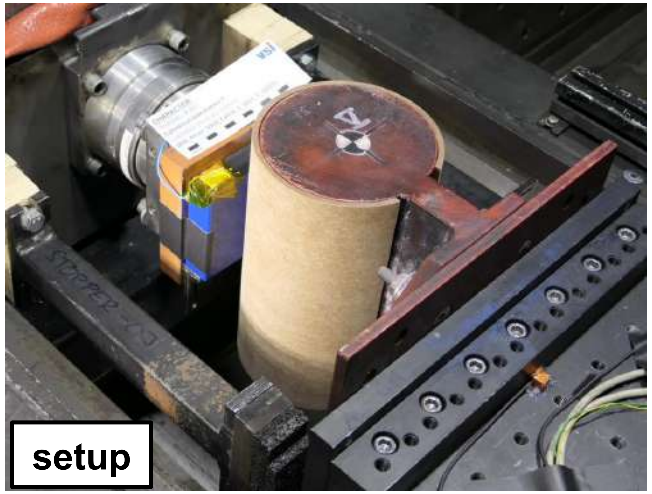
Quasi- static cell tests:

Load Case	Axis	Tests	Boundary	Speed	SOC	Sketch
Cylindrical Indention	X	3	-	1mm/s	0%	
Cylindrical Indention	Y	3	-	1mm/s	0%	
Flat Crush	X	3	-	1mm/s	0%	
Flat Crush	Y	3	-	1mm/s	0%	

Dynamic cell tests:

Load Case	Axis	Tests	Boundary	Speed	SOC	Sketch
Cylindrical Indention	Y	3	Mass = 91 Kg	3.5 m/s	0%	
Cylindrical Indention	Y	3	Mass = 200 Kg	2.4 m/s	0%	
Cylindrical Indention	Y	2	Mass = 200.Kg	2.4 m/s - without electrolyte	0%	

Mechanical Cell Testing

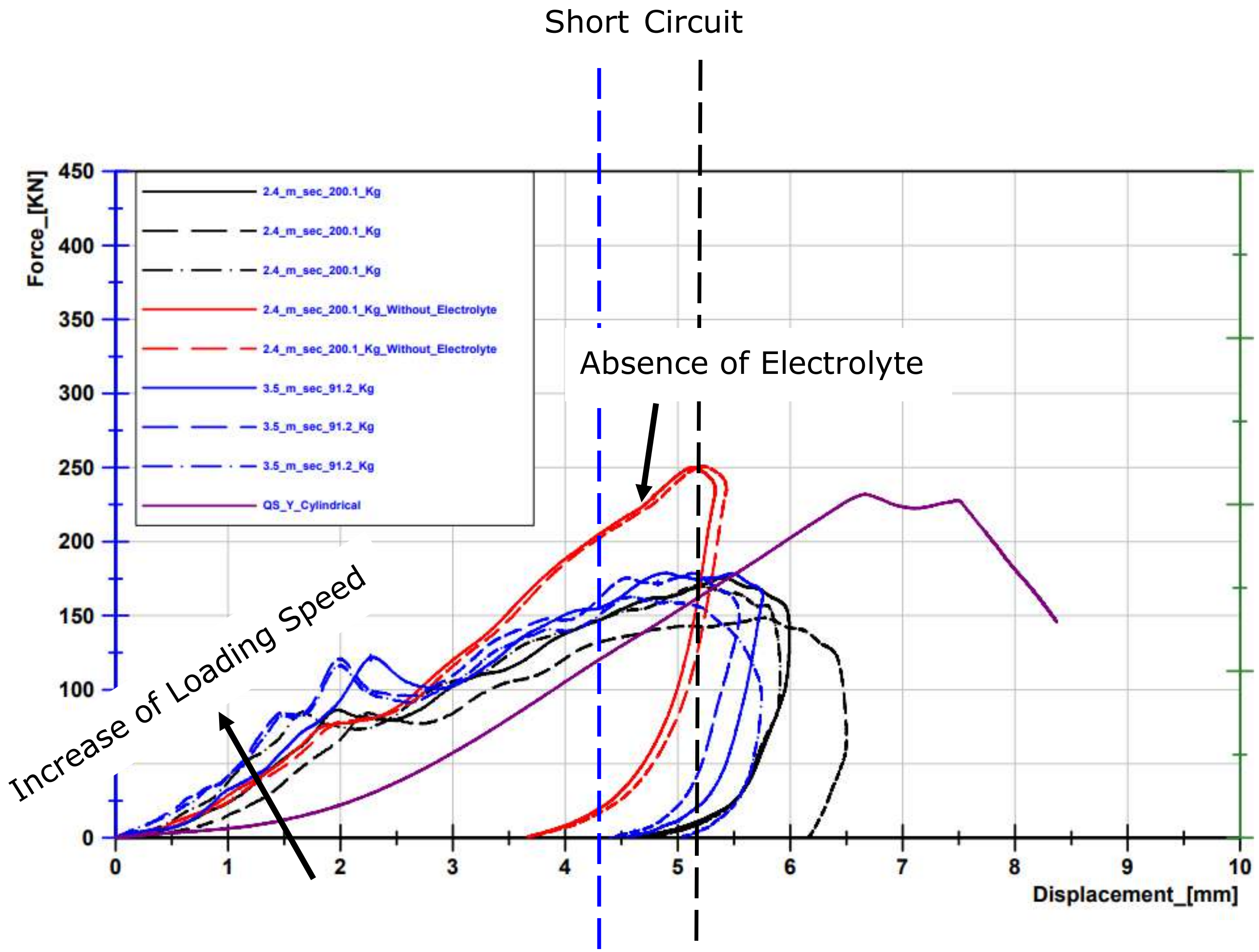


Increased loading speed:

- The cell will be stiffer at the beginning
- Clear and higher first peak
- Earlier short circuit

Absence of Electrolyte:

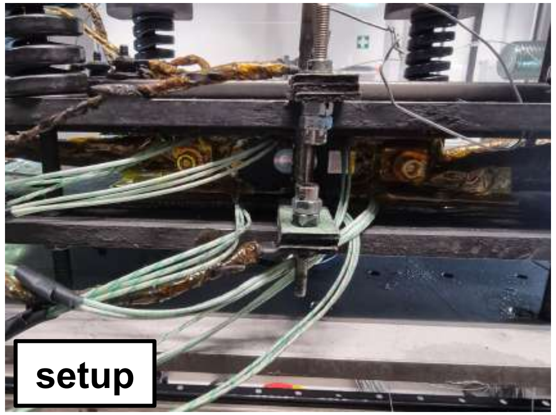
- Reduced or no plateau after first peak
- Stiffer behavior as the deformation proceed
- Max. force value is almost equal to the QS case

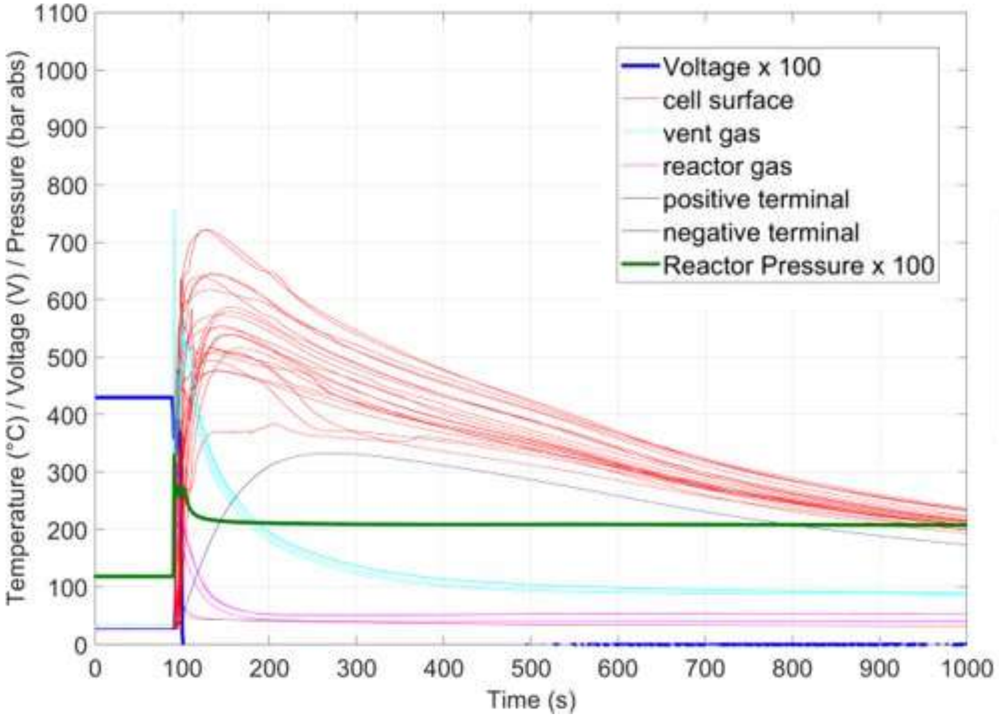


Thermal Runaway Cell Testing

- Six TR-tests on cells performed
  - TR by overtemperature (4 tests) & TR by nail penetration (2 tests)
- Maximum average cell temperature ~571°C in all tests
- ~4.3 mol of vent-gas released per cell

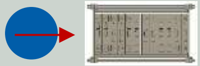
Example test TS0011 - overtemperature

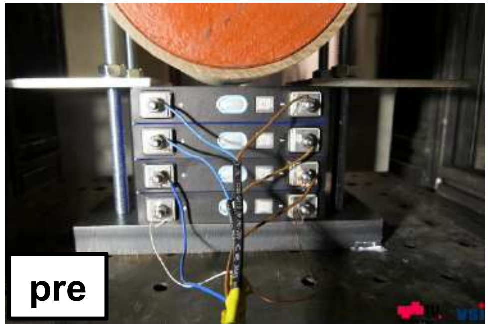


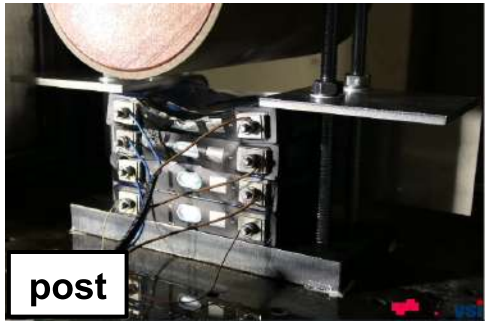


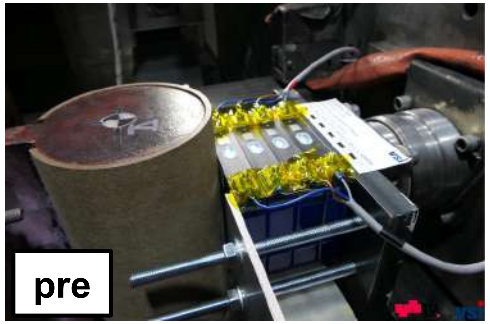
Mechanical Cell Stack Testing

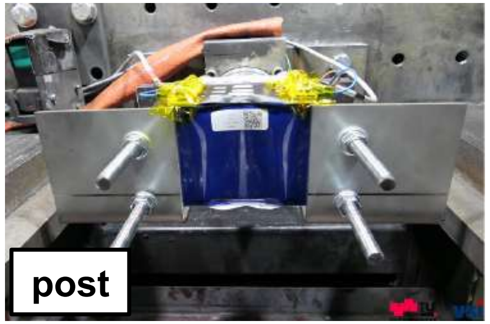
Quasi- static / Dynamic tests cell stack:

Load Case	Axis	Tests	Boundary	Speed	SOC	Sketch
Cylindrical Indention	Y	1	Preforce = 1kN	1mm/s	0%	
Cylindrical Indention	Y	1	Mass = 200 Kg, Preforce = 1 kN	3.5m/s	0%	





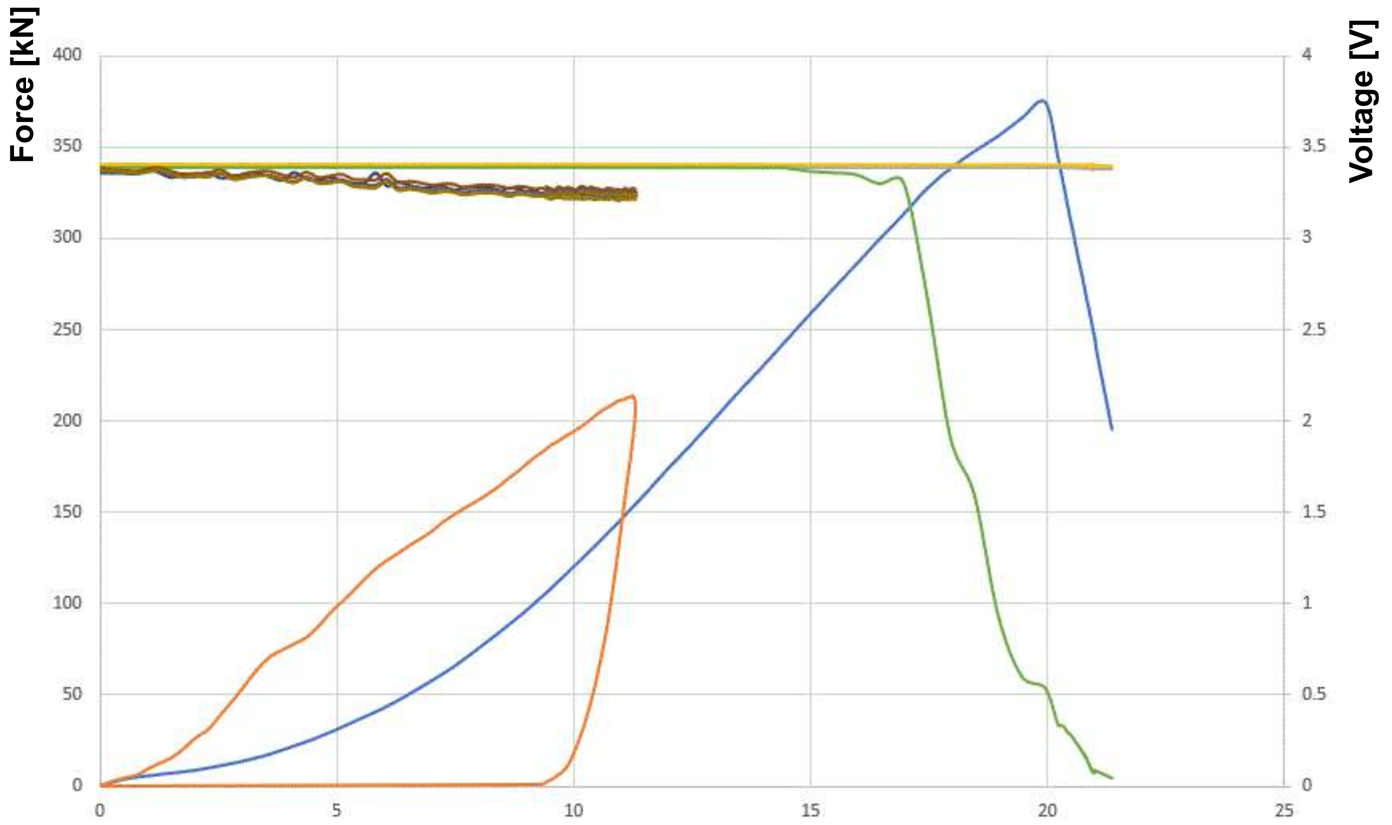




Mechanical tests performed at TU Graz | VSI - BSCG

Mechanical Cell Stack Testing

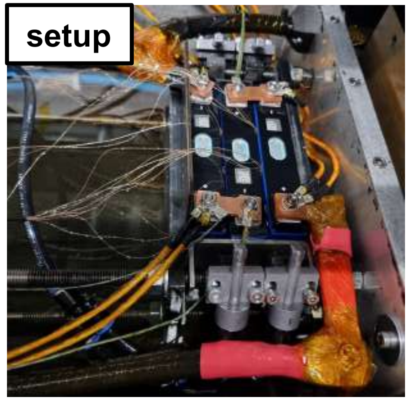
- Max force is higher
- Displacement is higher
- Short circuit:
  - First cell (quasi-static)
  - Not occurred (dynamic)
- Stack improves the strength and energy absorption

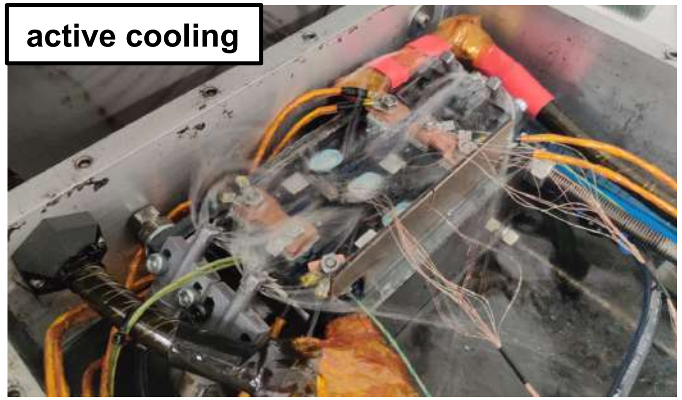


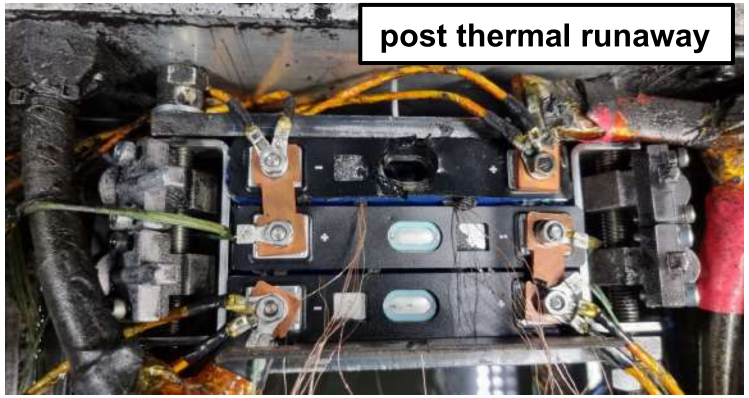
Thermal Runaway Cell Stack Testing

- TR test with 3-cell stack
  - Cells partially immersed in cooling oil, cooling through oil spray
  - Cooling improved from tests with 12-cell stack
    - More powerful cooler and better heat exchanger
  - TR-mechanism → nail penetration

3-cell stack





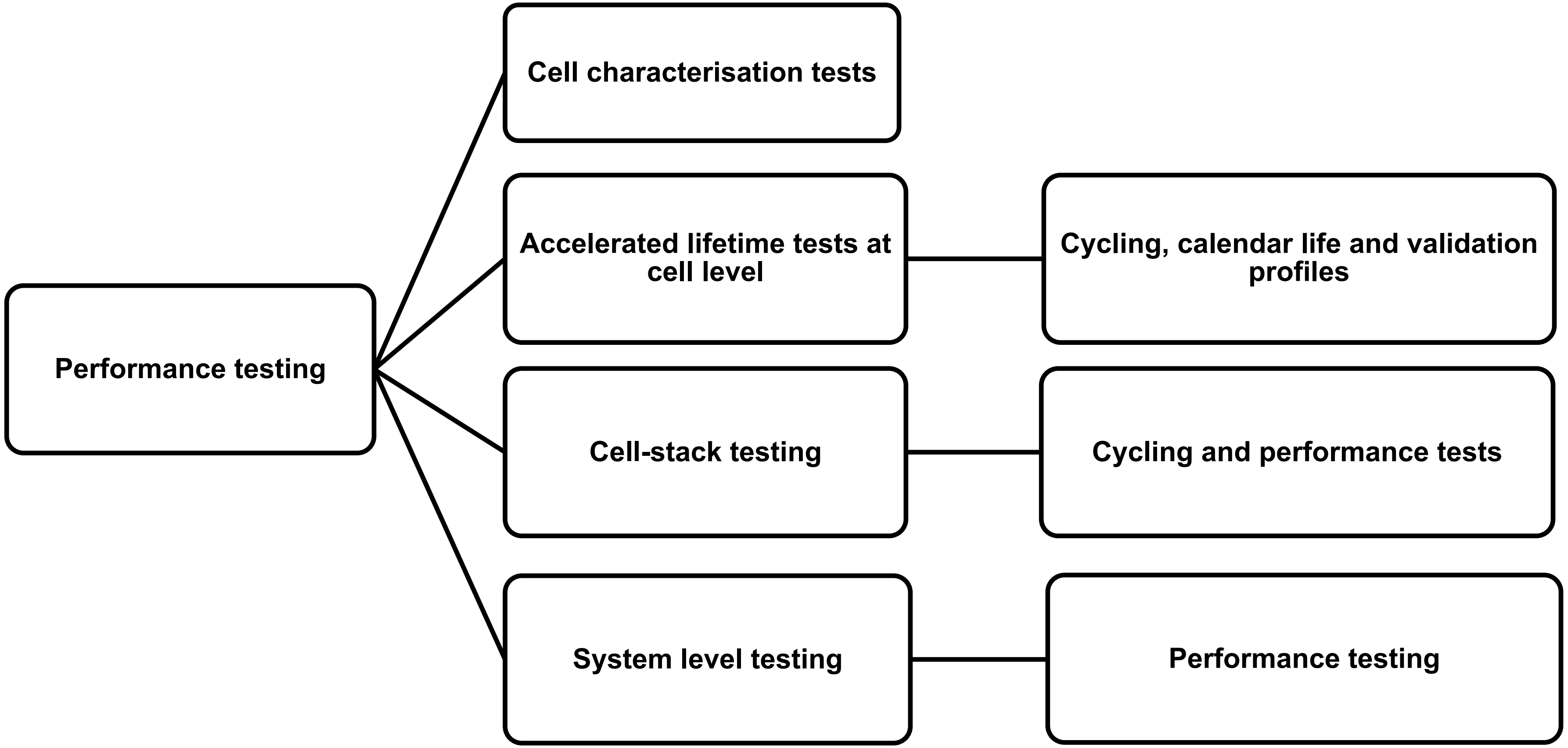


- No TR-propagation from trigger cell to neighbouring cell
- Highest temperature on non-trigger cell ~190°C
- **TR-propagation stopped by oil spray cooling system**

Performance Testing

Performance testing - overview

- Overview:



Performance testing – cell characterization tests

- Electrical characterisation:
  - Capacity tests, (Q)OCV vs. SoC, HPPC, EIS & fast-charging tests
  - Input for cell-model
  - Development of SoX algorithms

- Thermal characterisation:
  - Thermal conductivity tests
  - Input for cell-model
  - Development of the thermal management system

Performance testing – accelerated lifetime tests at cell level

- Cycling:
  - Variables are temperature, C-Rate, middle-SOC and depth-of-discharge (DOD)
  - Frequency of check-ups is based on full-equivalent cycles
  - Ageing evaluation is done on capacity decay and internal resistance

Cycling test matrix

	ΔDoD	100	80	70	50	20			10	
	Middle SoC	50	50	45	50	80	50	20	80	50
Temp.	C-Rate (CH-DCH)									
15°C	C/3 - C/3		C15-12							
	C/3 - 1C		C15-13							
25°C	C/3 - C/3		C15-07	C01-63						
	1C-C/3		C15-08	C01-61						
	C/3 - 1C	C01-65	C01-64	C01-67 C15-09	C01-66	C01-59	C01-60	C01-62	C15-10	C15-11
	2C - C/3 (With cooling)			C01-68						
	4C - C/3 (With cooling)			C01-58						
45°C	C/3 - C/3		C01-71							
	C/3 – 1C		C01-70							

Performance testing – accelerated lifetime tests at cell level

- Calendar life:
  - Variables are temperature and SOC
  - Temperature is changed each month according to temperature profile
  - Frequency of check-ups is time-based (months)
  - Ageing evaluation is done on capacity decay and internal resistance

Calendar life test matrix				
Temp / SoC	100	80	50	20
15 °C		C14-004		
25 °C	C14-007	C14-006	C14-008	C14-009
45 °C		C14-010		

Variable 1, Cold climate (Munich)													
MONTH	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEPT	OCT	NOV	DEC	**AVG**
MEAN T [°C]	2.7	4.3	9	12.5	18	20.5	23.1	23	18.8	13.2	6.9	3.7	12.98

Variable 2, Hot climate (Seville)													
MONTH	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEPT	OCT	NOV	DEC	**AVG**
MEAN T [°C]	16.5	18	21.8	23.8	27	32	35.5	34.5	30.5	25.5	20.2	16.8	25.2

Performance testing – accelerated lifetime tests at cell level

- Validation profiles:
  - Realistic driving profiles (incl. fast-charging):
    - Realistic 1: commuting to work combined with trips during the weekend (both slow and fast-charging)
    - Realistic 1 accelerated: same as Realistic 1 but without pauses
    - Realistic 2: same as Realistic 1 but without fast-charging
  - Frequency of check-ups is based on full-equivalent cycles
  - Ageing evaluation is done on capacity decay and internal resistance

Validation profiles			
Temperature / Profile	Realistic 1	Realistic 2	Realistic profile 1 Accelerated
Variable 1 (cold climate)		C01-056	
25°C	C01-72	C01-057	C01-073
Variable 2 (hot climate)		C14-11	

Variable 1, Cold climate (Munich)													
MONTH	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEPT	OCT	NOV	DEC	**AVG**
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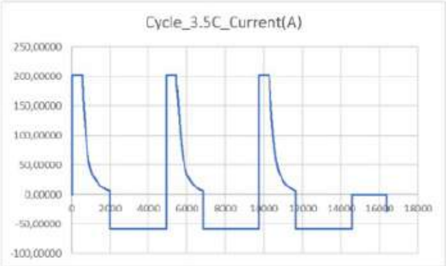
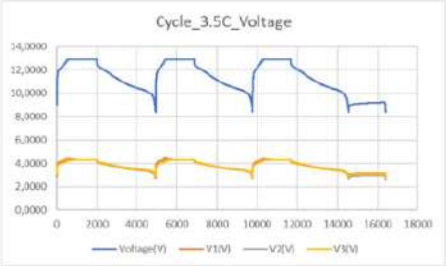
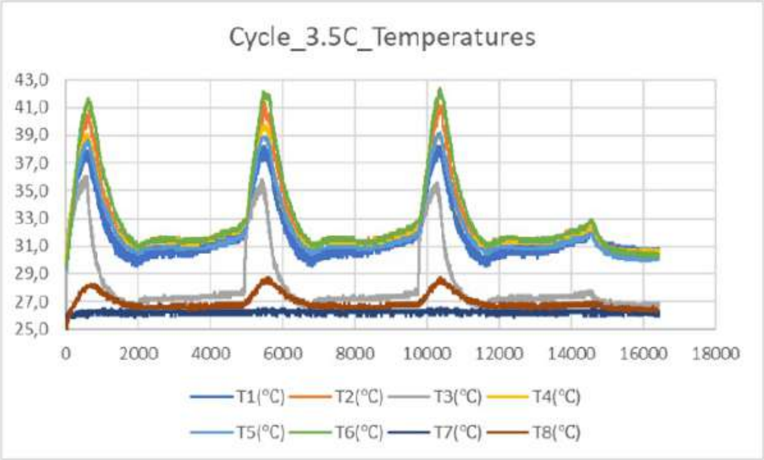
MONTH	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEPT	OCT	NOV	DEC	**AVG**
MEAN T [°C]	16.5	18	21.8	23.8	27	32	35.5	34.5	30.5	25.5	20.2	16.8	25.2

Performance testing – cell-stack testing

- Cycling tests on cell-stack with 3 and 12 cells:
  - Focus on fast-charging and development of thermal management system



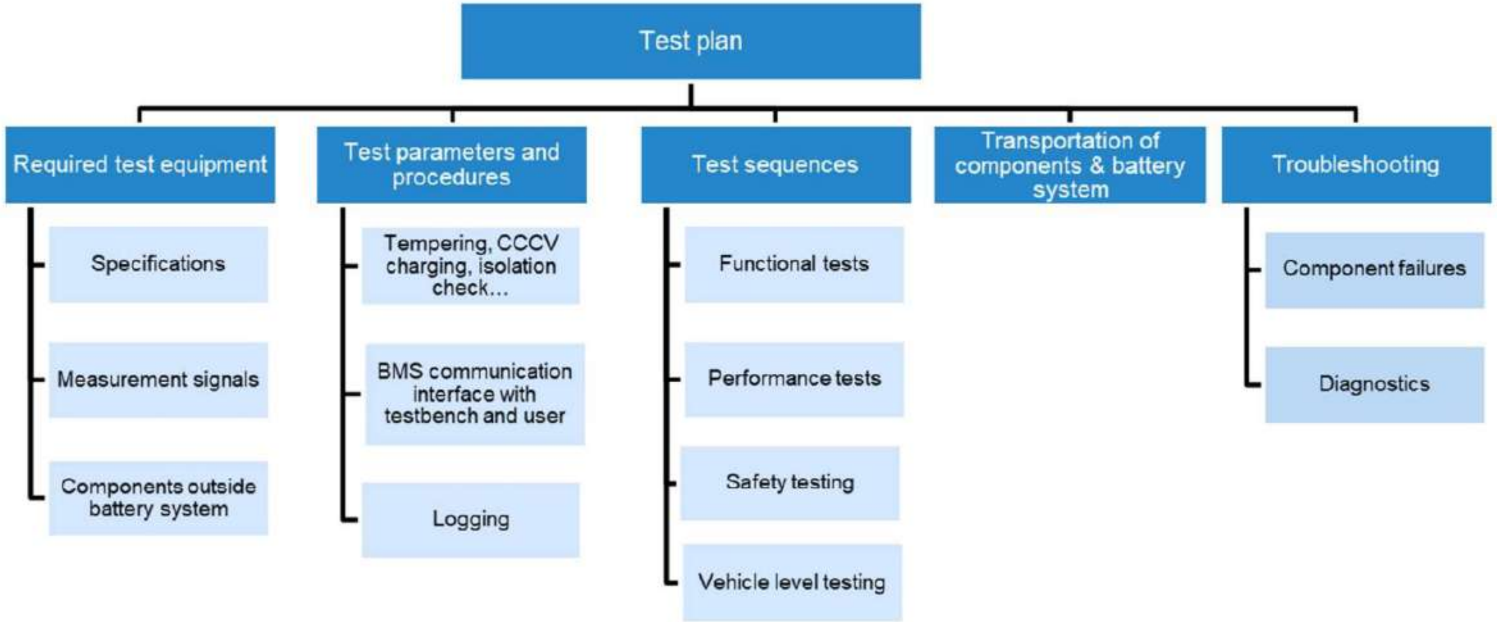




- Cycling tests will be repeated on final cell-stacks used in battery pack (14 and 24-cells):
  - Focus on fast-charging for selection of optimal nozzle configuration
  - Lifetime tests (validation profiles) for development of lifetime model of battery system

Performance testing – system level testing

- Battery system will be tested according to battery system test plan developed in LIBERTY:
  - Includes functional testing, performance testing, safety testing and vehicle level testing
  - All test descriptions contain objective, start criteria, test sequence and validation criteria
  - Transportation and troubleshooting procedures are also described



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