Safe and powerful batteries thanks to immersion cooling

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GIFAS – May, 25th 2023

www.e-mersiv.com / www.exoes.com

A unique expert in batteries

42 people

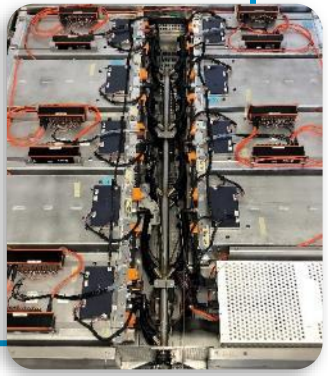
€7m sales

EXOES

- EXplorer Of Energy Systems
- Engineering on batteries and heat pumps
- Engineering on:
  - Component simulation & design
  - Prototyping
  - Tests & model calibration

E-MERSIV
Submerged battery packs

- Sells & manufactures battery packs
- Specialized in mmersion-cooled batteries made of prismatic cells
- Markets:
  - Specialty EVs
  - Premium cars
  - Mass market (licensing)



TRL3 TRL4 TRL5 TRL6 TRL7 TRL8 TRL9 Industrialization

How to increase EV customer adoption rate?

	Autonomy	Fast charge	Lifetime
Automotive Markets	2h highway driving	< 10 min	> 8 years

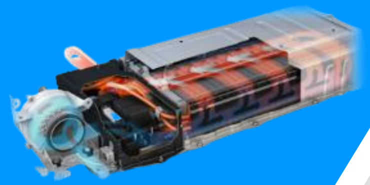
	Safety	Lightweight	Lifetime
Aeronautics Markets	No fire No explosion	>250 Wh/kg	> 8 years

Narrowing the user experience gap between fossil fuel vehicles and BEVs is key.
Improved battery thermal management is one of the keys.

Existing cooling solutions for batteries

Air-cooled

- Simple and easy to implement
- Low heat transfer
- Low compactness



Water/Glycol

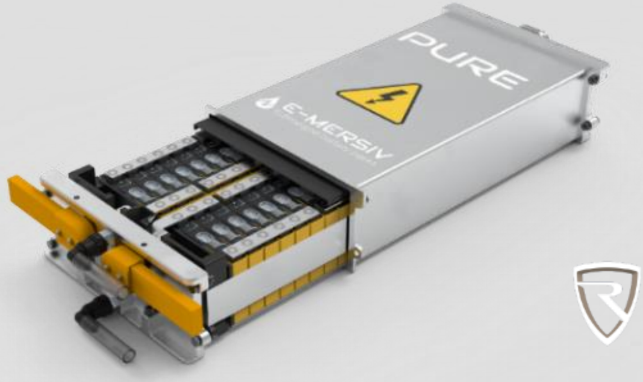
- Most common nowadays
- More compact and better efficiency than air
- Simplified vehicle thermal system with one-fluid-for-all

Refrigerant

- High heat-transfer and cooler
- Difficult to apply to large batteries
- No preheating mode

Immersion cooling technology

- Direct cooling of cells & busbars
- No fire propagation
- Preserved lifetime
- High C-Rates for HEVs
- Already in use on motorsport and high-performance supercars



Long life

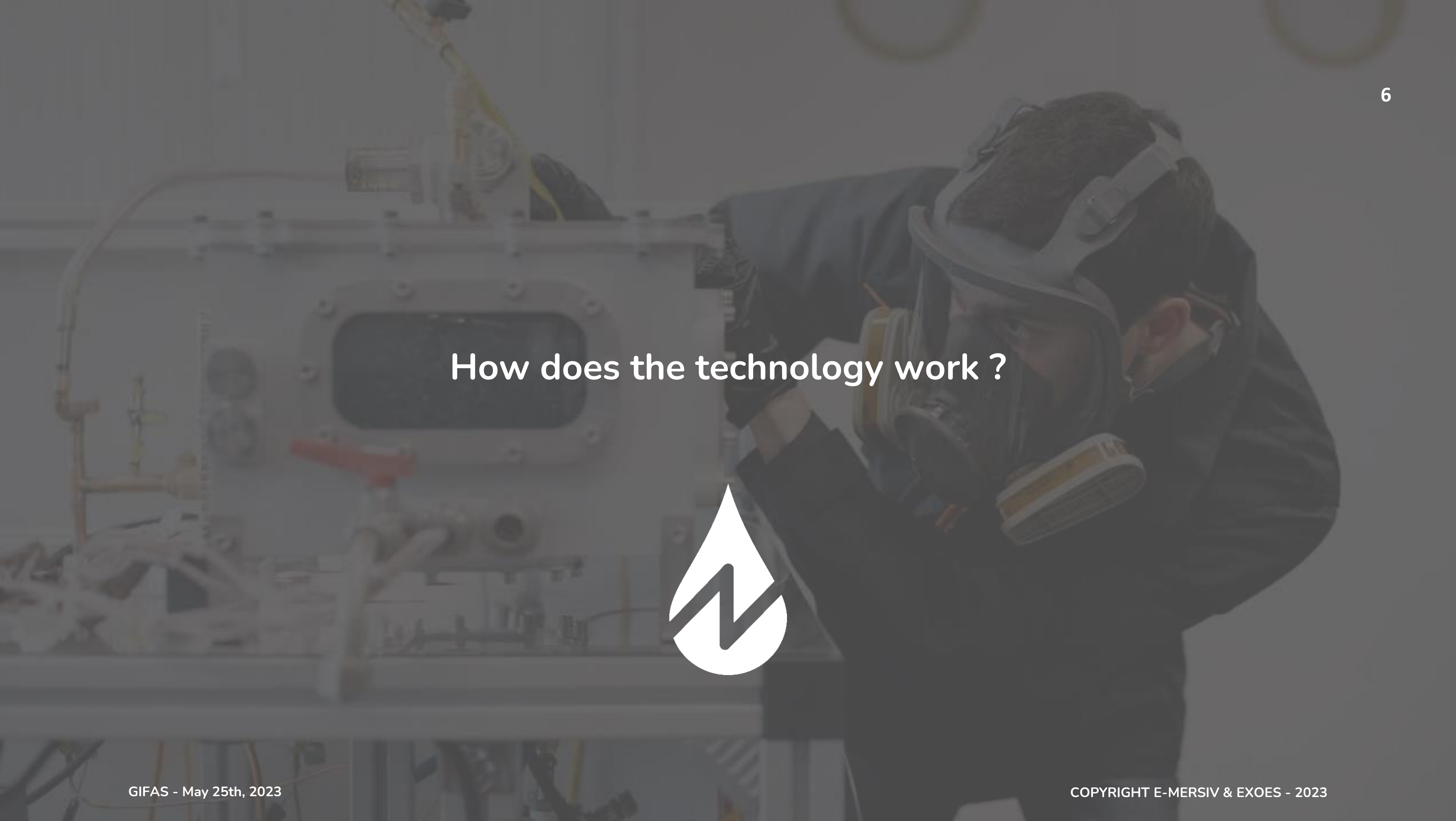
Charging Time

~4C rms

Power to Energy ratio

No fire

Safety

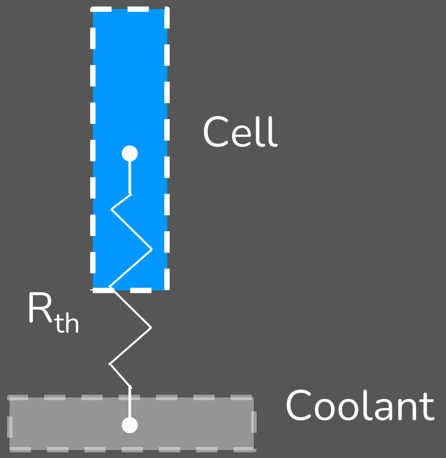


How does the technology work ?

How does immersion cooling work at cell level?

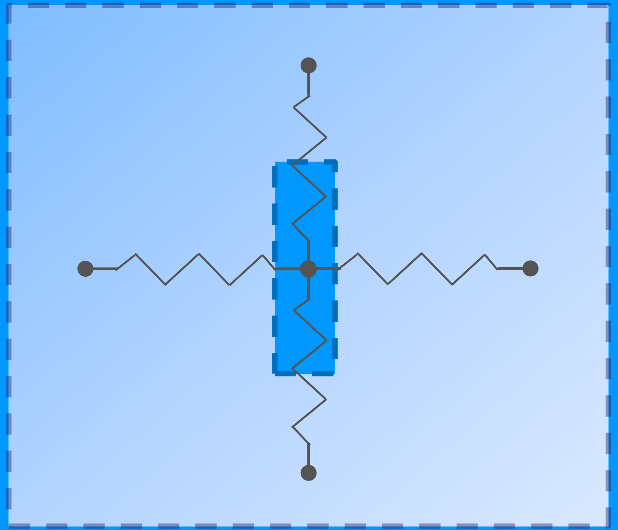
Immersion reduces the battery thermal resistance for better cooling:

Cold plate cooling



Thermal resistance typ. >0.8 K/W*
& busbar not cooled

Full immersion cooling

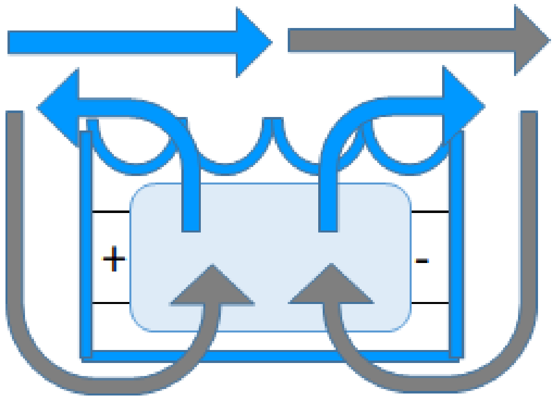


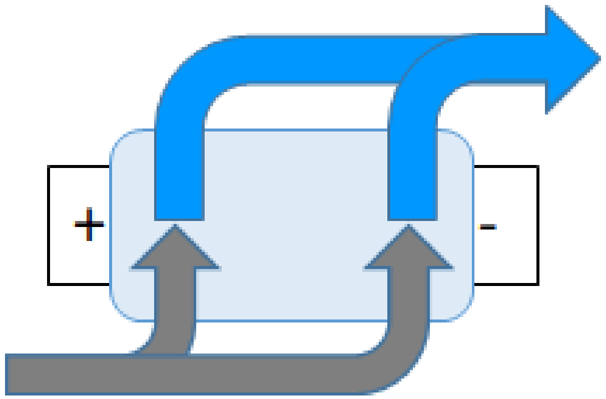
Thermal resistance typ. <0.2 K/W*
& hot spots cooling

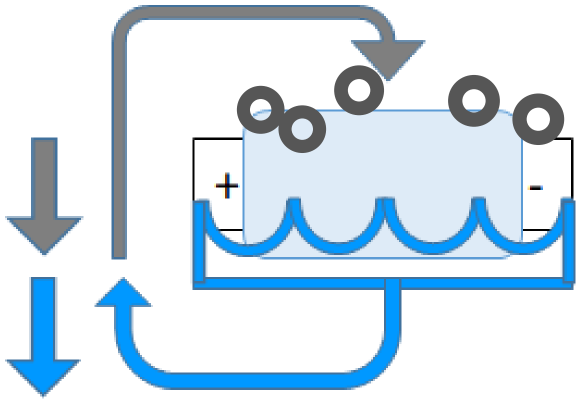
Immersion cooling is 2 to 5x better than cold plates

**: Calculated on prismatic cell – PHEV2 format*

How does immersion cooling work at battery level?







Static bath

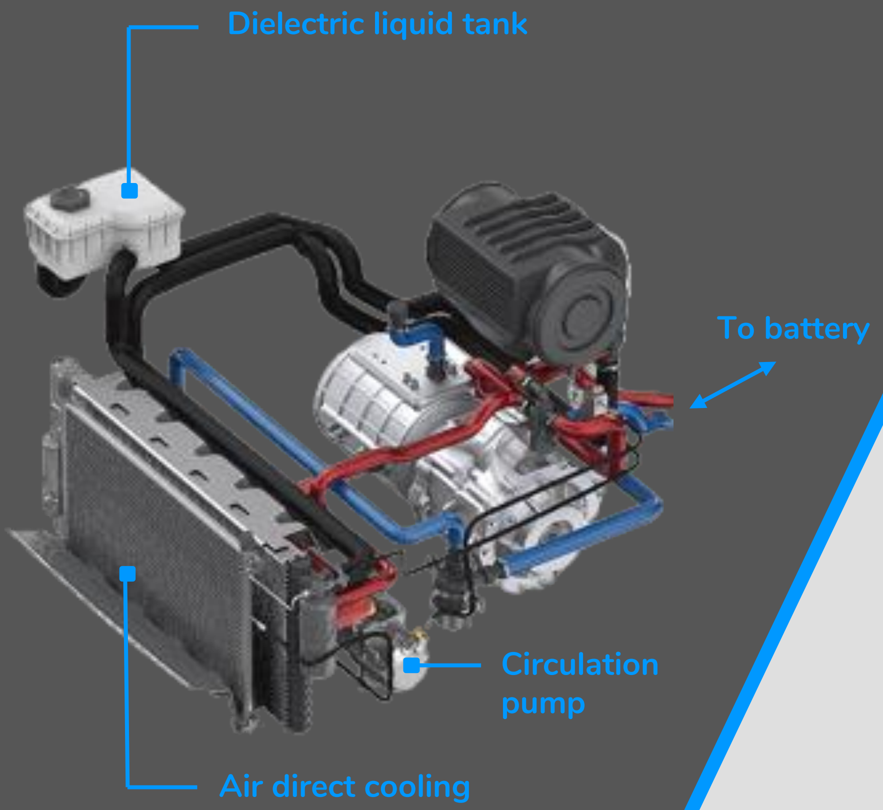
Full immersion

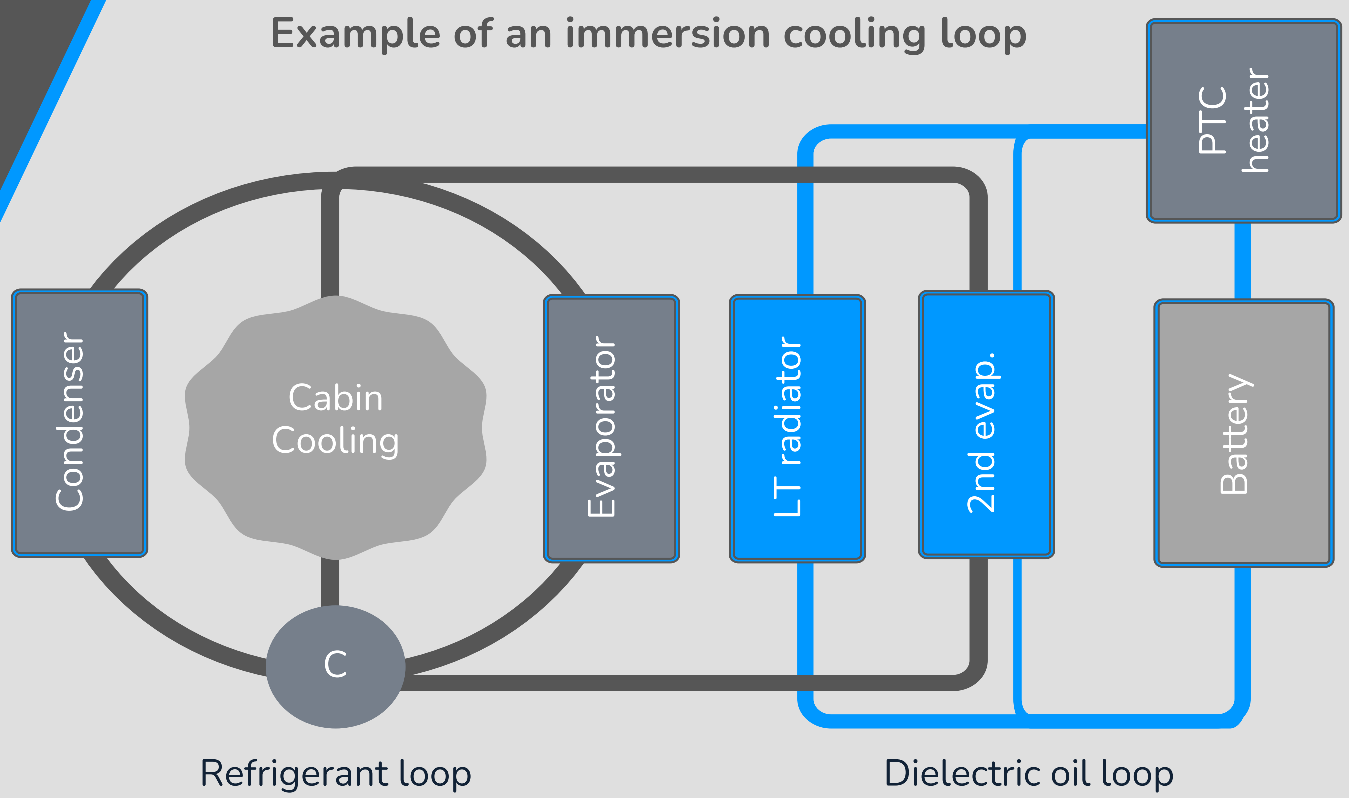
Spray / Jet cooling

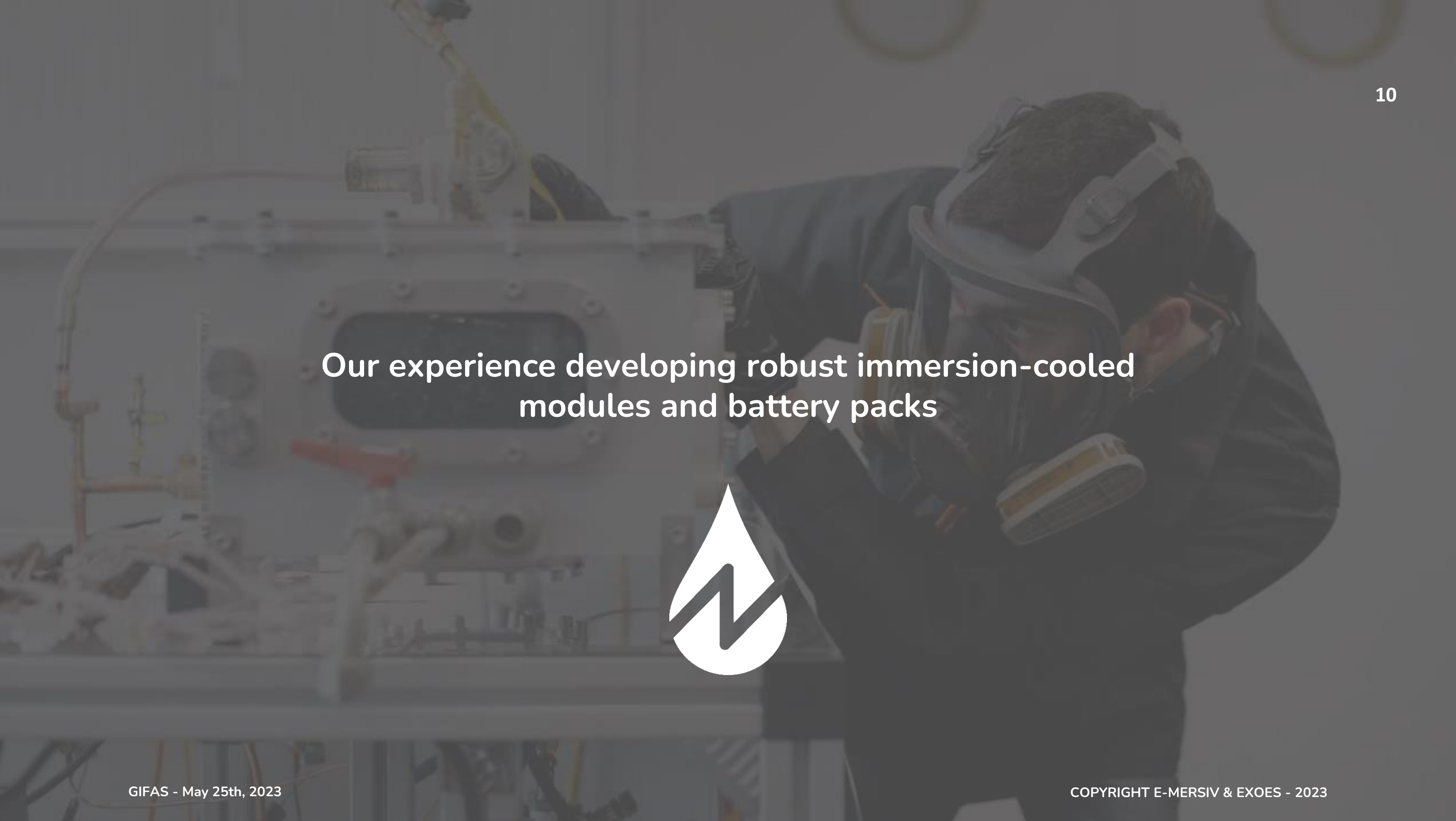
Technology selection based on:

- Cost
- Weight
- Safety level
- System performances
- Cell to pack vs modular

How does immersion cooling work at vehicle level?

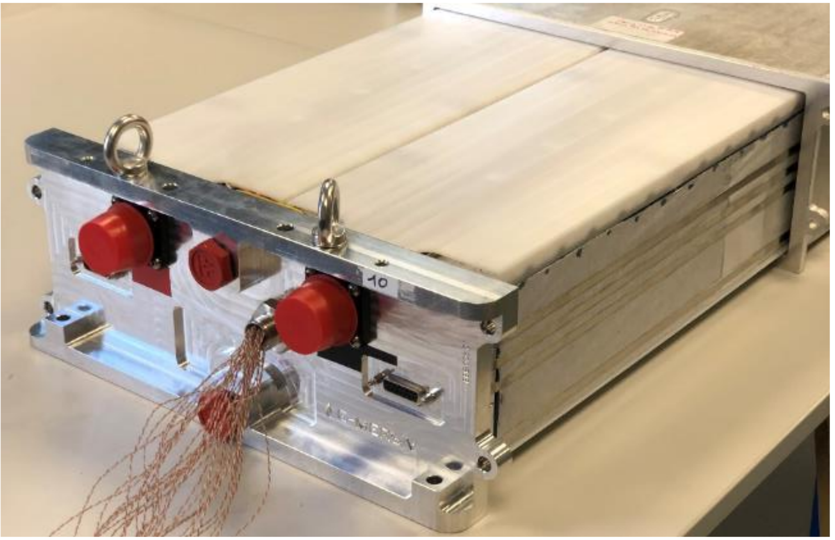




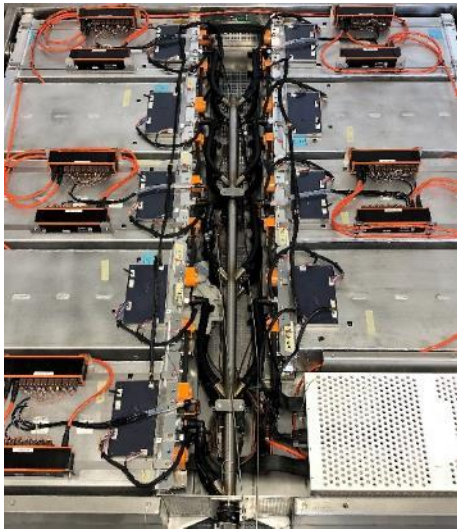


Our experience developing robust immersion-cooled modules and battery packs

Our module made of prismatic cells



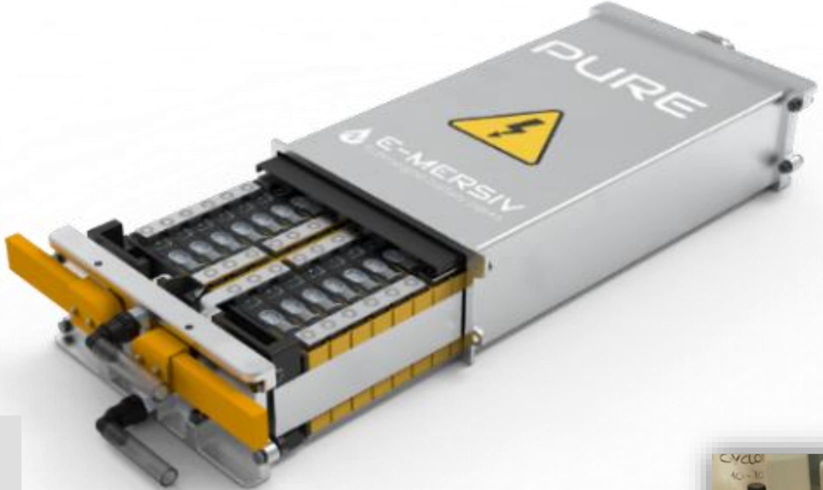
a module made
of 36x NMC
prismatic cells
(3p12s)



a 60kWh battery
made of 9x
modules

Prototypes developed in our laboratory,
in order to evaluate performance of
immersion cooling

A ruggedized product
to supply the specialty vehicle markets

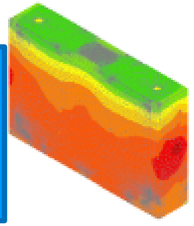


a module made
of 12x NMC
prismatic cells
(2p6s)

Battery development process

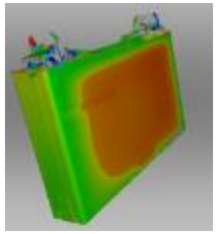
1

Thermohydraulic assessment (0D, 1D, 3D CFD)



2

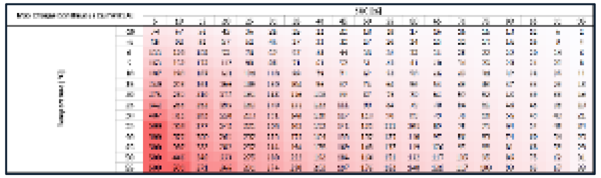
Swelling and internal stress (FEA)



3

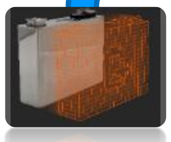
Dedicated module design

5



BMS integration

4

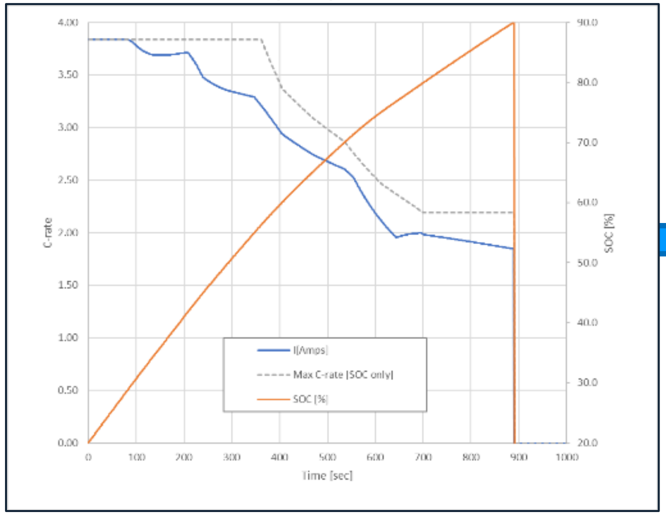


Physical model of anode potential

6

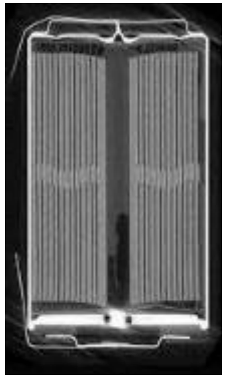
Actual tests

Performance / Aging / Abuse / Vibration



7

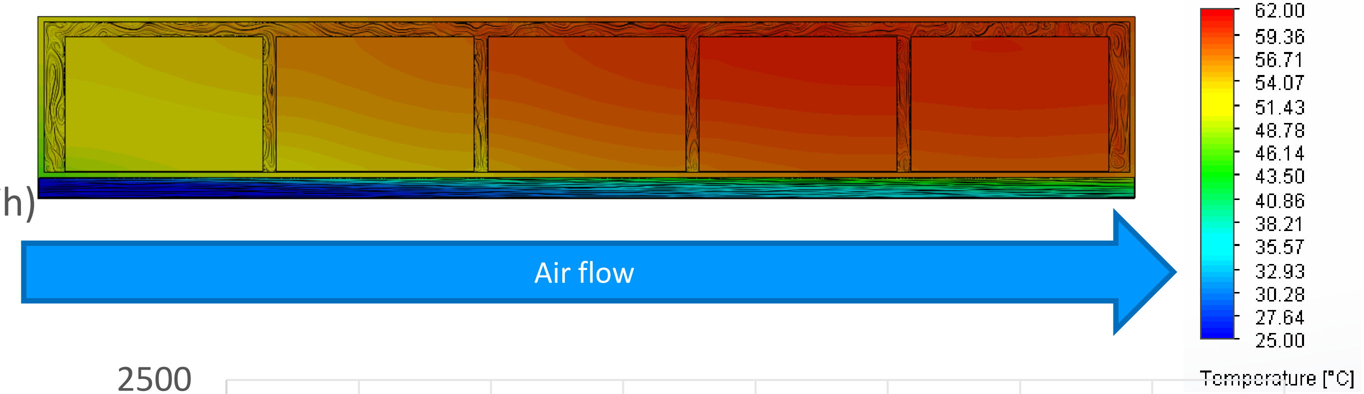
Validation w/ Swelling/Plating analysis after X fast-charging cycles



Simulation: a static bath with bottom air cooling

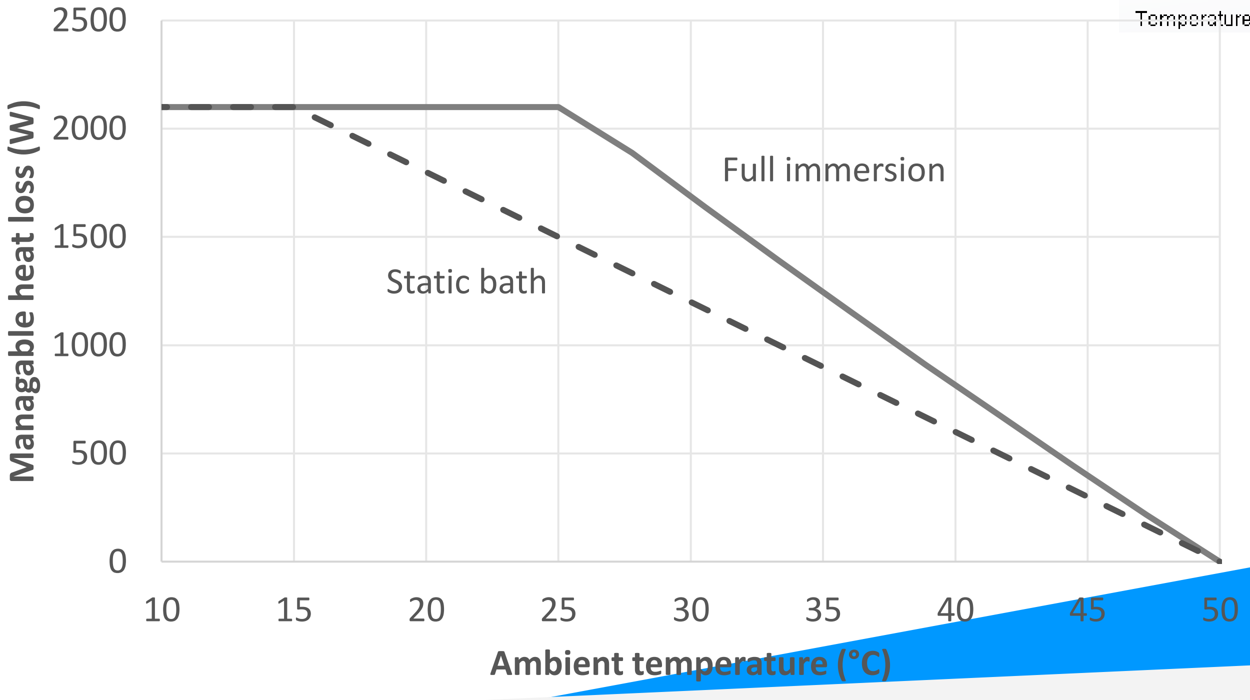
Conditions

- Constant heat generation 10W/cell (~2C) – 200x cells (~45kWh)
- 25°C air flow
- Air flow of 300m3/h - (Forced oil flow 15L/min)



Results

- Battery thermal resistance <3K/W
- Inhomogeneity 15K with static bath vs <5K with full immersion
- Temperature increase +37°C with static bath vs +25°C

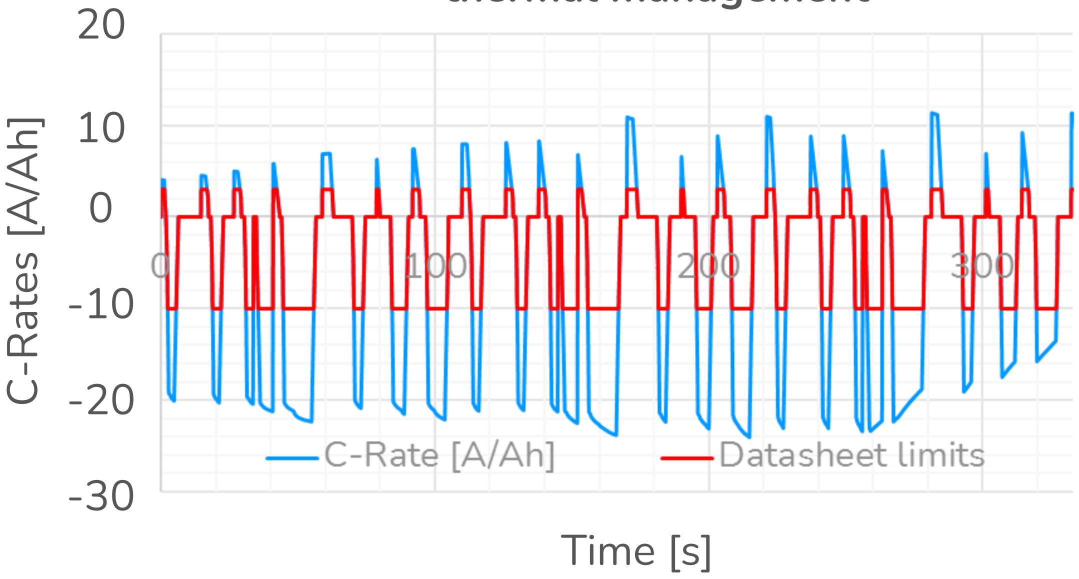


Full immersion provides a better cooling capacity and can be controlled with active flow rate

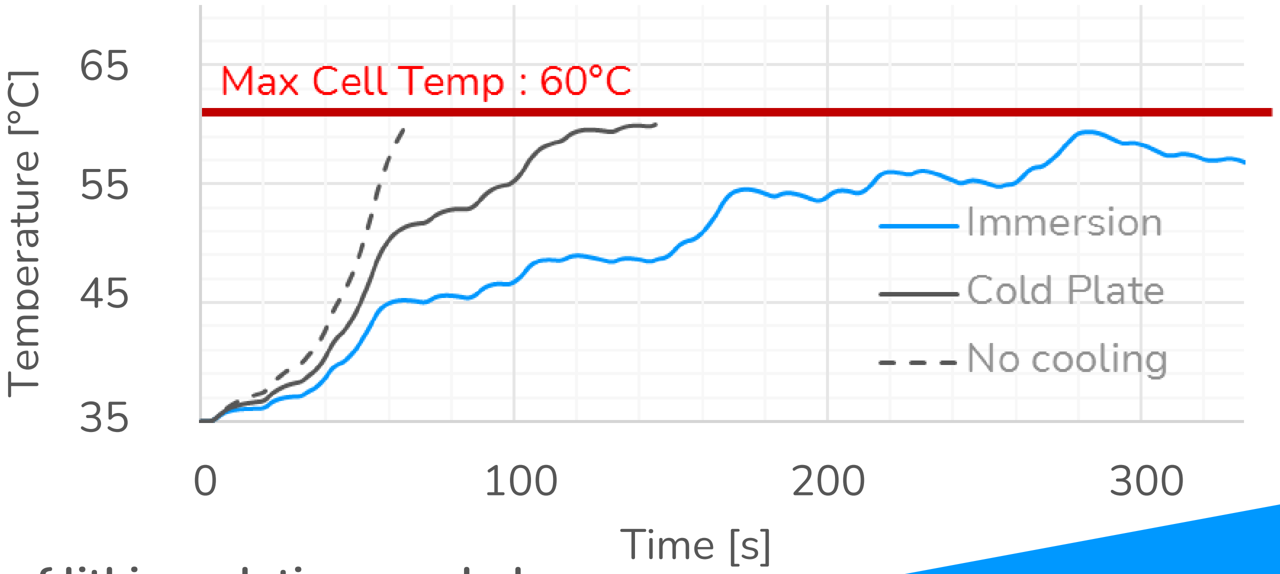
Simulation: Full immersion benchmark for racing EV

- Racetrack in France: 3× laps of 111s
- Battery 400V | 8.7kWh | 160kW peak

Power on racetrack thanks to improved electric and thermal management



Battery temperatures with various cooling options



Accurate management of lithium plating coupled to enhanced cooling performance enables up to 4× times more power to energy ratio

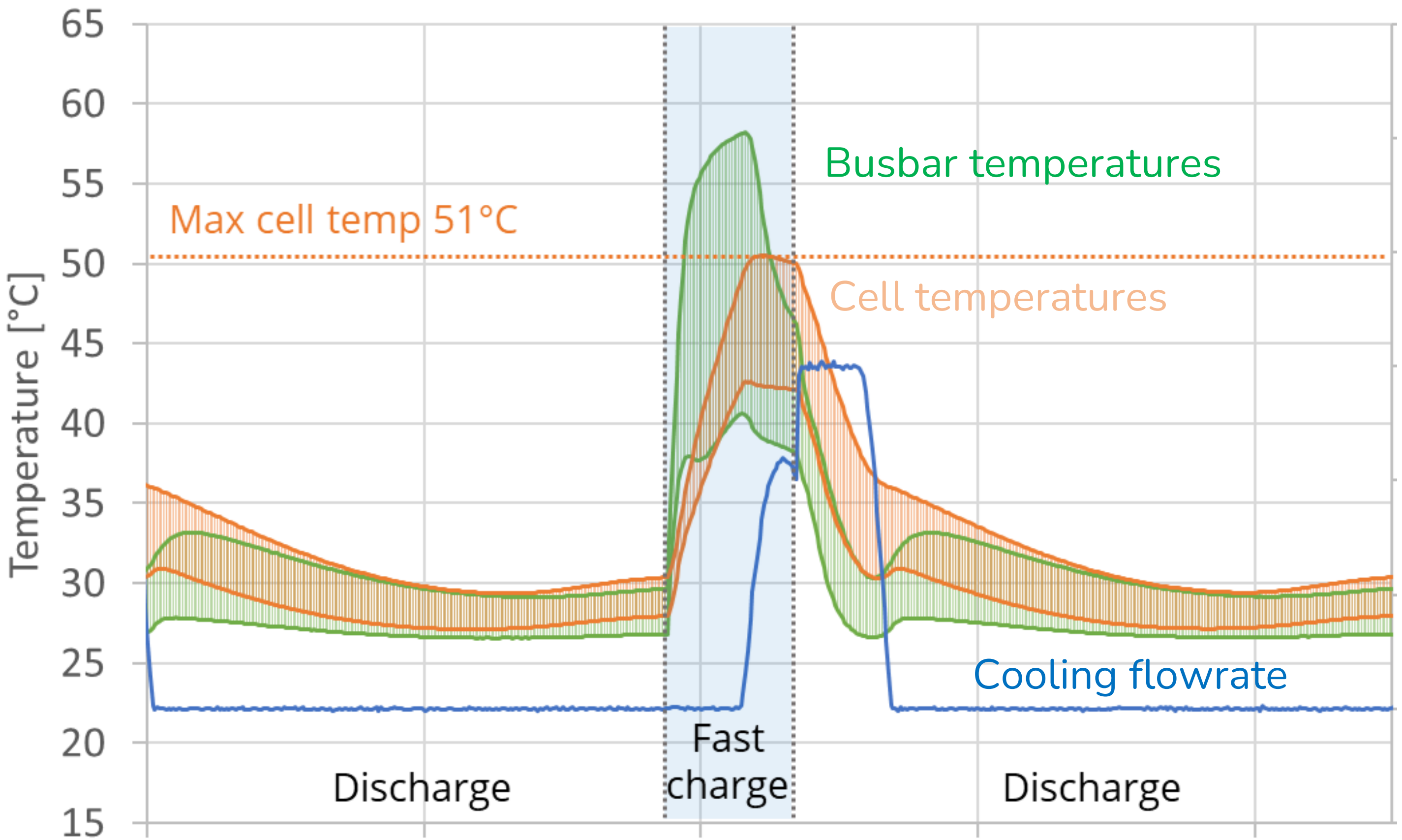
Demonstration of fast charge capability

Test Conditions

- Charge from 20 to 80%
- Followed by C/2 discharge
- Cooling at 25°C

Results

- Charge in 14min
- Max cell temp. <51°C
- Max ΔT on cells <6K



Repetition of fast charges authorized
Back to initial state in less than 30min

Data courtesy of Shell

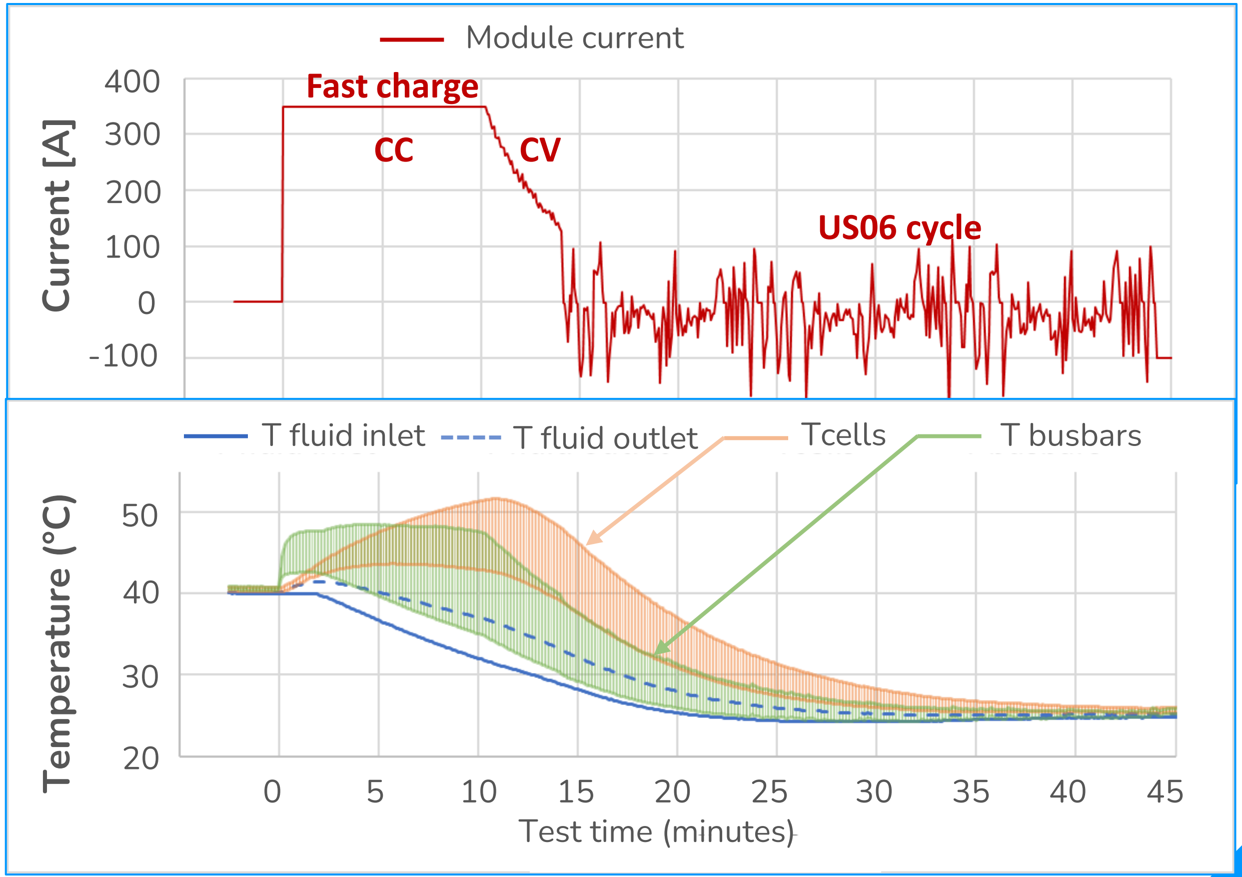
Fast charge + US06 (EPA highway criving cycle)

Test Conditions

- Initial temperature 40°C
- 3.5C charge from 5 to 65% (~10min)
- Cooling at 6L/min and 25°C
- Followed by a US06 cycle

Results

- Max cell temp. <53°C
- Max busbar temp. <50°C
- Max ΔT on cells <10K
- Duration above 35°C <23min

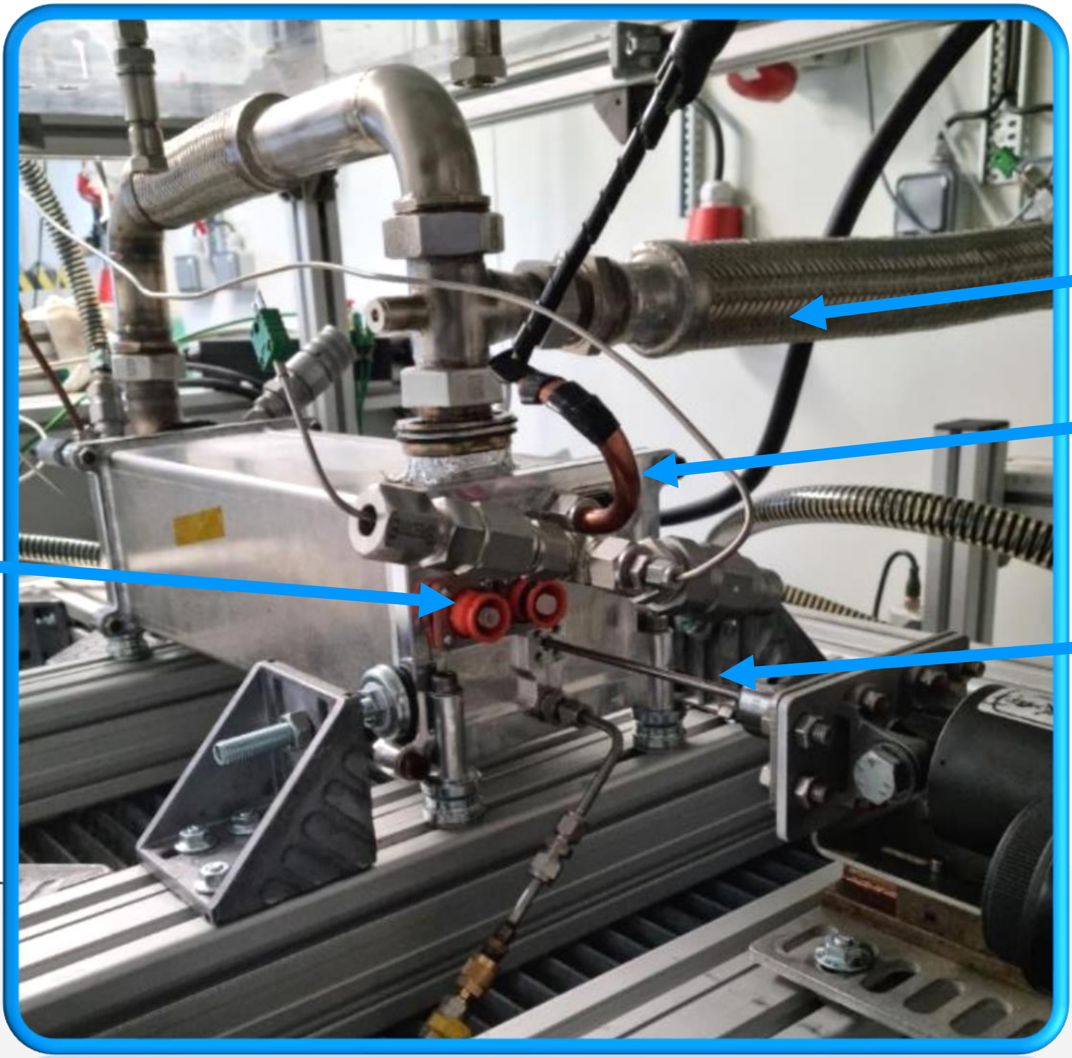


Data courtesy of EXOES and Lubrizol
(for data on safety test from Lubrizol – contact us)

>3C charge accessible with immersion cooling

No active cooling required during normal driving

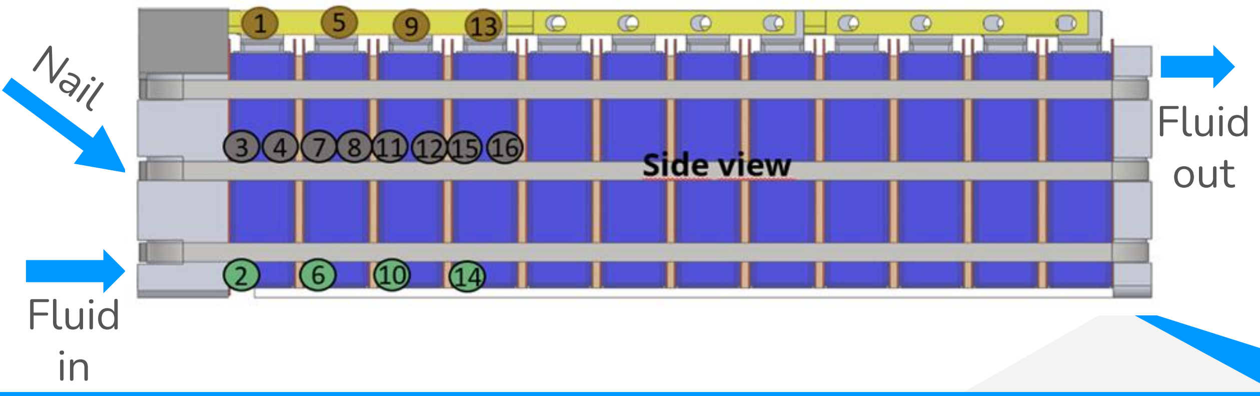
Nail Penetration Test (NPT)

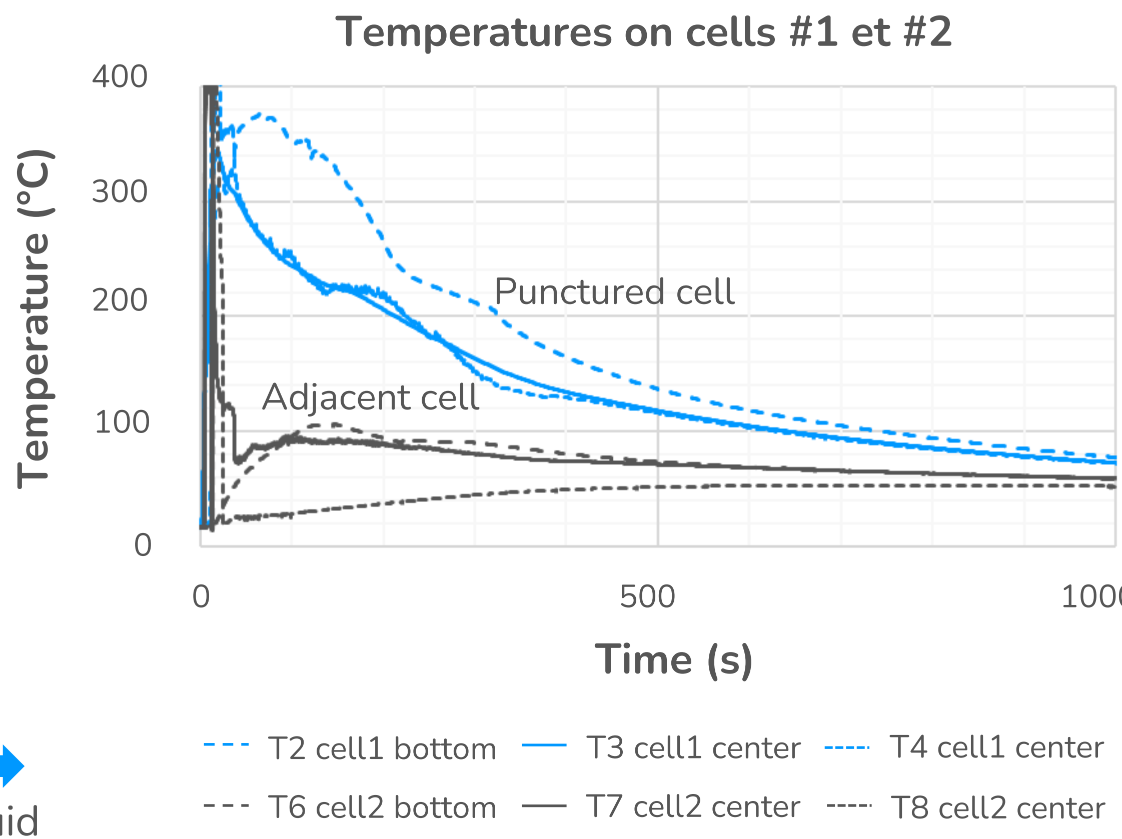


For NPT Test results and Fluids Benchmark, feel free to reach out to Exoes or Lubrizol.

The cooling prevented the fire propagation

- No Active flow rate by pumping action.
  Flow of 0.3 L/min induced by gravity
- Punctured cell temp. increased up to 350°C in 20s after the vent broke
- Adjacent cell temp. increased up to 105°C within 100s





No propagation to the adjacent cell

Data courtesy of EXOES and bp for data on performance test from bp – contact us)

The adjacent cell suffered but did not burn

Data courtesy of EXOES *and* bp

Battery design

has been improved

for greater robustness

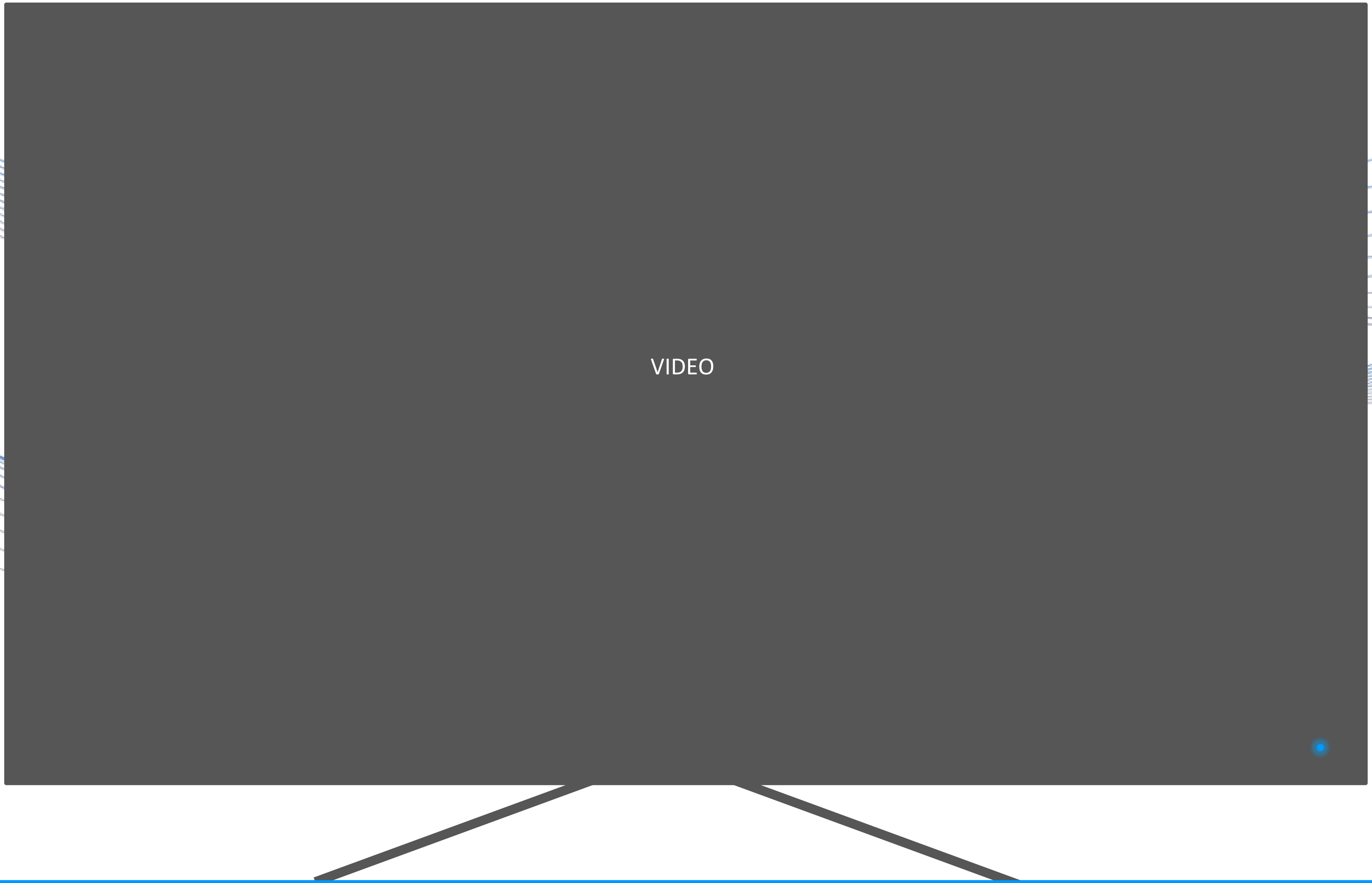
Cell#	Fuse burnt	Internal short circuit	Weigth [g]	Swelling [mm]
1	Yes	Yes	731	+3
2	No	No	860	+1
3			860	+1
4			863	Not checked
5			858	
6			860	
7			859	
8			863	
9			861	
10			861	
11			861	
12			861	

Lots of ashes , but…

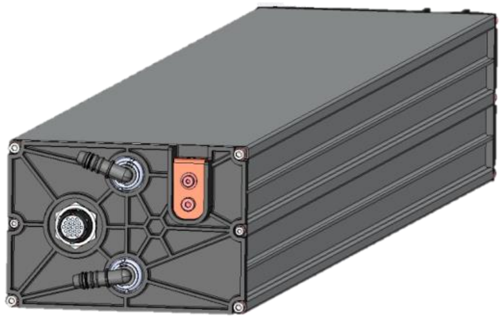
… the adjacent cell is intact !

* *measured after a complete discharge process and a several days of relaxation*

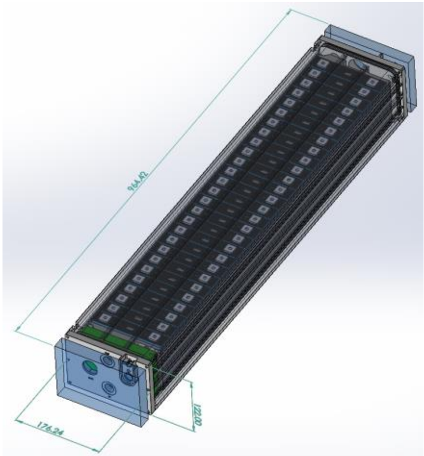
The adjacent cell suffered but did not burn



Our standard battery development for aeronautics



- 2x standard versions: 40kWh & 120 kWh
- 520 – 820 V
- Disassembly in modules <35kg
- Compliant with DO311A – IDAL C (in2026)



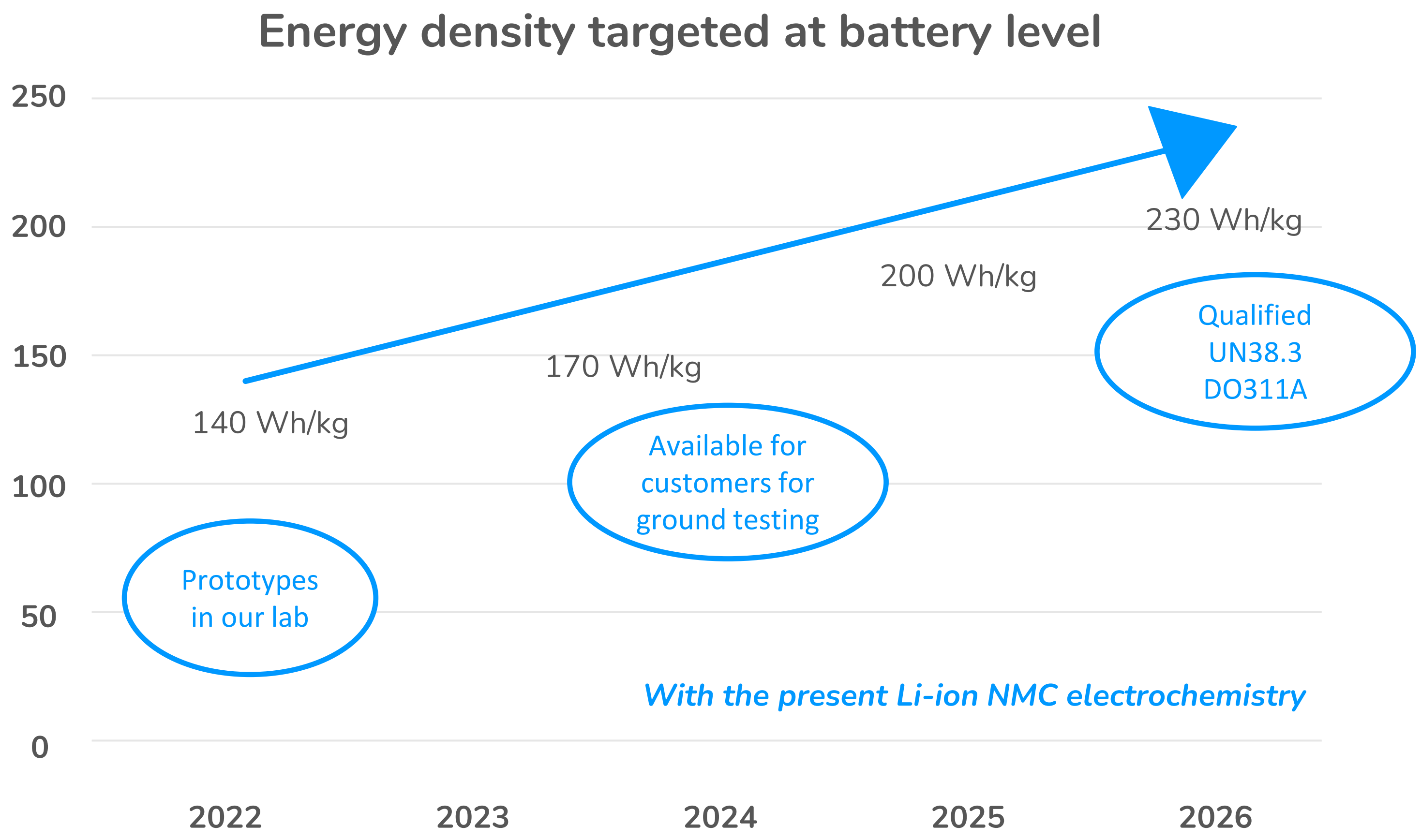
30 min
Charge from 20 to 80% SOC
35°C initial and cooling temperature

370 kW
Continuous discharge power
Temperature derating expected

170 Wh/kg
Energy density (wet - BOL)
with casing, powerbox and cooling loop

2,000 Cycles
Lifecycle 100%DOD
1.2C/1C 80%SOH
25°C at cell

Conclusion : our roadmap on energy density



Based on our cell supplier road maps,
we can expect the following energy density at battery level

E-MERSIV
Submerged battery packs

EXOES

Thank you. Any question?

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