The end of range anxiety thanks to fast charging and immersion cooling in BEVs

Antoine Dubreuil (Simulation Department Leader / Project Leadership)
Rémi DACCORD (CTO and Co-Founder)

Frankfurt – July 14th ,2022

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

A unique expert in immersion cooled batteries

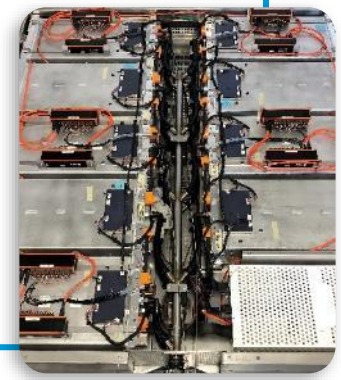
- An expert in **advanced thermal systems**
- Worldwide customer database (35% in France)
- Awarded by **11 customers**: **OEMs, fluid makers and cell makers** for advanced engineering on batteries and heat pumps

- Engineering on:
  - Component simulation & design
  - Prototyping
  - Tests & model calibration

E-MERSIV
Submerged battery packs

- Sells & manufactures immersion-cooled battery packs

- Markets:
  - Racing
  - Premium cars
  - Mass market (licensing)



TRL3 TRL4 TRL5 TRL6 TRL7 TRL8 TRL9 Industrialization

How To Increase EV Customer Adoption Rate?

Mass Market

> 300 km	< 10 min	> 8 years	30 min
Highway range	Charging time	Lifetime	To reach a fast charger on the highway

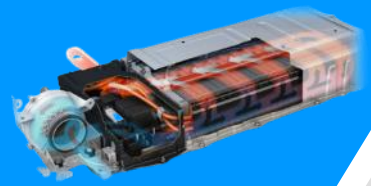
Narrowing the user experience gap between fossil fuel vehicles and BEVs is key

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

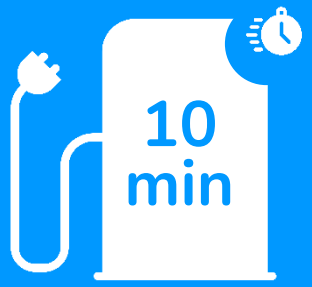
Immersion cooling technology

- Direct cooling of cells & busbars
- No fire propagation
- Ultra fast charging enabled for BEVs
- High C-Rates for HEVs
- Already in use on motorsport and high-performance supercars

RIMAC AUTOMOBILI

McLaren

Koenigsegg



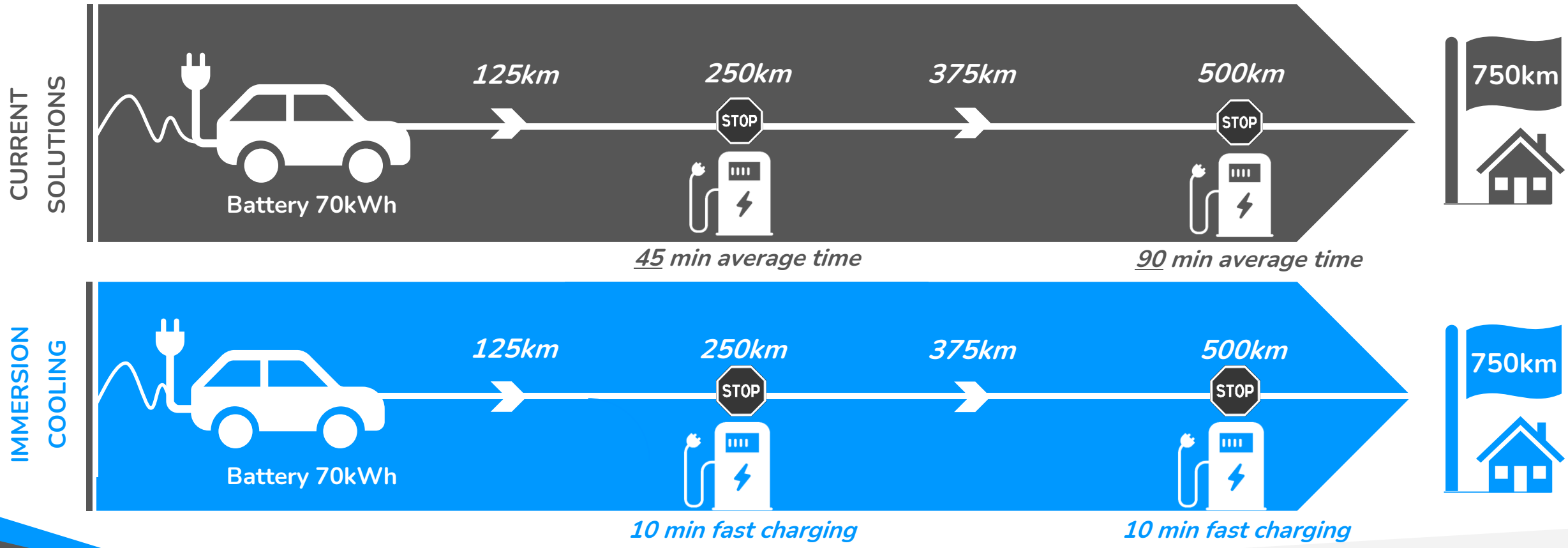
Charging Time

Power to Energy ratio

Safety

SAFER
For end customer

No more range anxiety on highways with immersion

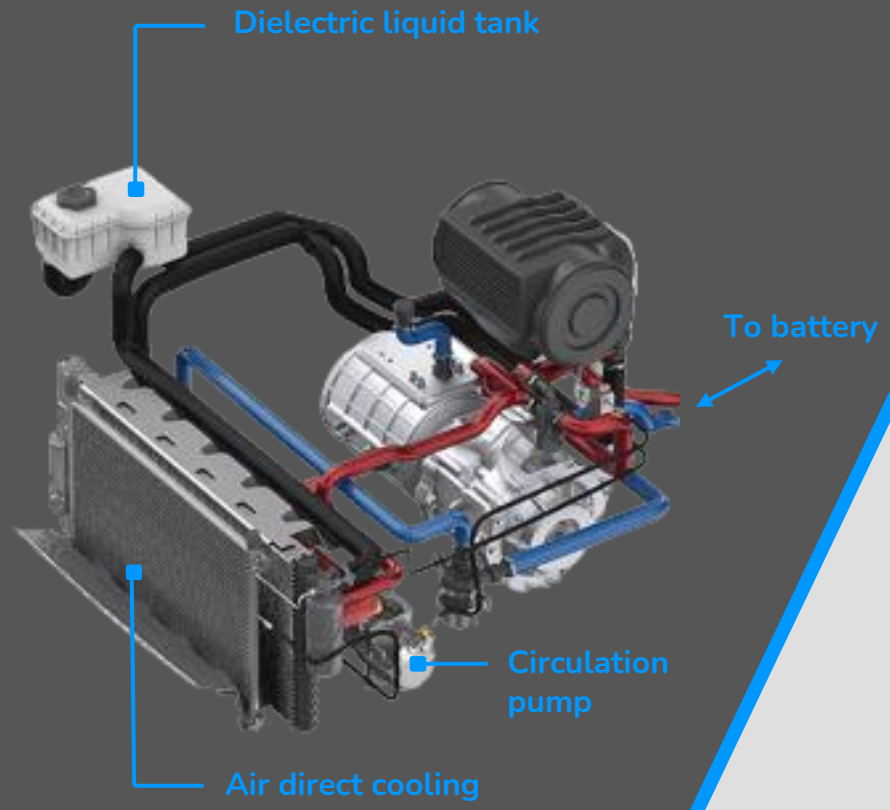


10 minutes break every 2 hours of driving

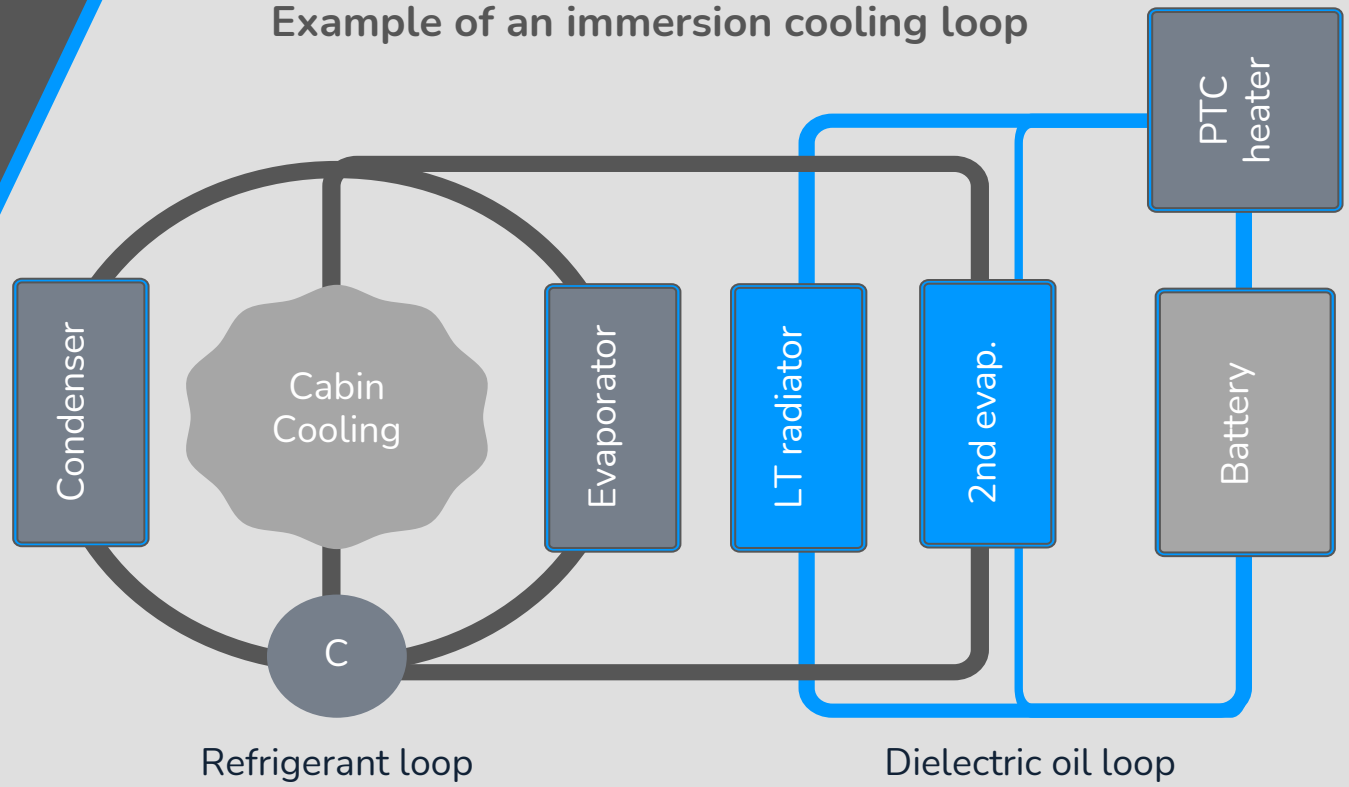
How does the technology work ?

How Does Immersion Cooling Work?

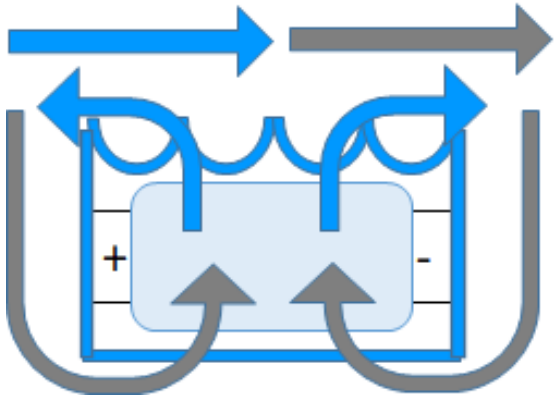
At vehicle level

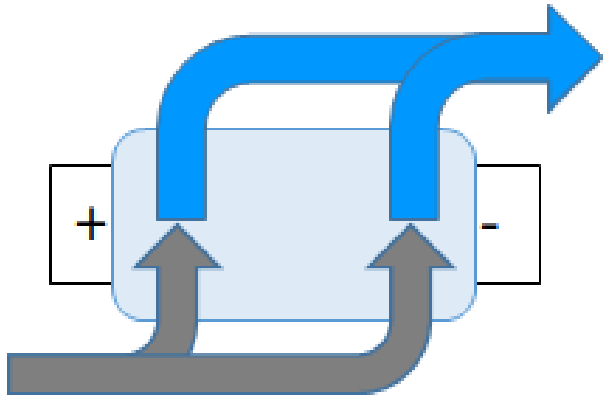


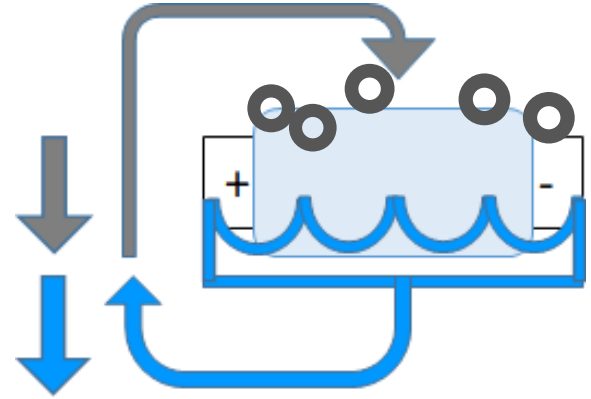
Example of an immersion cooling loop



How Does Immersion Cooling Work?







Static bath | **Full immersion** | **Spray / Jet cooling**

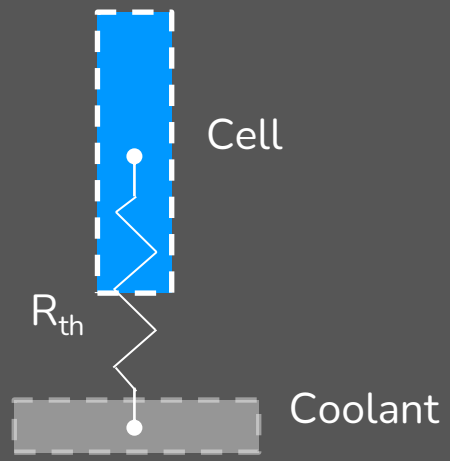
Technology selection based on:

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

How Does Immersion Cooling Work?

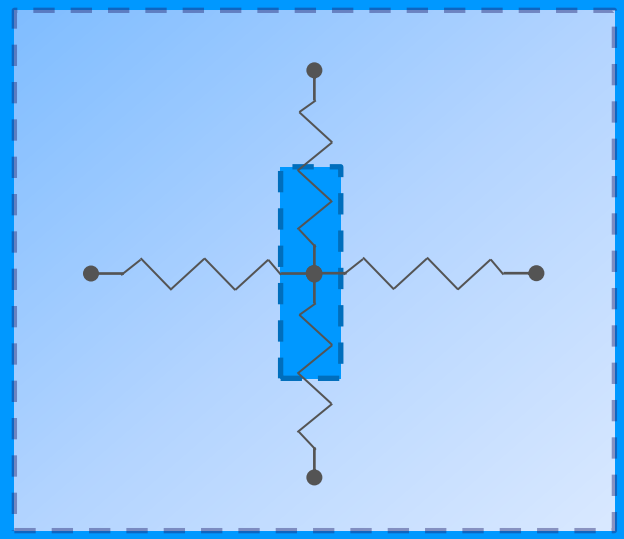
Immersion reduces the battery thermal resistance for better cooling:

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

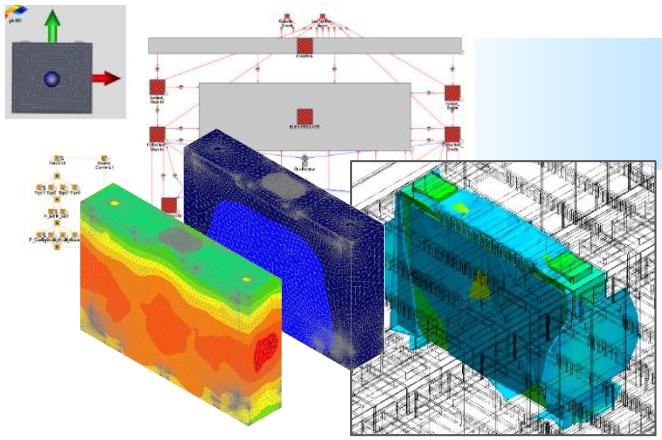
Immersion cooling is 2 to 5x better than cold plates

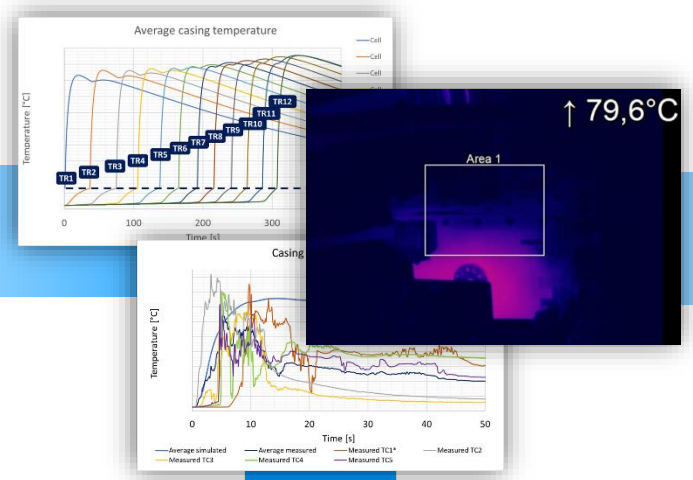
*: *Calculated on prismatic cell – PHEV2 format*

Our experience developing robust immersion-cooled modules and battery packs

We correlate all our models for increased fidelity and maturity from early concept stages

Modelling Capabilities





Testing Capabilities

GT Gamma Technologies

MATLAB SIMULINK

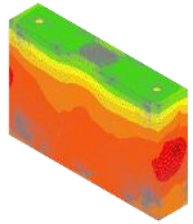
SOLIDWORKS

SOLIDWORKS FLOW SIMULATION

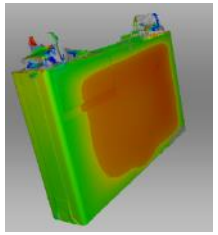
Proprietary correlated Model Based Development combined with comprehensive testing capabilities to support accelerated xEV Thermal Management Systems development from **Advanced Engineering to SOP**

Development process

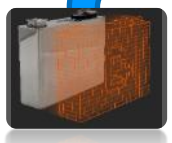
1 Thermohydraulic assessment (0D, 1D, 3D CFD)



2 Swelling and internal stress (FEA)

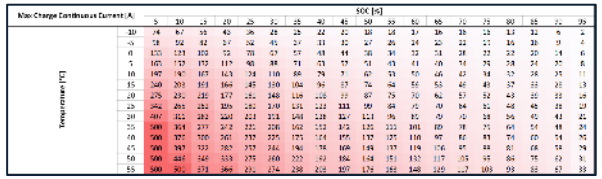


3 Dedicated module design



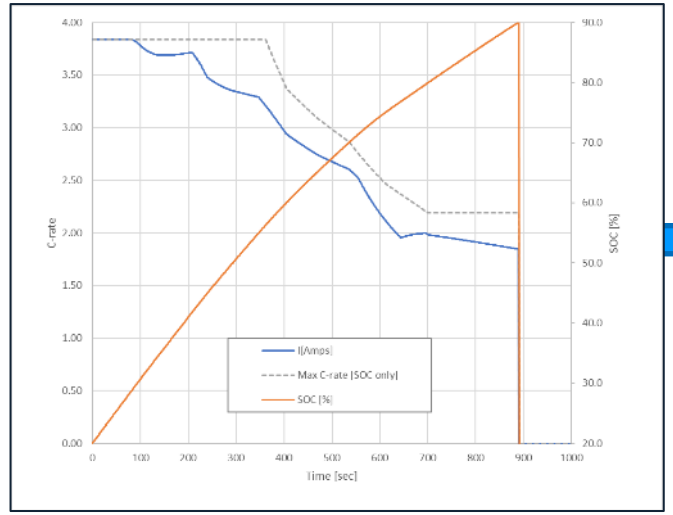
4 Physical model of anode potential

5

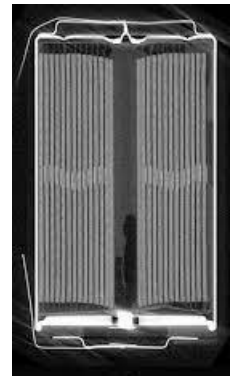


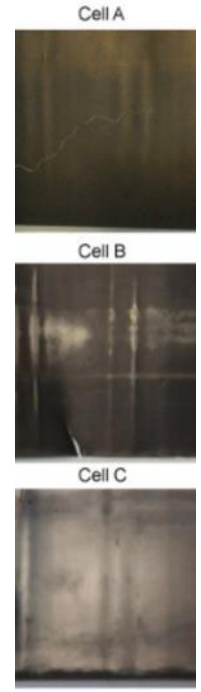
BMS integration

6 Actual tests
Performance / Aging / Abuse / Vibration

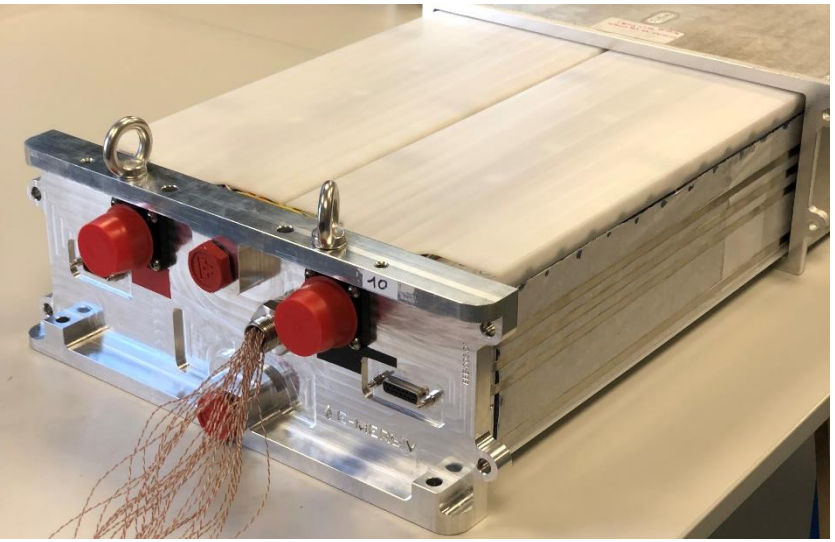


7 Validation w/ Swelling/Plating analysis after X fast-charging cycles

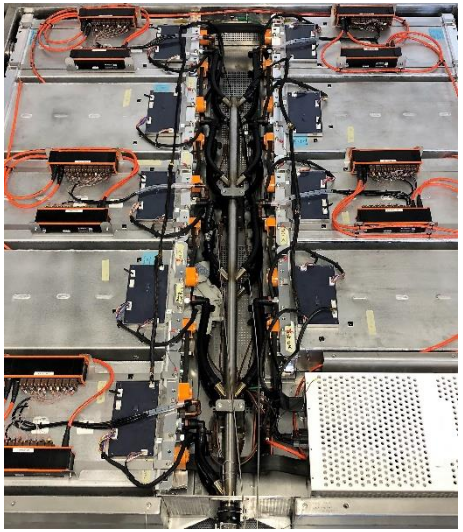




Our last battery pack design

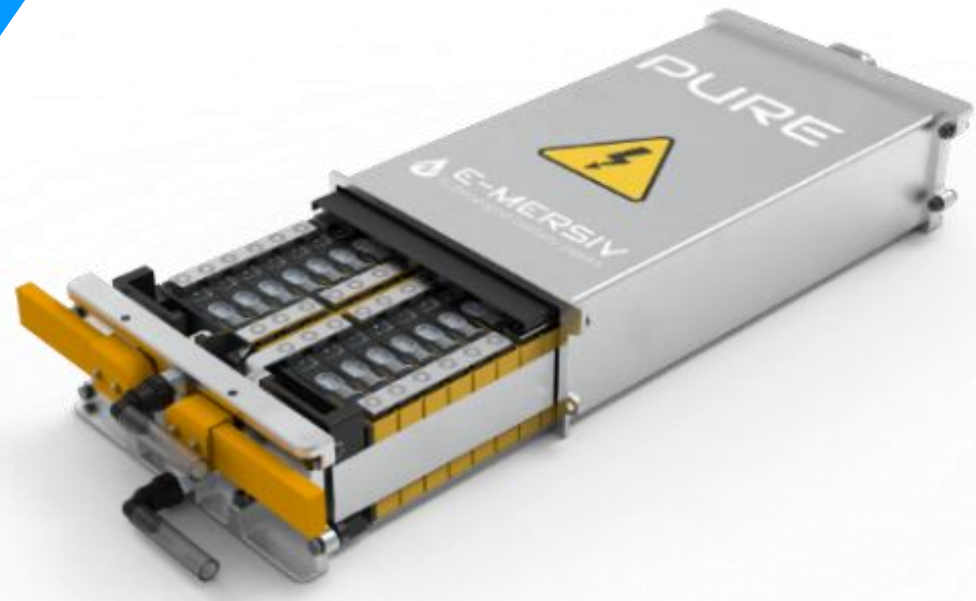


a module made of 36x NMC prismatic cells (3p12s)



a 60kWh battery made of 9x modules

A ruggedized product
to supply the specialty vehicle markets

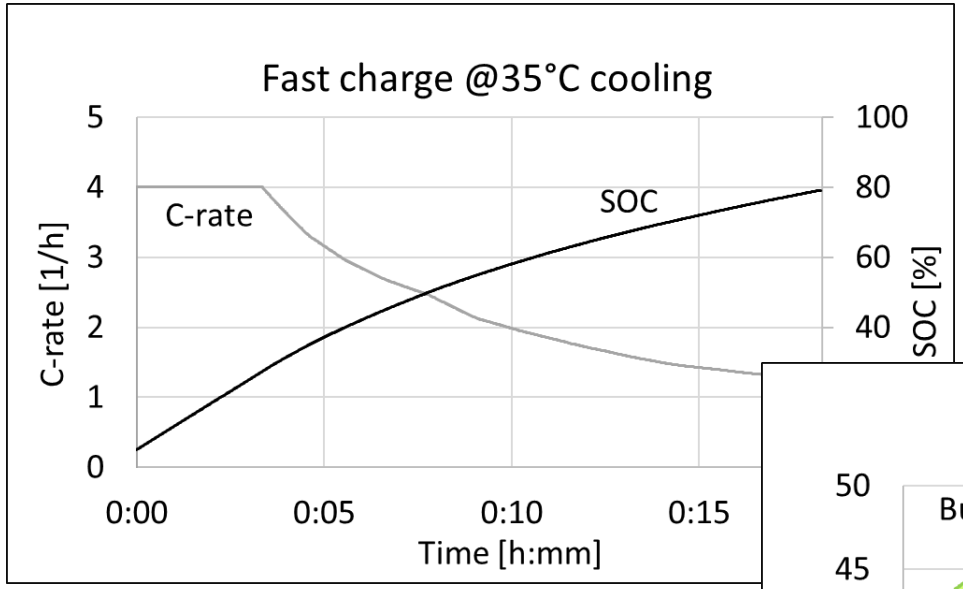


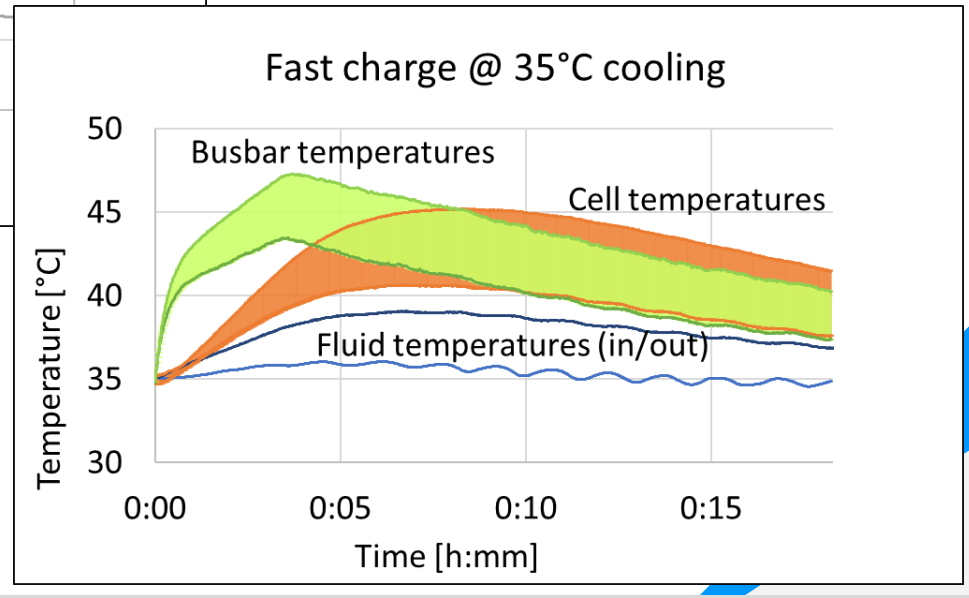
Feasibility of fast charges

Data courtesy of MOTUL

Test Conditions

- Charge 5 to 80%
- Initial temperature 35°C
- Cooling at 0.3L/min/cell
- Cooling at 35°C





Results

- Max cell temp. <45°C *(max cell limit is 55°C)*
- Max ΔT on cells <5K
- Average C-rate = 2.5C
- Peak C-rate = 4C

»» 4C peak charge accessible:
»» From 5 to 80%SOC in 18min30sec (Average 2.5C)

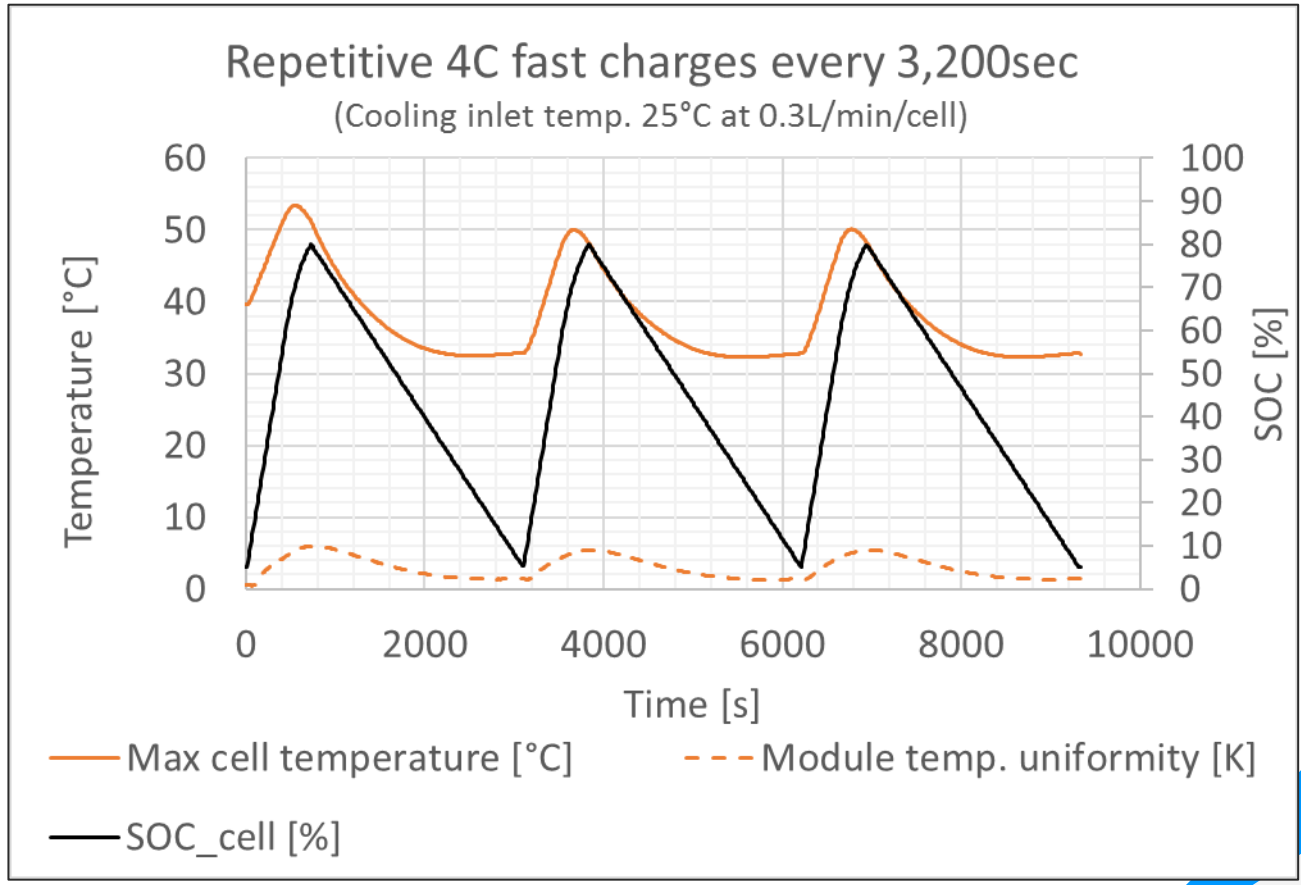
Repeatibility of fast charges

Test Conditions

- 4C charge from 5 to 80%
- Followed by 1C discharge
- Cooling at 0.3L/min/cell
- Cooling at 25°C

Results

- Max cell temp. <55°C *(max cell limit is 55°C)*
- Max ΔT on cells <6K
- No derating !



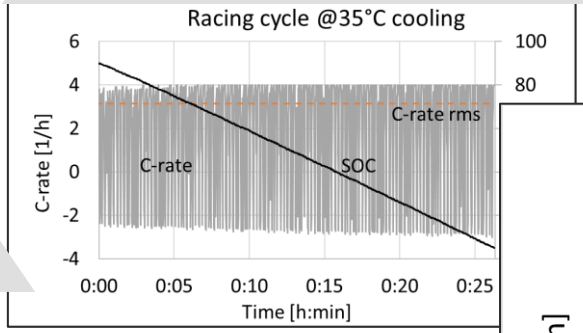
Data courtesy of bp

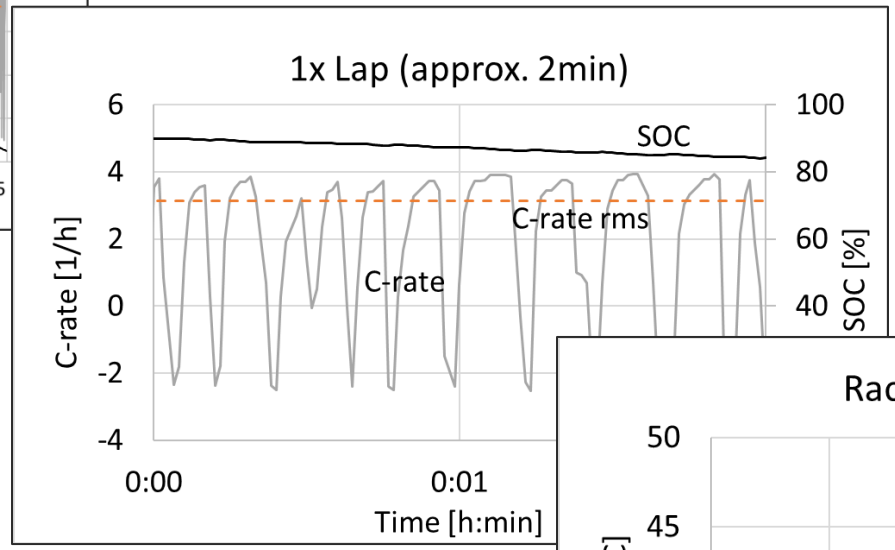
»» Repetition of 4C charges accessible
»» Back to initial state in less than 30min

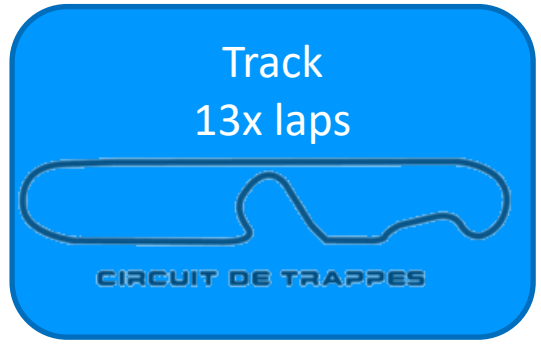
Feasibility of racing cycle

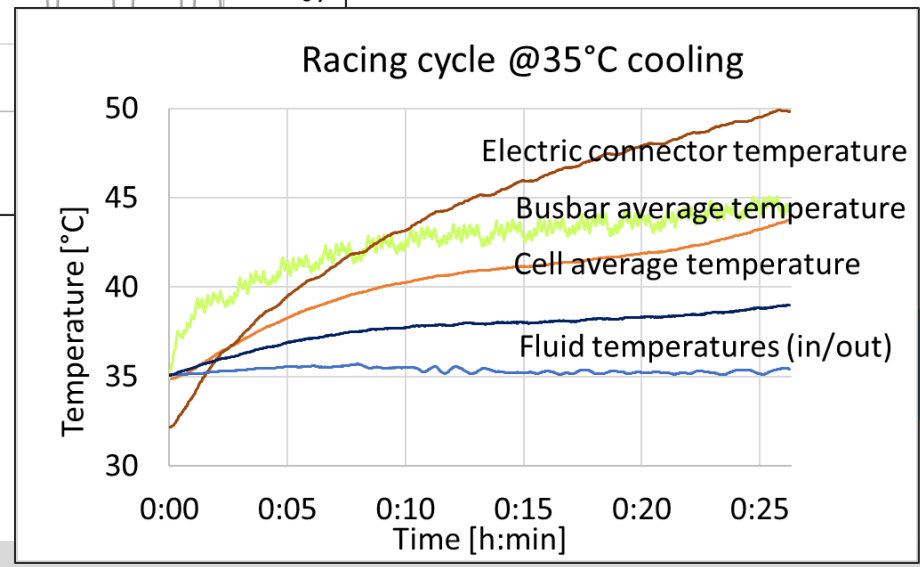
Test Conditions

- Racing cycle from 90% to 5%SOC
- Vehicle 950kg / 240kW / 60kWh
- Initial temperature 35°C
- Cooling at 0.3L/min/cell
- Cooling at 35°C









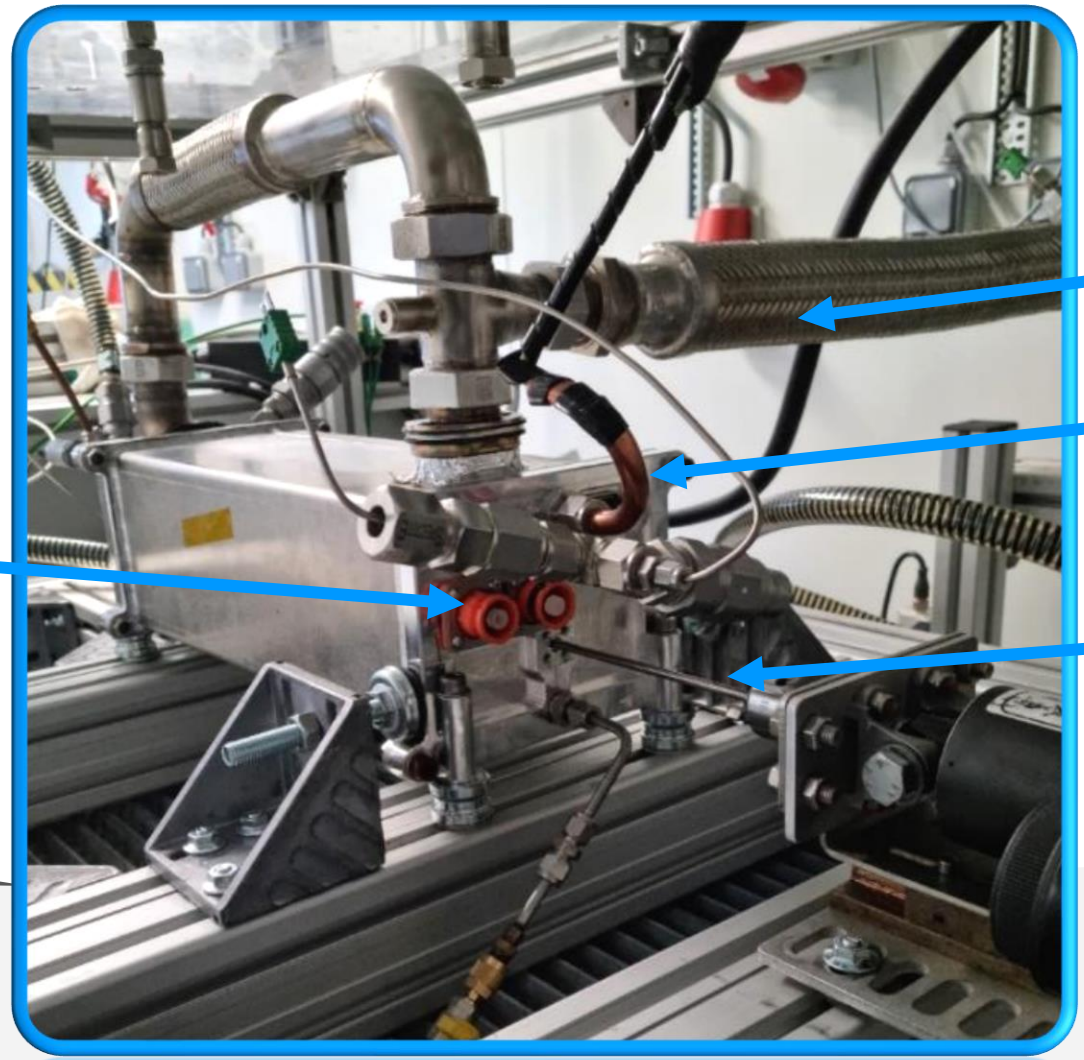
Data courtesy of MOTUL

Results

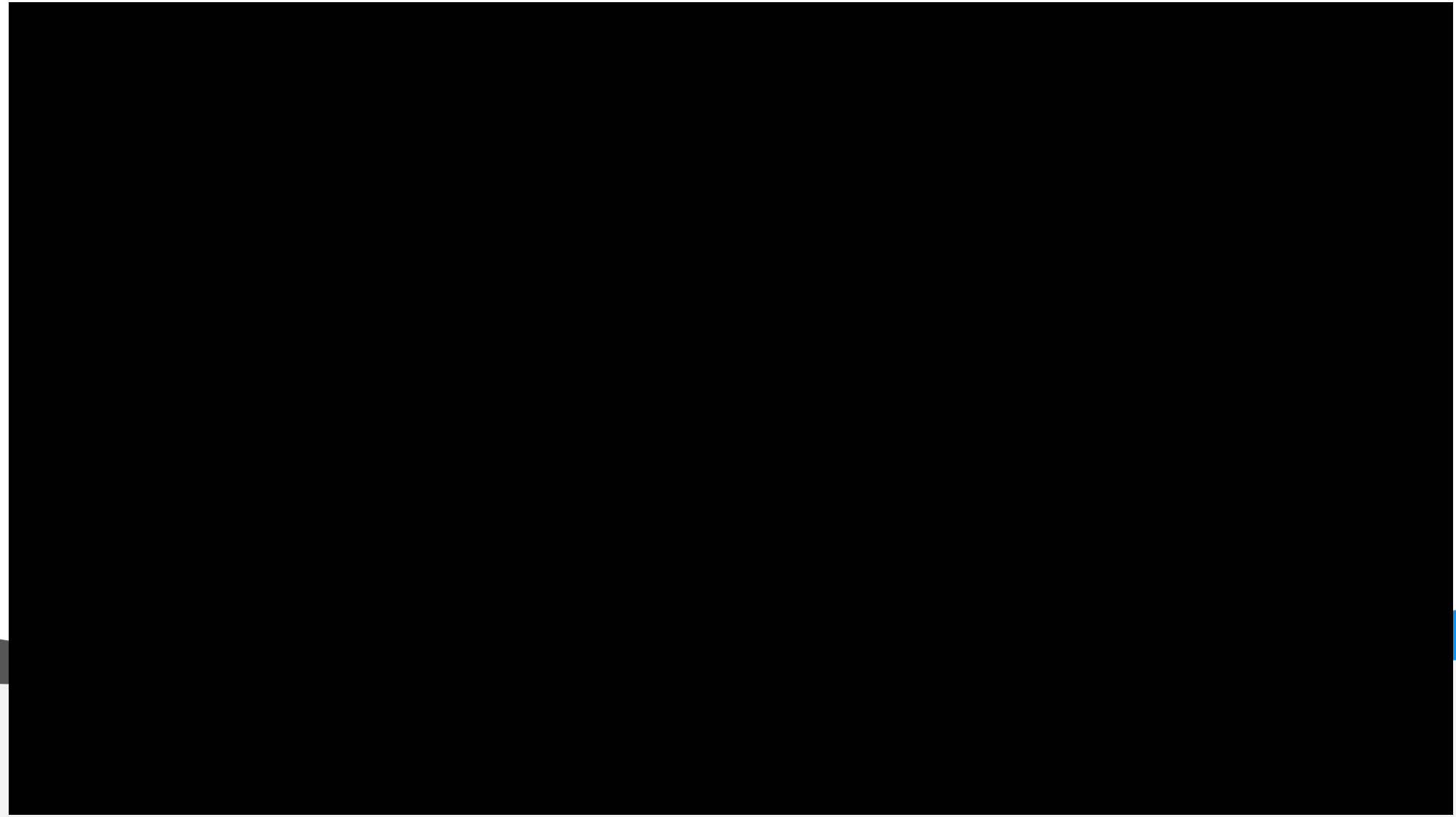
- Max cell temp. <45°C *(max cell limit is 55°C)*
- Max ΔT on cells <5.5K
- Average C-rate = 3.1C
- Peak C-rate = 4C

»» 4C peak discharge and charge possible
»» Average 3.1Crms from 90 to 5% SOC

Nail Penetration Test (NPT)



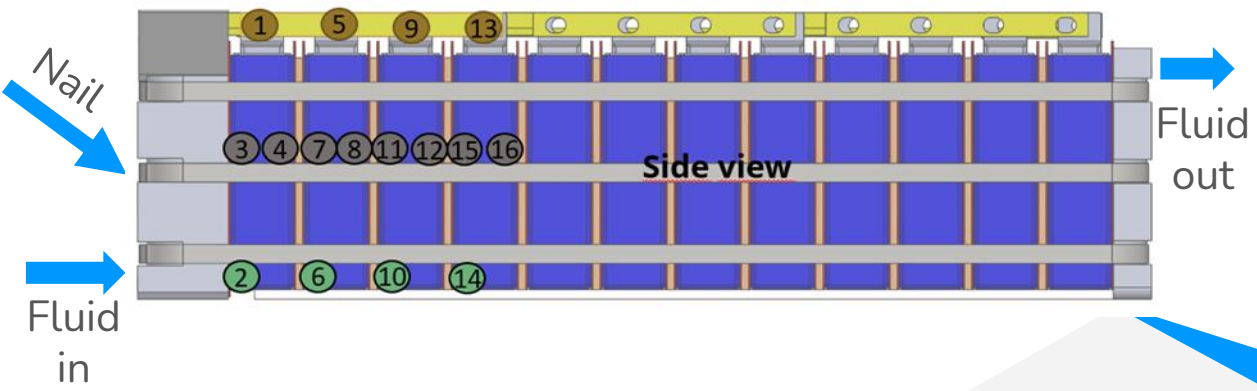
VIDEO - Nail Penetration Test (NPT)

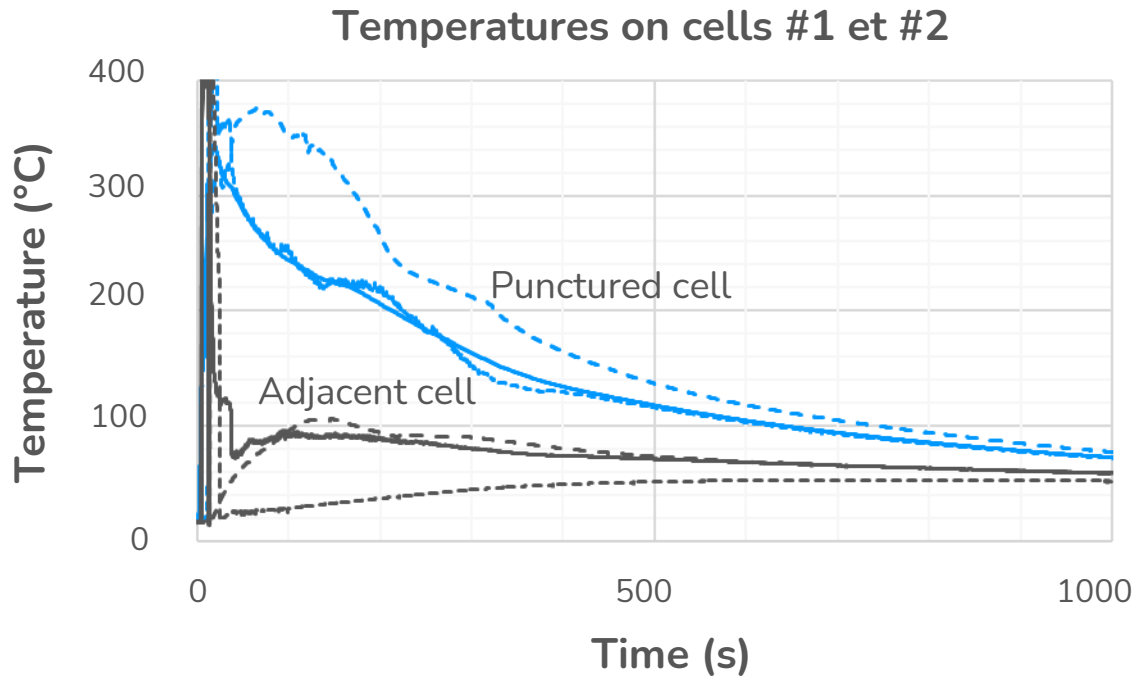


Video courtesy of bp

The cooling prevented the fire propagation

- No Active flow rate by pumping action.
  Flow of 0.025 L/min/cell 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





Data courtesy of bp

No propagation to the adjacent cell

The adjacent cell suffered but did not burn

Data courtesy of bp

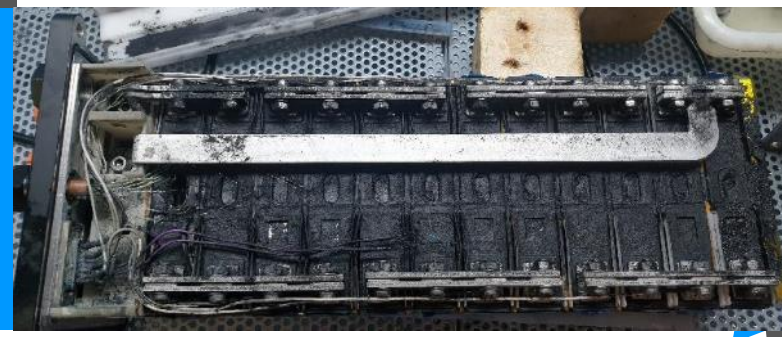
Battery design

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*

Conclusion

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

- We have demonstrated that immersion allows:
  - Increased thermal performances
  - Increased safety levels
  - No extra cost nor weight compared to current battery designs

- **The cooling fluid becomes a key component.** It has to be:
  - Good heat-transfer fluid
  - Robust dielectric properties
  - Easily pumped at all temperatures
  - Safe: not flammable
  - Environment friendly (low LCA)

Thank you. Any question?

Antoine Dubreuil (Simulation Department Leader / Project Leadership) | Rémi DACCORD (CTO and Co-Founder)
antoine.dubreuil@exoes.com

Frankfurt – July 14th ,2022