The thermal management expert in electromobility

Immersion Cooling of Battery Packs: High Power Performance and Safety Benefits

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November 13th 2024

EXOES GROUP PRESENTATION

Our Group

bpifrance
Meridiam

Arnaud Desrentes
Rémi Daccord
& key employees

EXOES

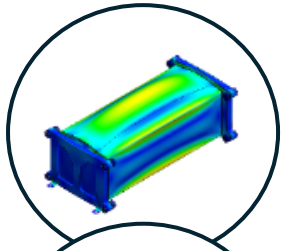
Lab
Engineering

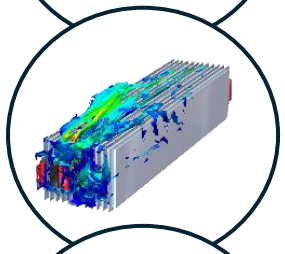
Battery & Cooling
With E-MERSIV technology

Test centers

70
employees

7M€
Revenues


Design


Simulation


Prototyping


Testing


Test rigs

EXOES supplier of HV batteries for aeronautics

Nominated by Flying Whales:

- 60 tons cargo aircraft
- LTO Battery 9kWh 500kW 800V
- Cooled by immersion
- Used as a buffer

For aeronautics batteries,
Safety and Power are critical

→ We selected immersion cooling technology

IMMERSION COOLING OF BATTERIES

For safety and performance

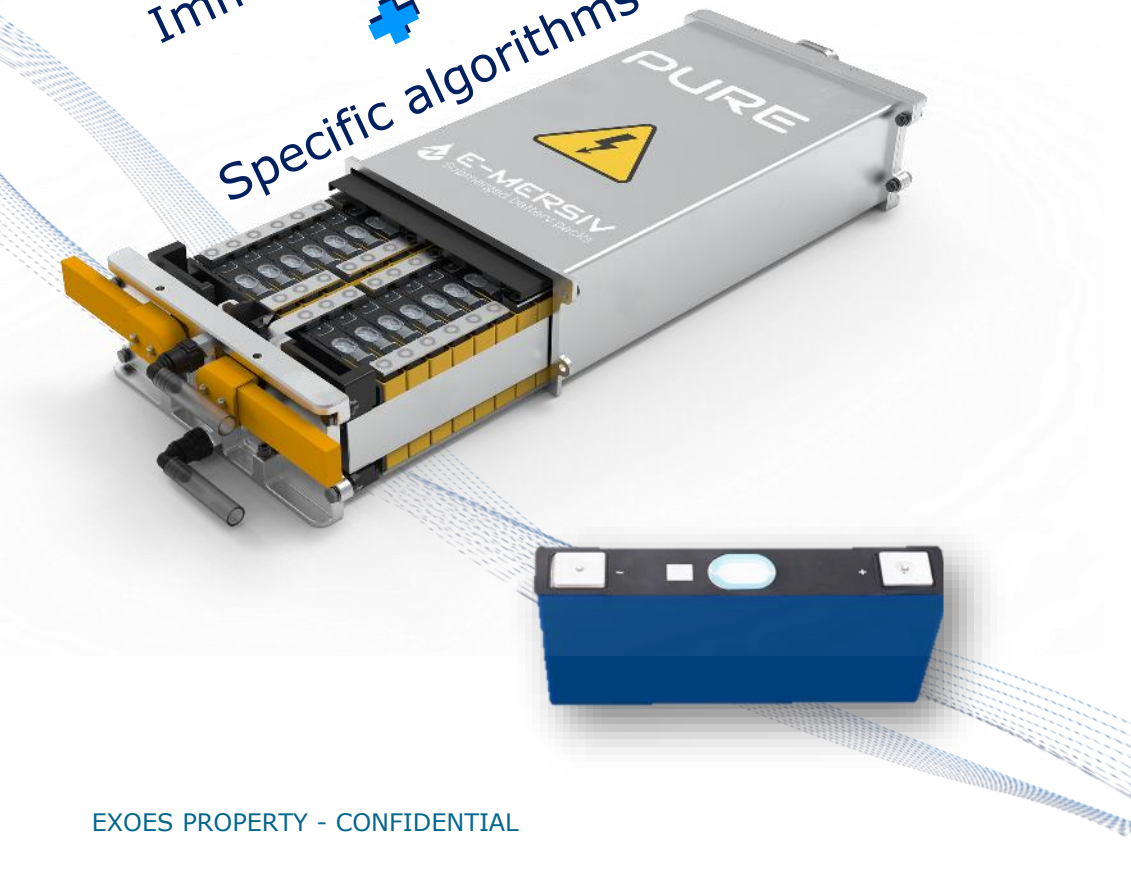
Our technology: E-MERSIV

Thermal conditioning by immersion and control algorithms
to achieve densities of 225 Wh/kg & >1 kW/kg at module level with cells available by 2027

Immersion cooling

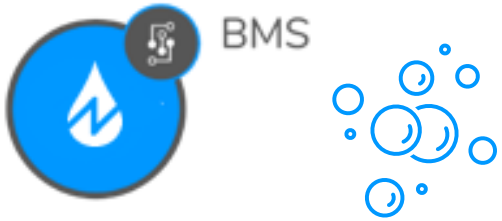
+

Specific algorithms



1. High energy cells

2. Immerged in a dielectric fluid

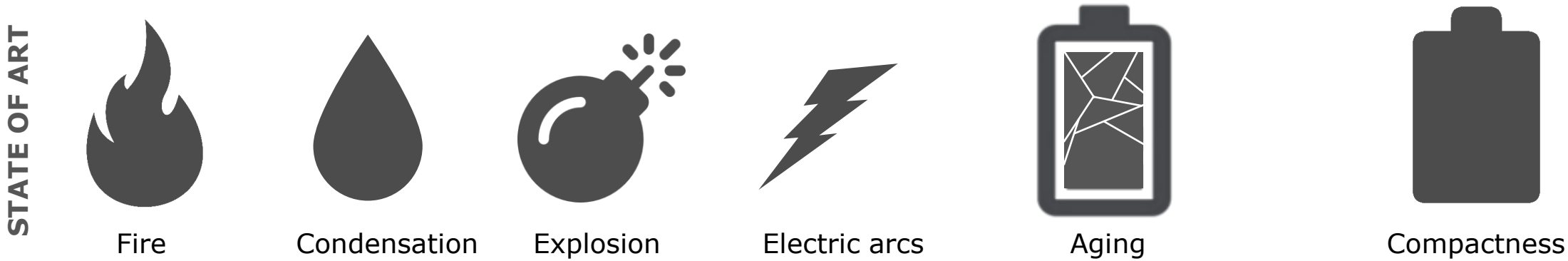


3. Compactly assembled in containment modules

4. Constantly monitored to ensure operability and expected lifespan.

Immersion for safe and powerful batteries

E-MERSIV patented technology



#1: Safer

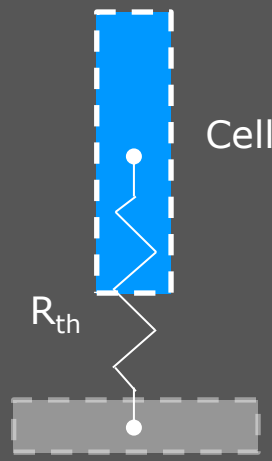
#2: Longer

#3: Higher energy density

How does immersion cooling work at cell level?

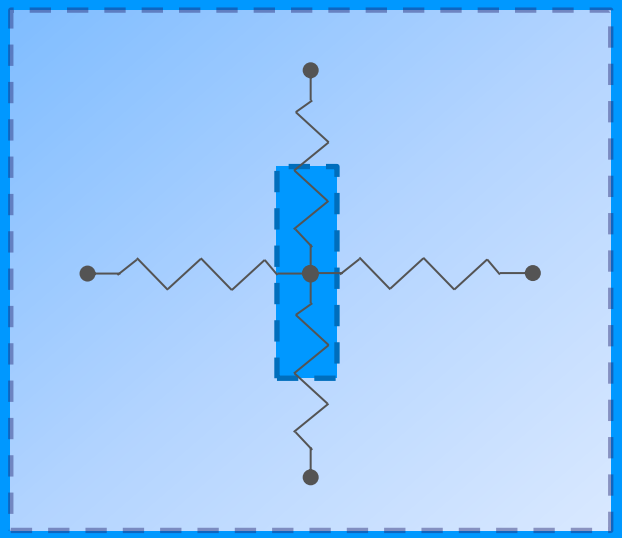
Immersion reduces the battery thermal resistance for better cooling:

Cold plate cooling



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

Full immersion cooling

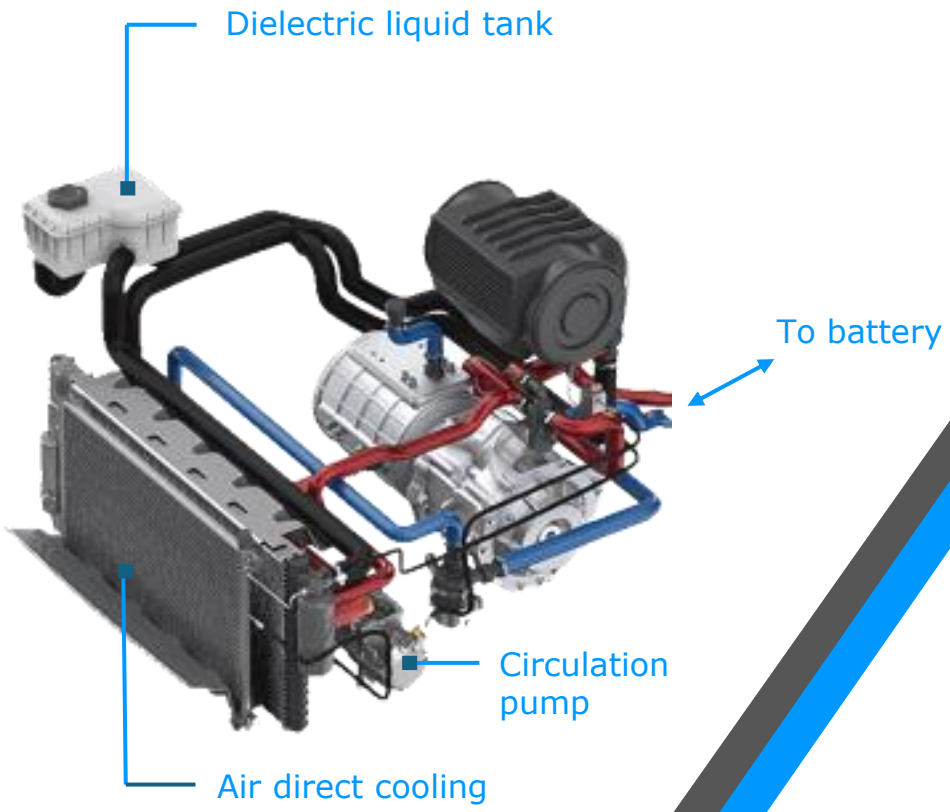


Thermal resistance typ. <0.2 K/W*
& hot spots cooling

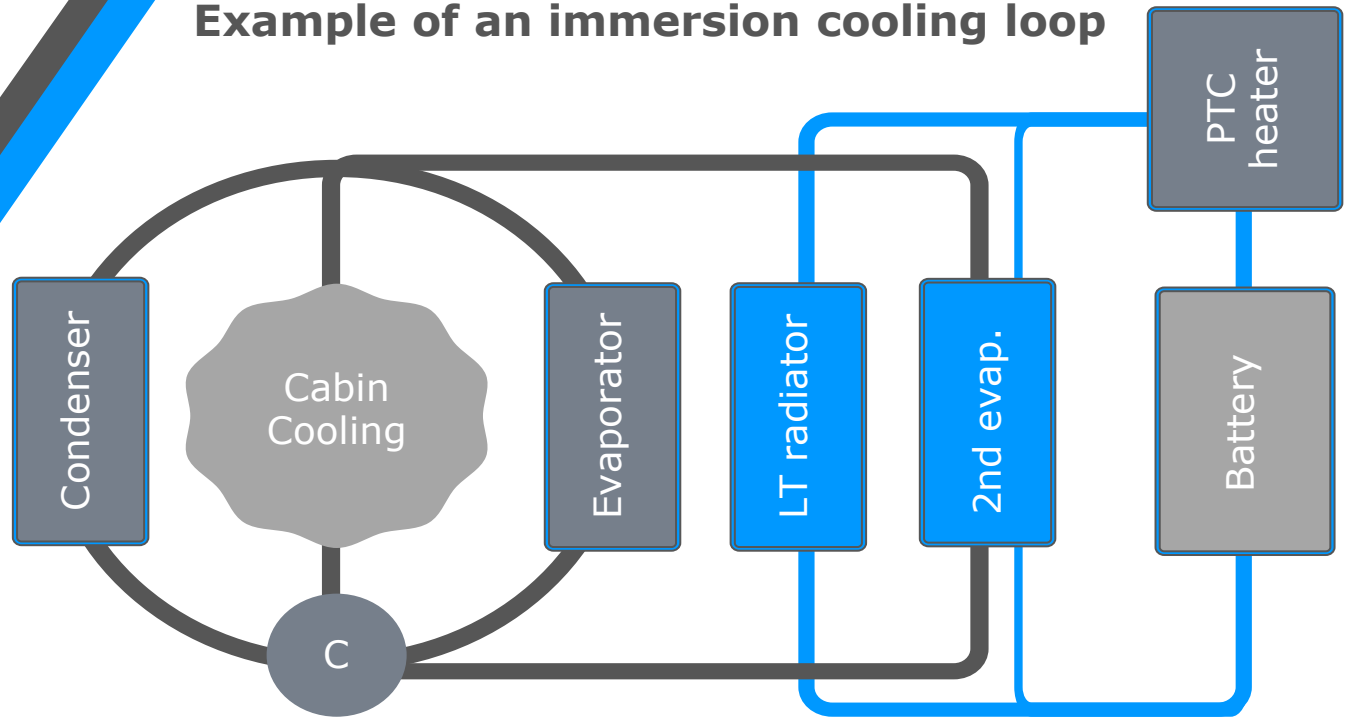
Immersion cooling is 2 to 5x better than cold plates

*: *Calculated on prismatic cell – PHEV2 format*

How does immersion cooling work at vehicle level?

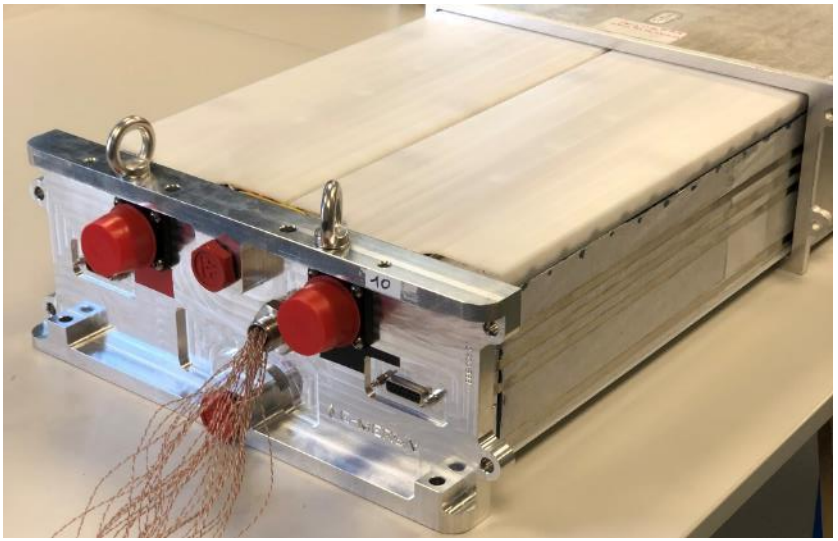


Example of an immersion cooling loop



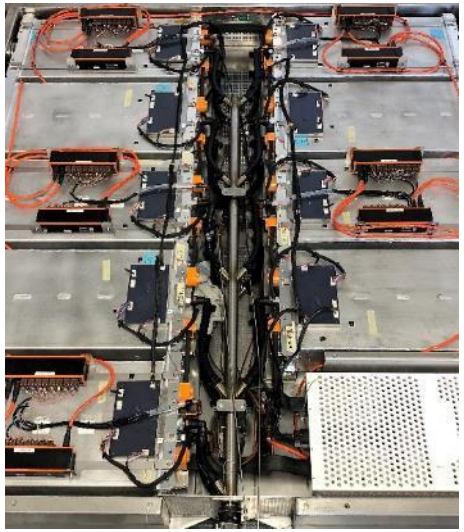
SAFETY AND PERFORMANCE TESTS

Our module made of prismatic cells



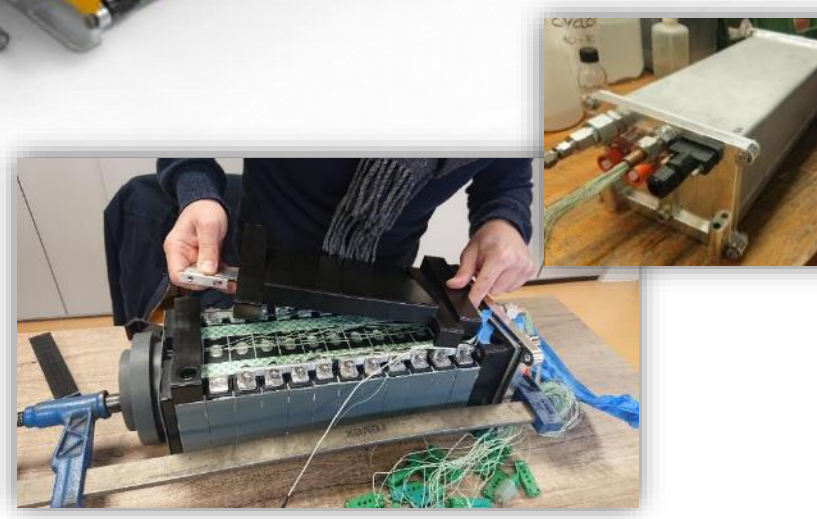
a module made of 36x NMC prismatic cells (3p12s)

A ruggedized product to supply the specialty vehicle markets



a 60kWh battery made of 9x modules

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



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

Module thermal runaway triggering methods

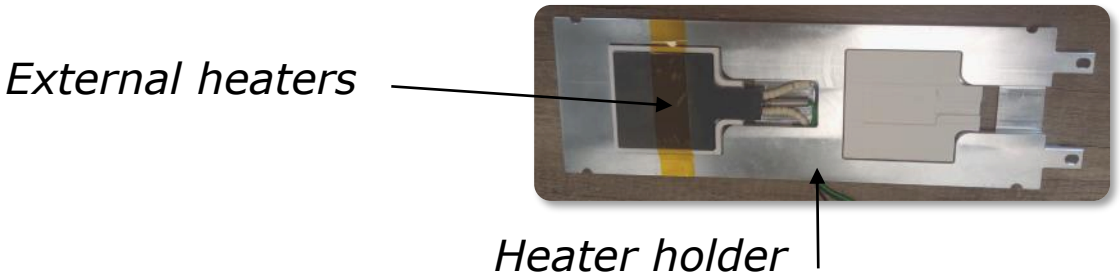
In our containerized test rig, we perform several module abuse tests:

Nail penetration / indentation

- Protocol adapted from GB38031 standard

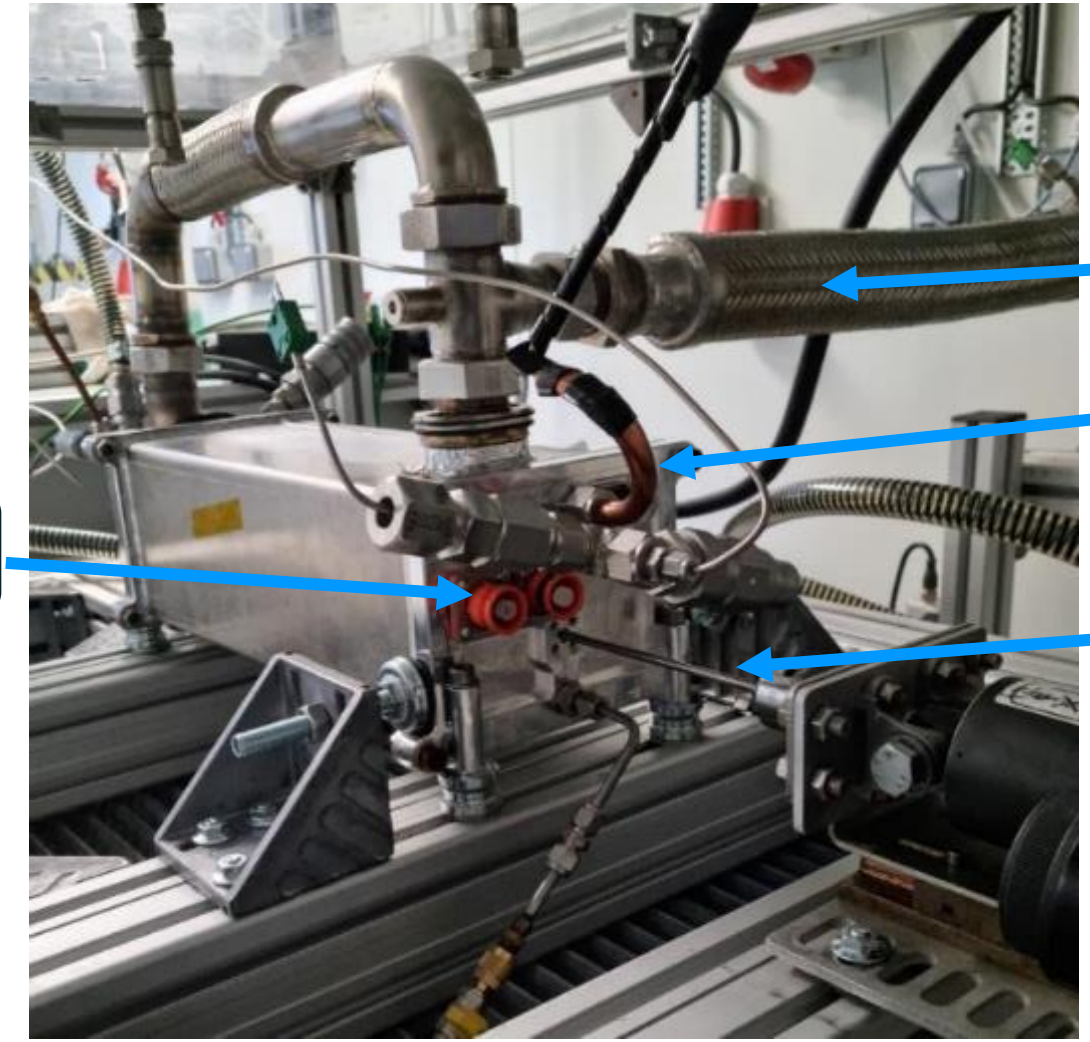
Heating pad

- Protocol adapted from ISO6469 standard
- Best repeatability



Nail penetration test on prismatic cells module

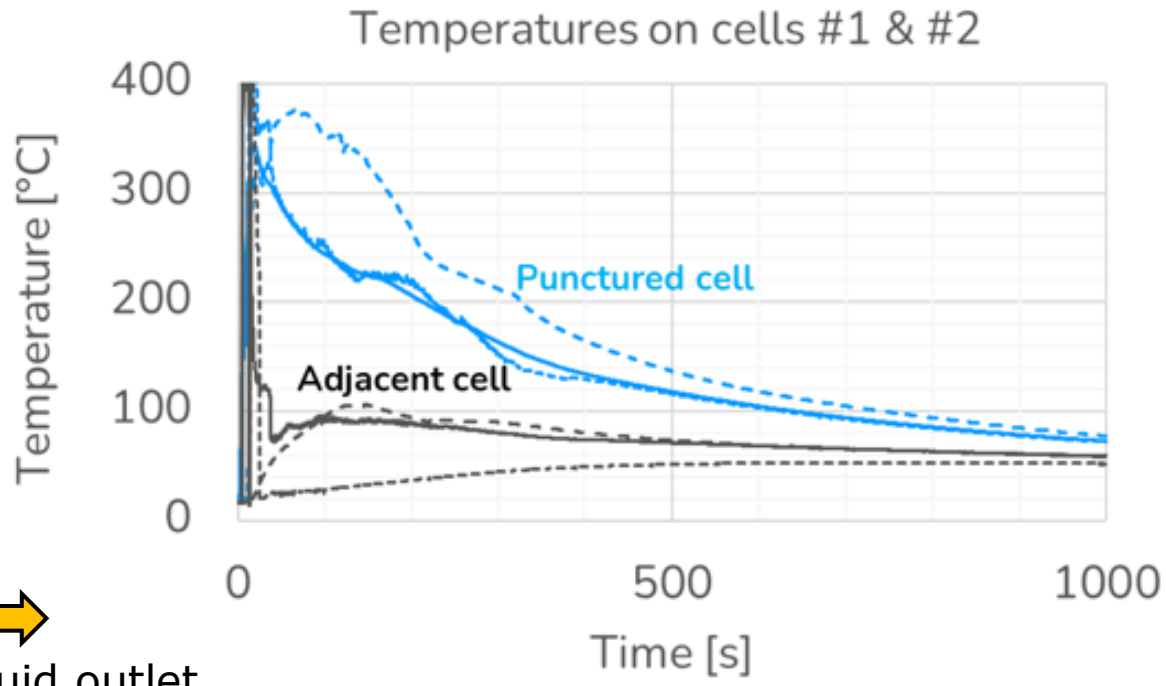
- A module made of 12x NMC prismatic cells
- Abuse test performed with **nail penetration**
- **No active cooling**

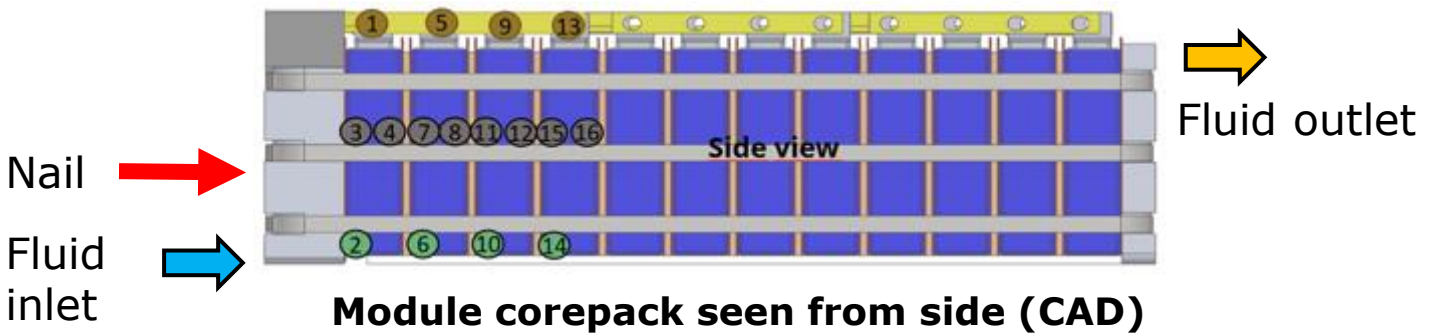


Immersion cooling prevented thermal runaway and fire propagation

- No Active flow rate by pumping action
- Flow of 0.025 L/min/cell induced by gravity
- Punctured cell temperature increased up to 350°C in 20s after the vent ruptured
- Adjacent cell temperature increased up to 105°C within 100s ➔ **no propagation**

Abuse test - temperatures





Module corepack seen from side (CAD)

The adjacent cell is intact

Cell#	Weigth [g]	Swelling [mm]
1	731	+3
2	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	

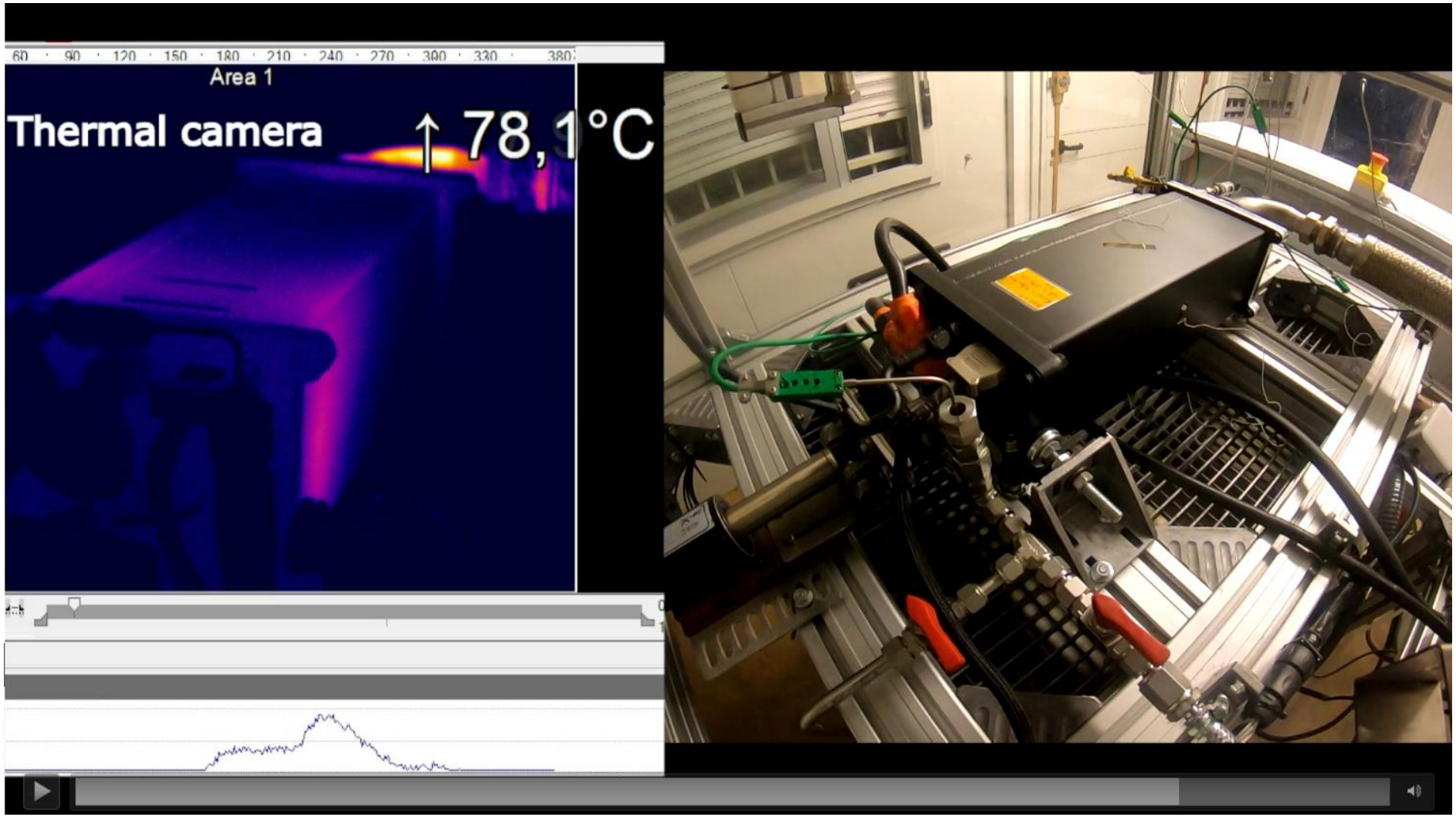
- Measurements showed 15% mass reduction for triggered cell
- No damage observed nor measured on neighbouring cells

Adjacent cell

Module corepack seen from top with visible ashes

Data courtesy of bp Castrol

VIDEO - Nail Penetration Test (NPT)

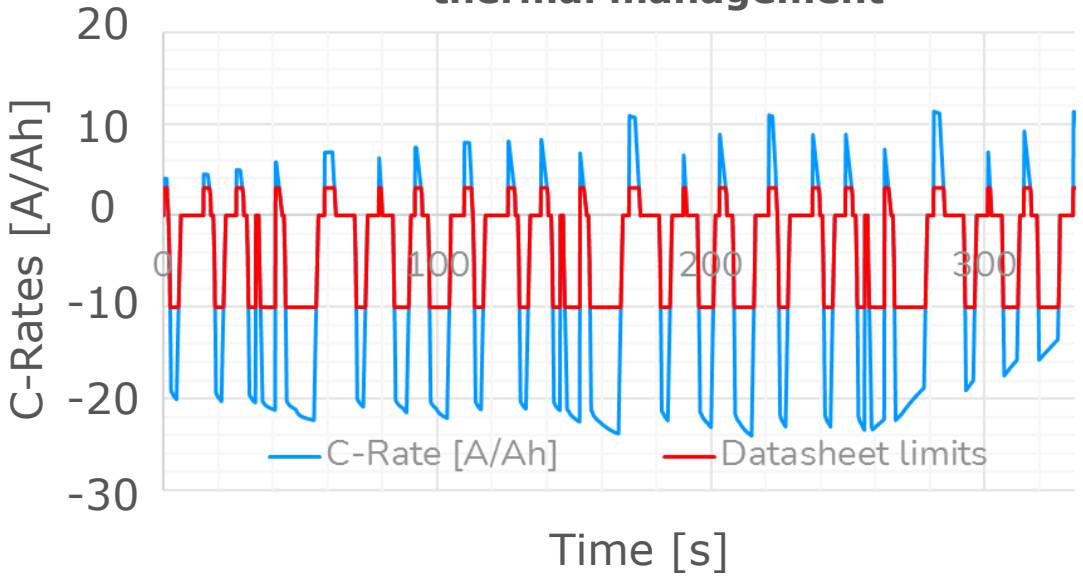


Video courtesy of bp Castrol

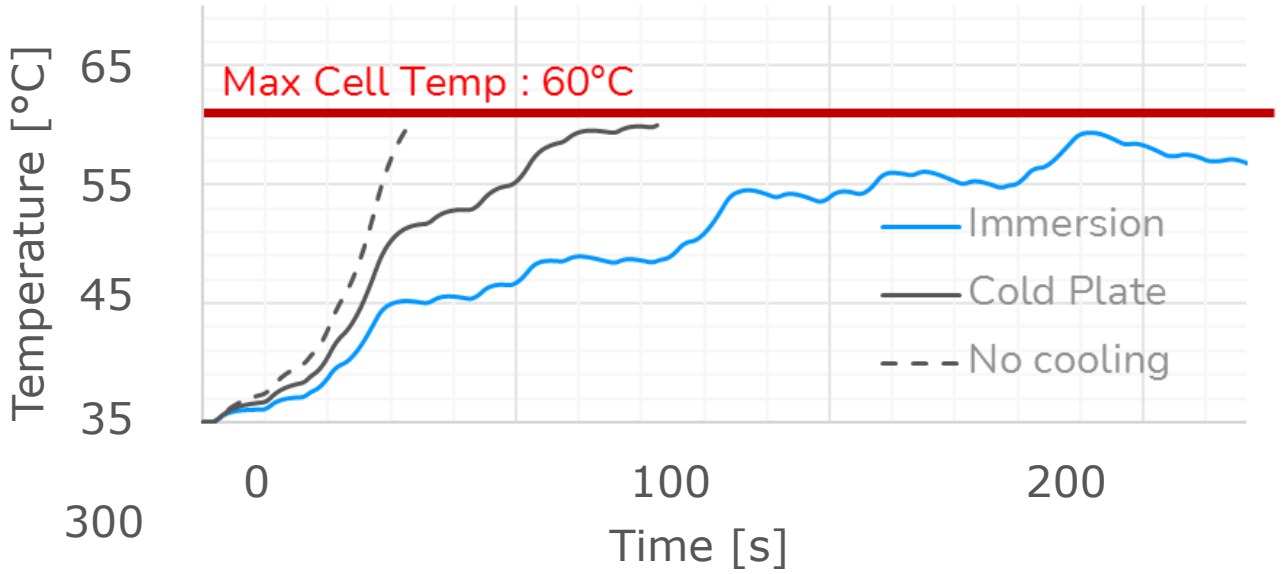
Simulation: Full immersion benchmark for racing EV

- Racetrack in France: 3× laps of 111s
- Battery 400V | 8.7kWh | 160kW peak (Murata 18650 VTC6 : 100Wh/kg / 85kg / ~2kW/kg)

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

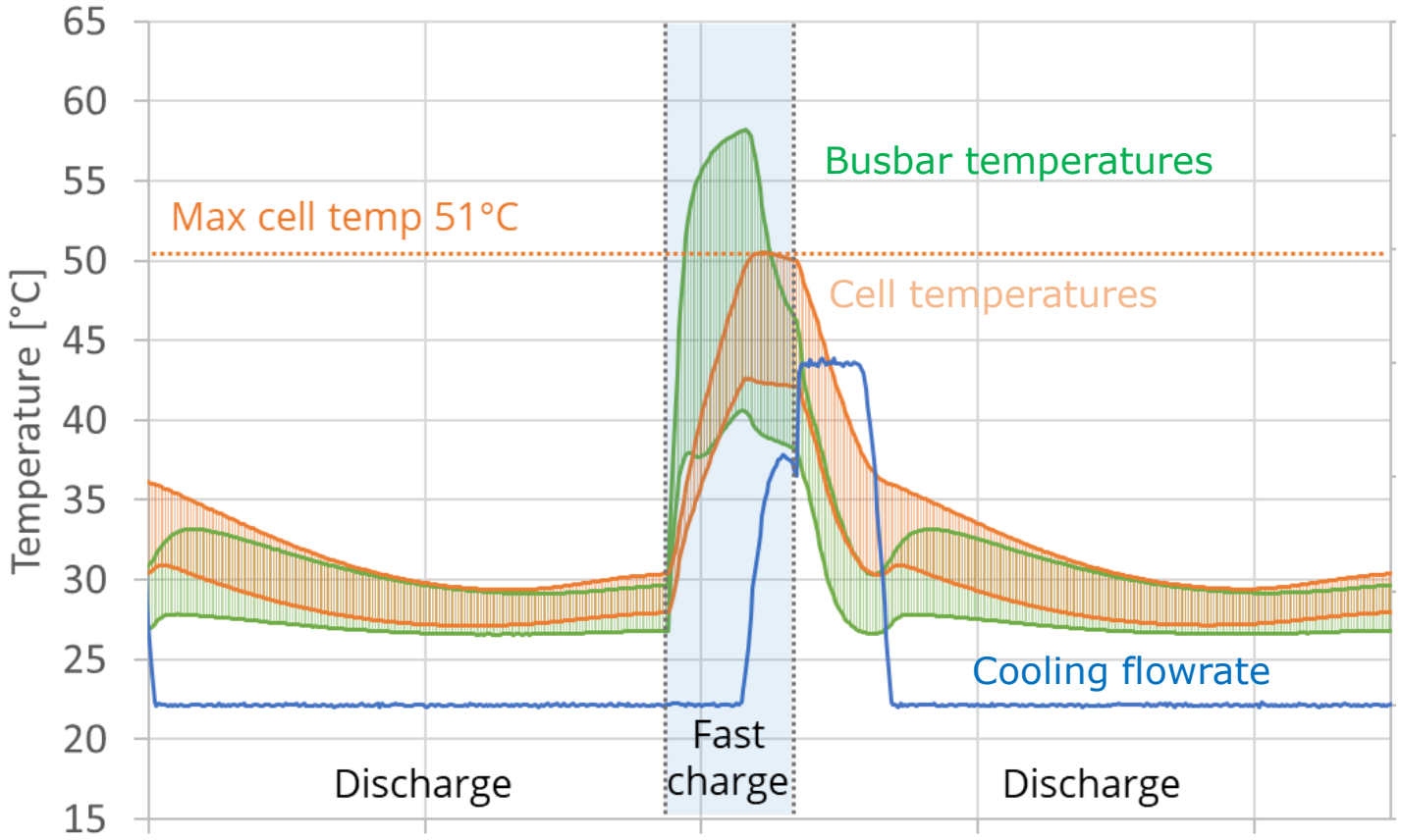
Demonstration of fast charge capability with full immersion

Test Conditions

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

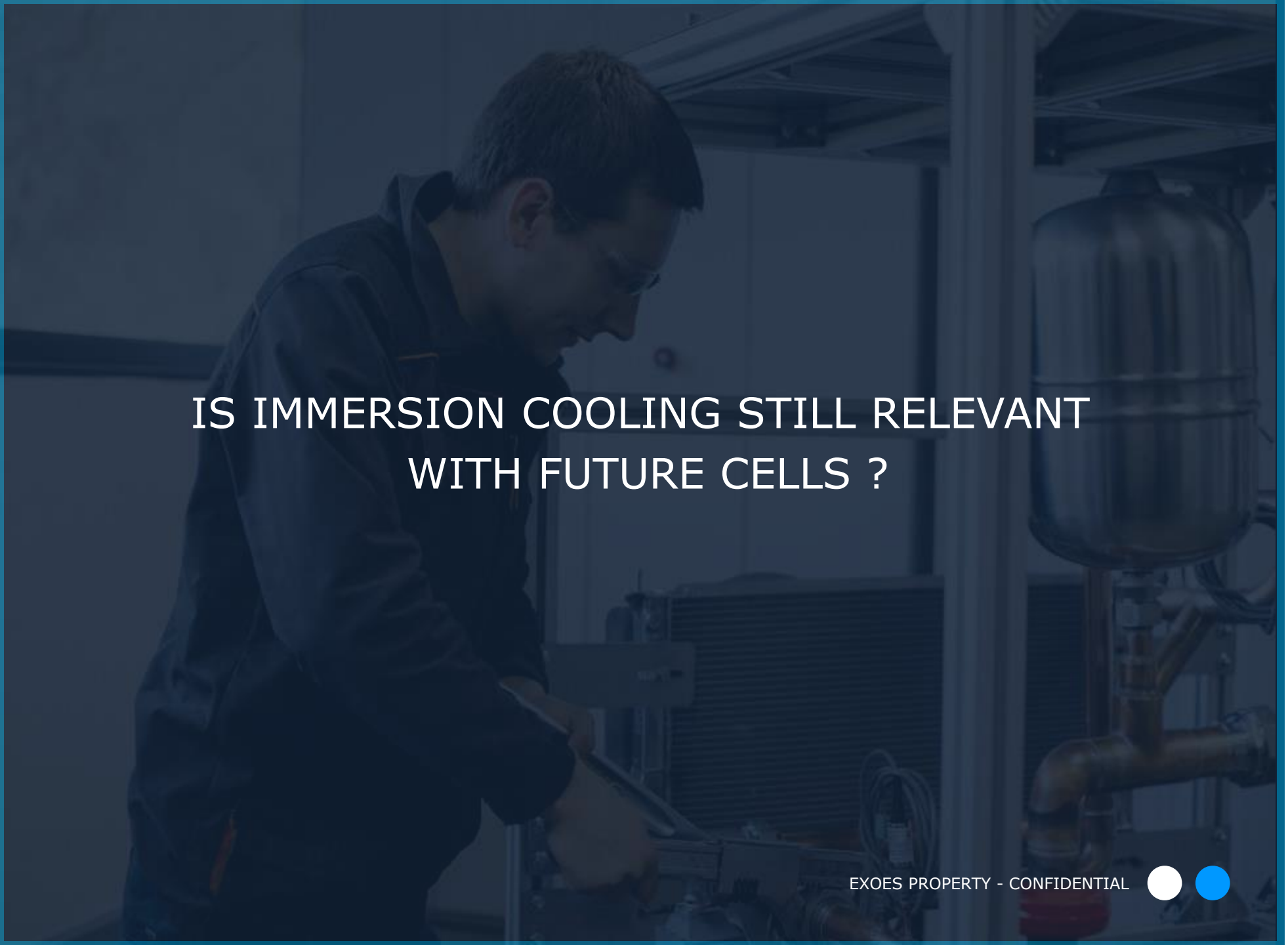
Results

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



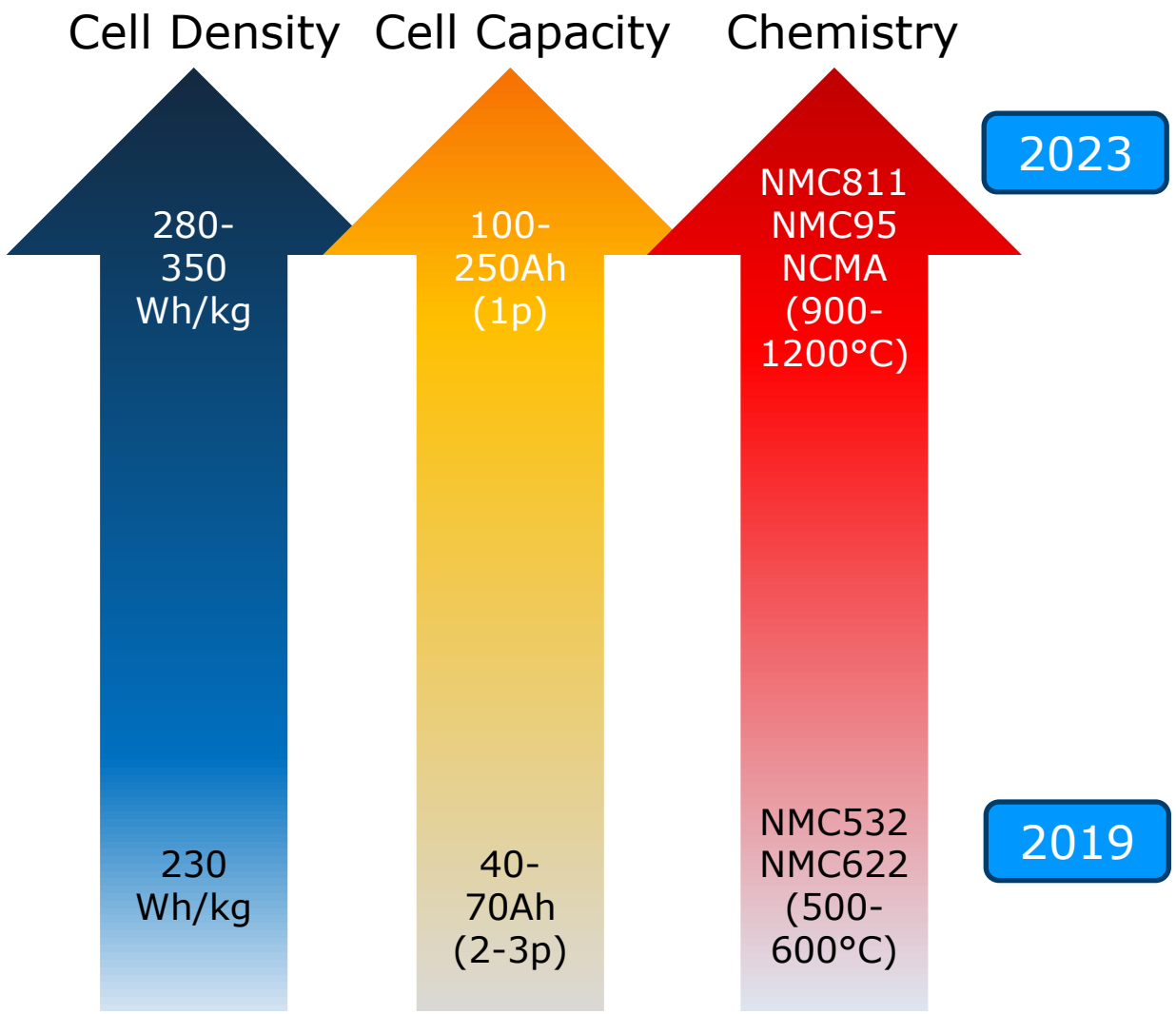
Repetition of fast charges authorized
Back to initial state in less than 30min

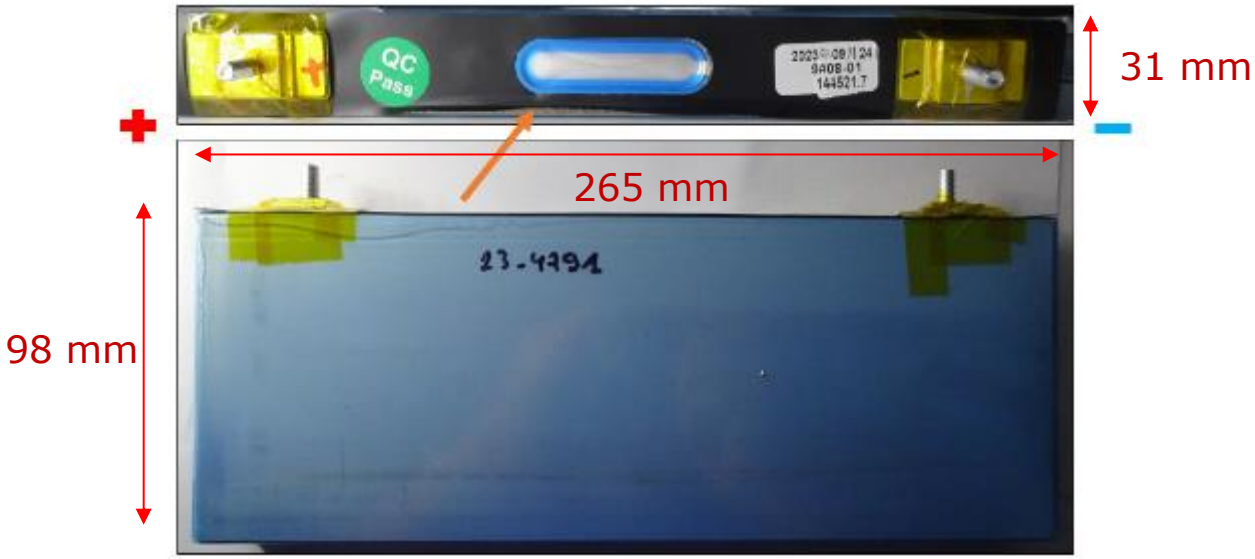
Data courtesy of Shell



IS IMMERSION COOLING STILL RELEVANT WITH FUTURE CELLS ?

CELL EVOLUTION





CATL 141Ah - NMC 92 – 1.9 kg, 270 Wh/kg

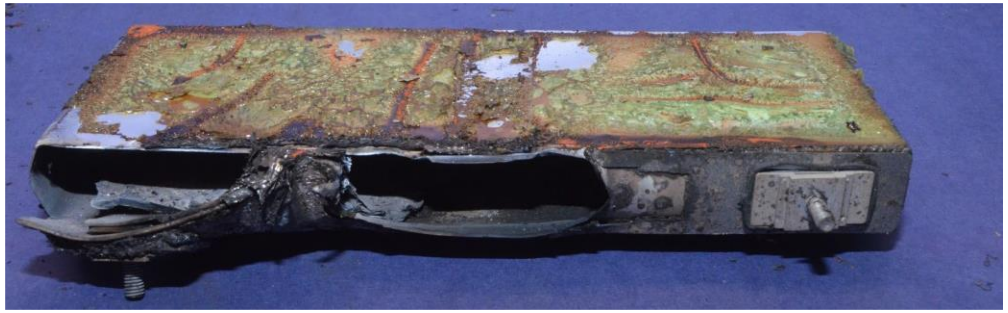
CALB 50Ah – NMC 532 – 0.86 kg, 224 Wh/kg

Evolution of NMC cells

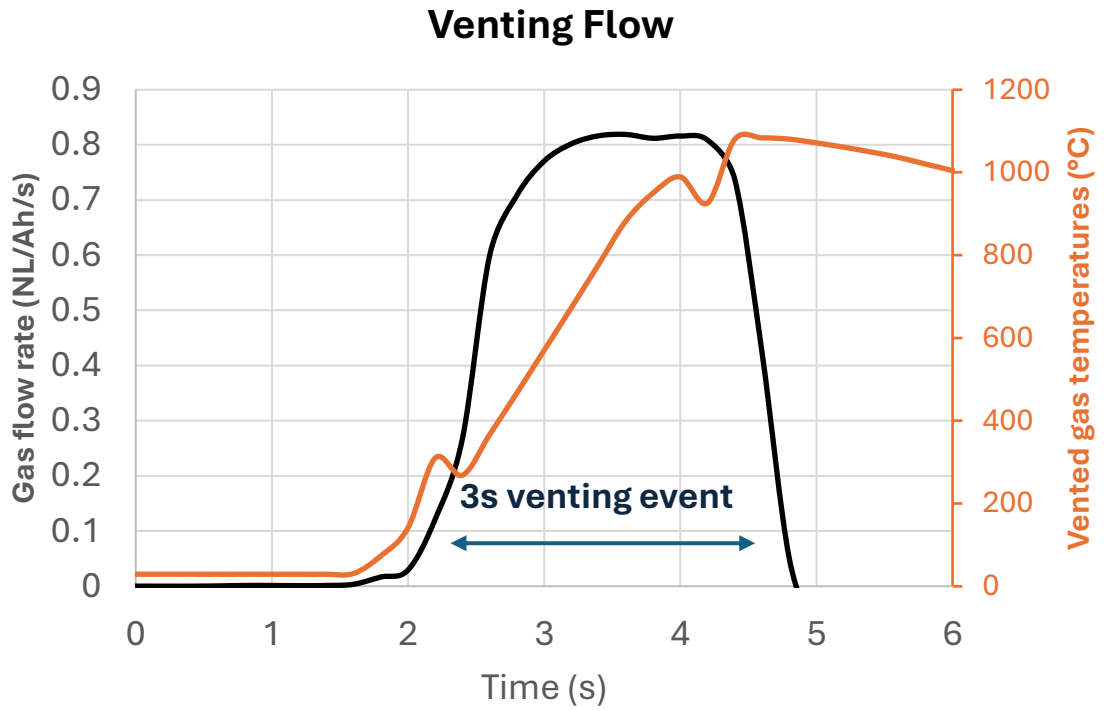
Data courtesy of Castrol bp

- NMC 92 cells have shown extremely short and violent thermal runaway event :
  - 3s-venting with 0.9 NL/s/Ah peak flow rate
  - 1000°C maximum cell temperature
- 0.5 kWh NMC 92 reach the limits of what can be tested inside existing ARC calorimeters.

NMC 92 cell before cell abuse test

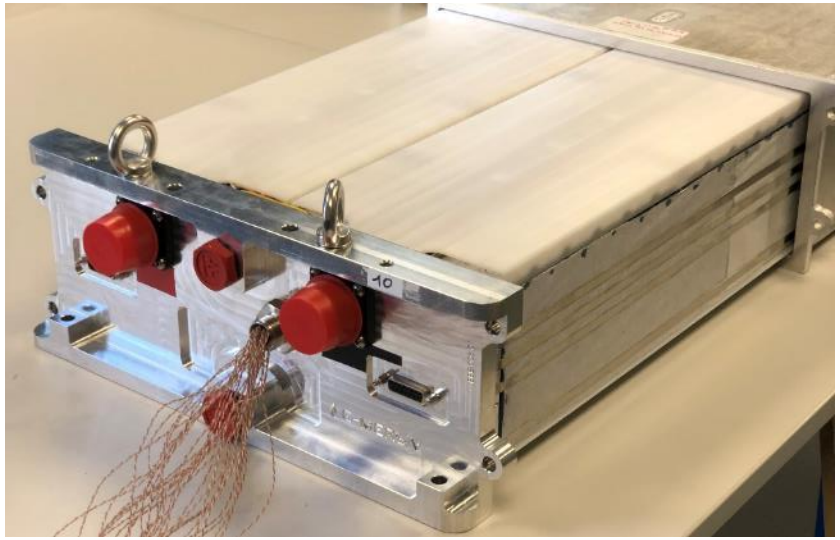


NMC 92 cell after cell abuse test



Venting curve with NMC 92 cell

Impacts of new Nickel rich chemistries



EXOES works in partnership with bp Castrol to develop immersion cooled battery modules with nickel rich chemistries NMC cells

Impacts on module design:

Higher exhaust gas rate

- Venting channel oversizing

Higher exhaust gas temperature

- Reinforced casing for confinement

Higher energy release

- Hard to reach passive non-propagation (even with immersion cooling)

Impacts of new Nickel rich chemistries

Impacts on abuse test bench:

Higher exhaust gas flow rate

- Filtration oversizing to limit the risk of explosive atmosphere
- Oversizing of vents section

Post combustion & Higher exhaust gas temperature

- Exchangers to cool down exhaust gas before filtration
- Modelling of the test bench filtration system with post-combustion to size the exchangers

Abuse test bench commissioning test

0:01

0:05

0:06

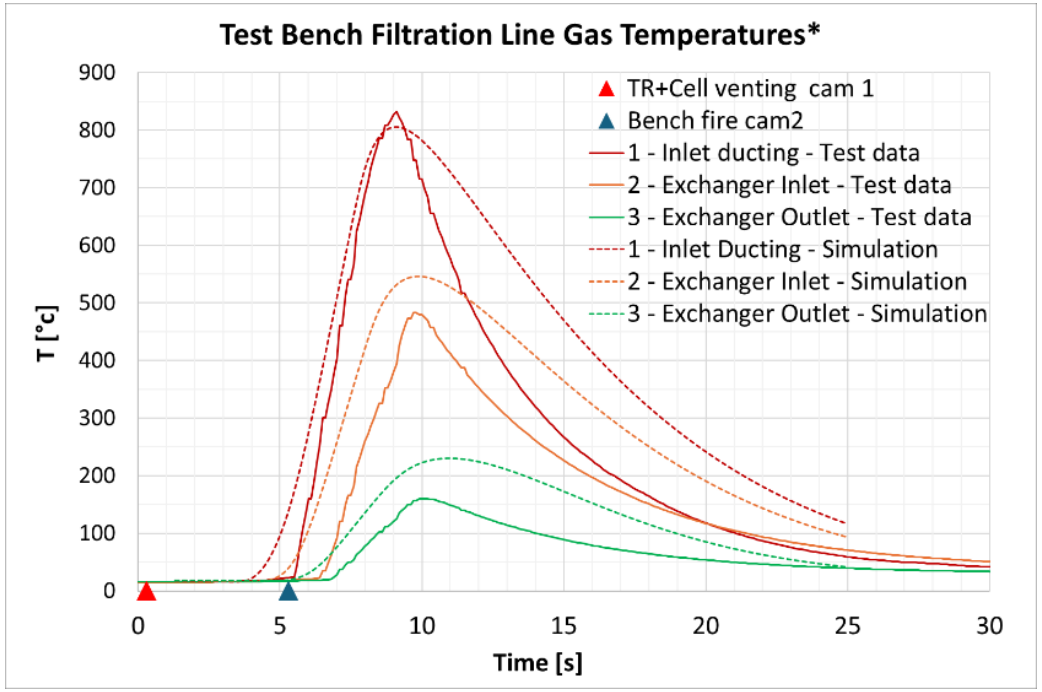
0:07

0:11

- Bench commissioning test with a test module :
  1x NMC 811 cell inside an oil bath
- The test results have been used to calibrate a 1D model of the bench filtration unit, including oil and gas combustion.
- The filtration unit is being adapted to push back the limits :

Bench sizing case :
- abuse test with 10kWh NMC811 module
- full propagation and post-combustion of vented gas

Test/Simulation comparison



*Measured values with sensor inertia

What about LFP cells?

Thermal stability

- LFP **more stable** than NMC
- Onset temperature : 180°C > 130-140°C

Heat Release

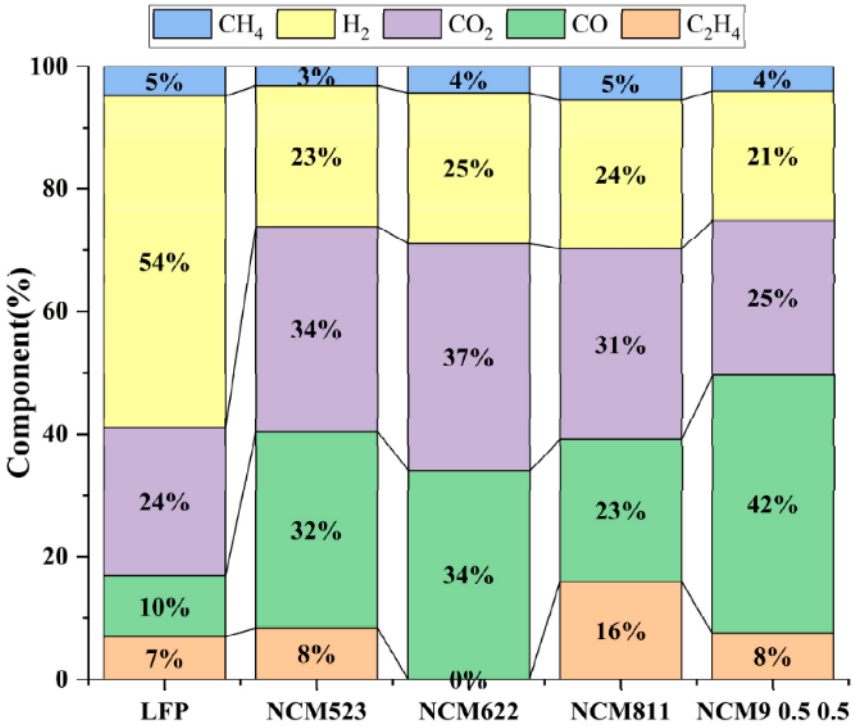
- **Lower heat release** (without fire)

Gas flow rate

- **Smaller normalized gas production** :
  0.569 NL/Ah (LFP) < 1.8-2.8 NL/Ah (NMC)

Gas combustion

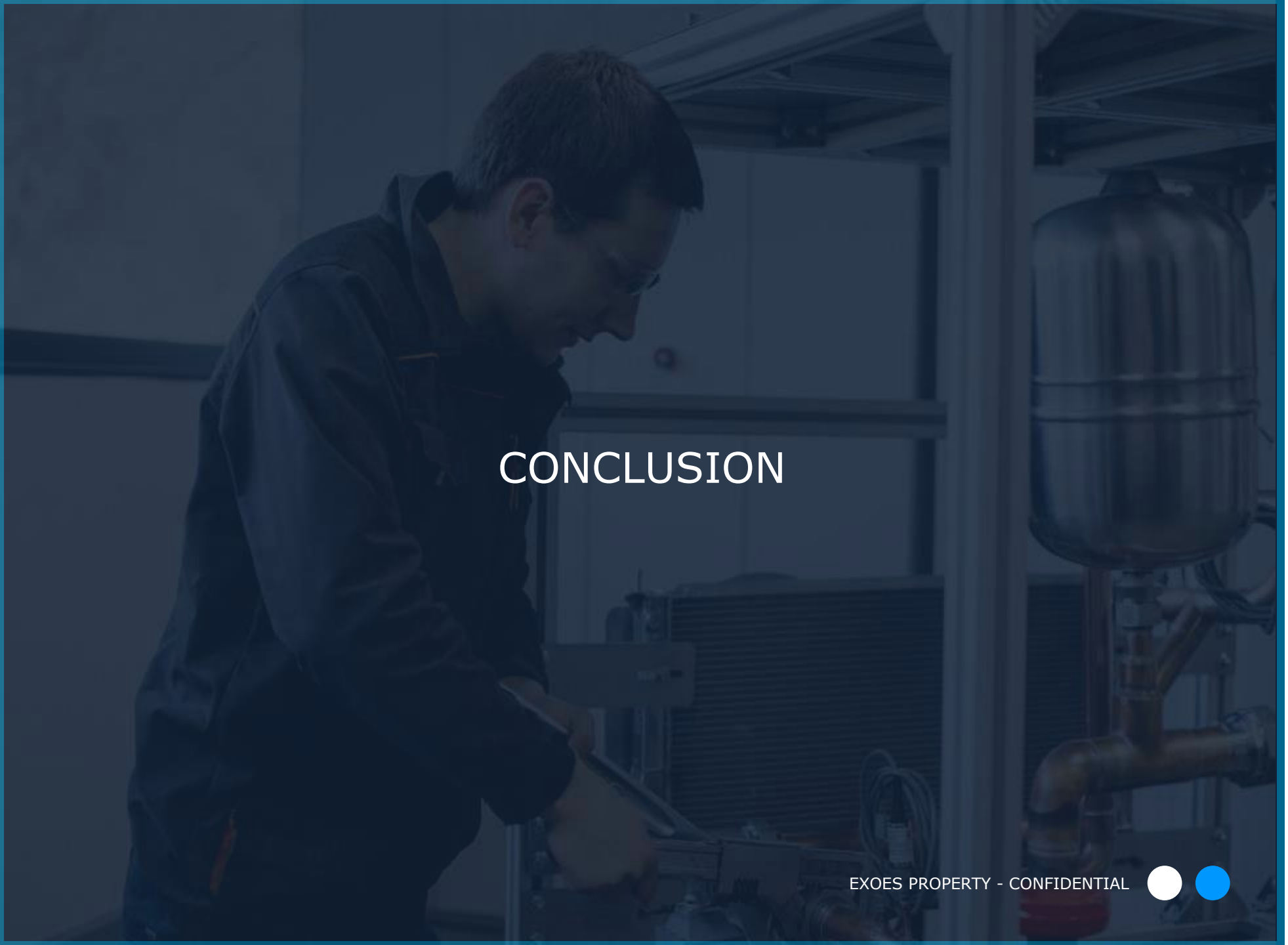
- **Higher proportion** of H_2 in vented gas
- **Higher explosion** risk (lower LFL)
- **Same heat release** as NMC when considering vented gas post-combustion



Comparison of main gas content in different batteries after TR,

*Shen, H.; Wang, H. et al, Thermal Runaway Characteristics and Gas Composition Analysis of Lithium-Ion Batteries with Different LFP and NCM Cathode Materials under Inert Atmosphere. Electronics **2023**, 12, 1603.*

EXOES is currently prototyping and testing immersion cooled LFP modules to demonstrate the advantages of immersion.



CONCLUSION

IS IMMERSION STILL RELEVANT WITH FUTURE CELLS?

NMC Chemistry

- New Nickel rich chemistries and larger cells are challenging, even for immersion cooling.
- Ensuring no Thermal Runaway propagation without any active flow rate is difficult.

It has required design adaptations on both modules and abuse test benches.

LFP Chemistry

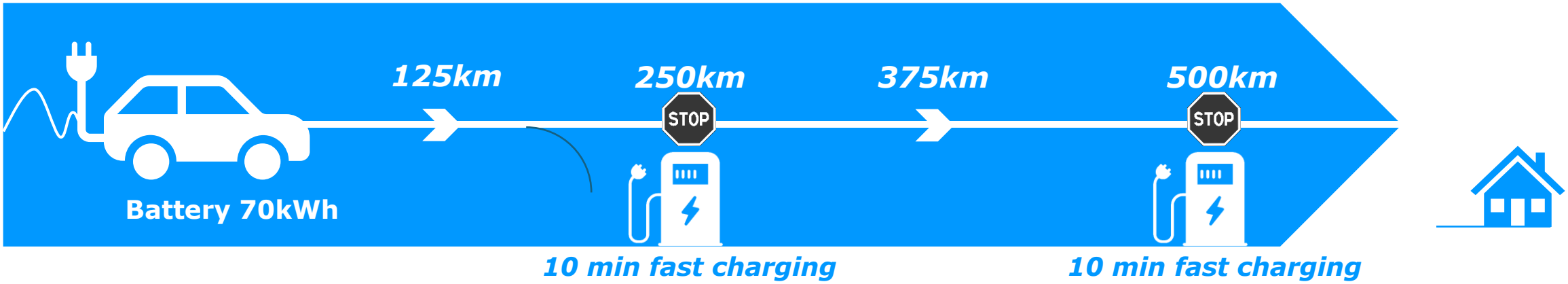
- LFP cells are generally considered safer and more stable.
- However, the energy release is as high as NMC in case of gas post-combustion.

EXOES is currently prototyping and testing immersion cooled LFP modules to demonstrate the advantages of immersion.

Conclusion

Immersion cooling is a promising technology to enable fast charging, safer batteries and democratize electric mobility

Electric cars can become the 1st and only car of a family and not limited to the 2nd



EXOES

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