



## Application of AutoLion 1D in Battery Simulation at Cell, Module and Pack Levels

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# FPT INDUSTRIAL: THE POWERTRAIN BU PART OF IVECO GROUP

## IVG Key figures

8  
BRANDS

IVECO GROUP

COMMERCIAL & SPECIAL VEHICLES

IVECO

IVECO  
BUS

HEULIEZ

ASTRA

MAGIRUS

IDV

POWERTRAIN

FPT  
POWERTRAIN TECHNOLOGIES

FINANCIAL SERVICES

IVECO  
CAPITAL

14.4 bn€  
CONSOLIDATED REVENUES

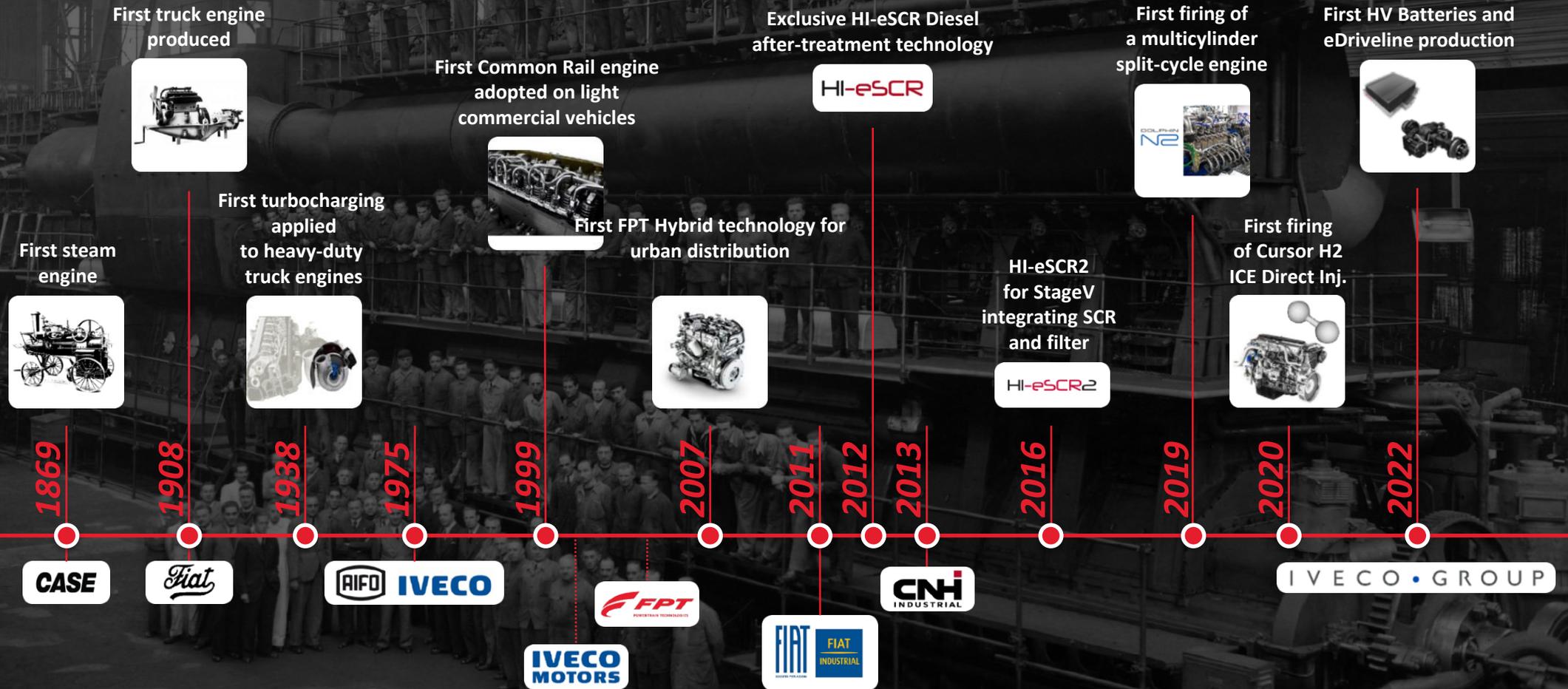
160  
COUNTRIES

34,000  
EMPLOYEES

28  
PLANTS

# FPT'S HISTORY

A young Brand with over 100 years of know-how



# Company introduction and scope of the study

## Scope of the study

### Problems and commercial impacts

- Developing accurate electrochemical models is essential for designing high-performance, efficient, and safe batteries
- Traditional battery design often relies on experimental testing, which can be expensive, time-consuming, and limited in scope

### Choice of simulation and GT-AutoLion

- Virtual electrochemical models offer a more efficient and flexible alternative for analysing and solving battery design challenges
- GT-AutoLion is a powerful software that utilizes physics-based principles to model and design lithium-ion batteries

### Purpose of the activity

- Create and calibrate a “Pseudo 2D (P2D) electrochemical model” for the Lithium-ion battery
- Evaluate the thermal behaviour of a battery pack and a full vehicle model using Phase Change Materials (PCM)

# Agenda

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- Company introduction and scope of the study
- **AutoLion Single Cell Model**
  - Experimental activities
  - Model building and optimization
  - Applications at cell, module and full battery pack levels
- **Phase Change materials (PCM) for battery thermal management**
  - PCM introduction
  - PCM effects thanks to AutoLion simulations
  - Simple application of full battery pack aging simulations with and without PCM
- **Full vehicle model implementation**
  - Simplified approach to evaluate chiller-compressor energy saving with PCM
- **Conclusions and acknowledgements**

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# AutoLion Single Cell Model

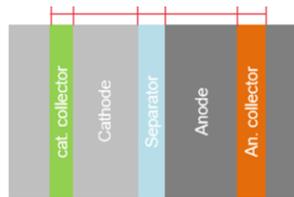
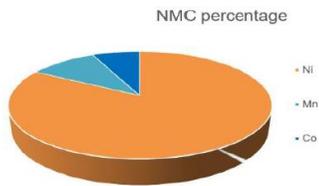
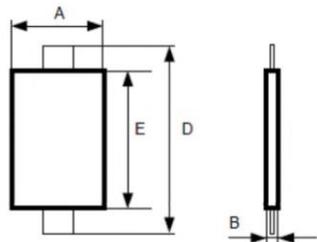
## Experimental activities

### Experimental activities needed to build up the model

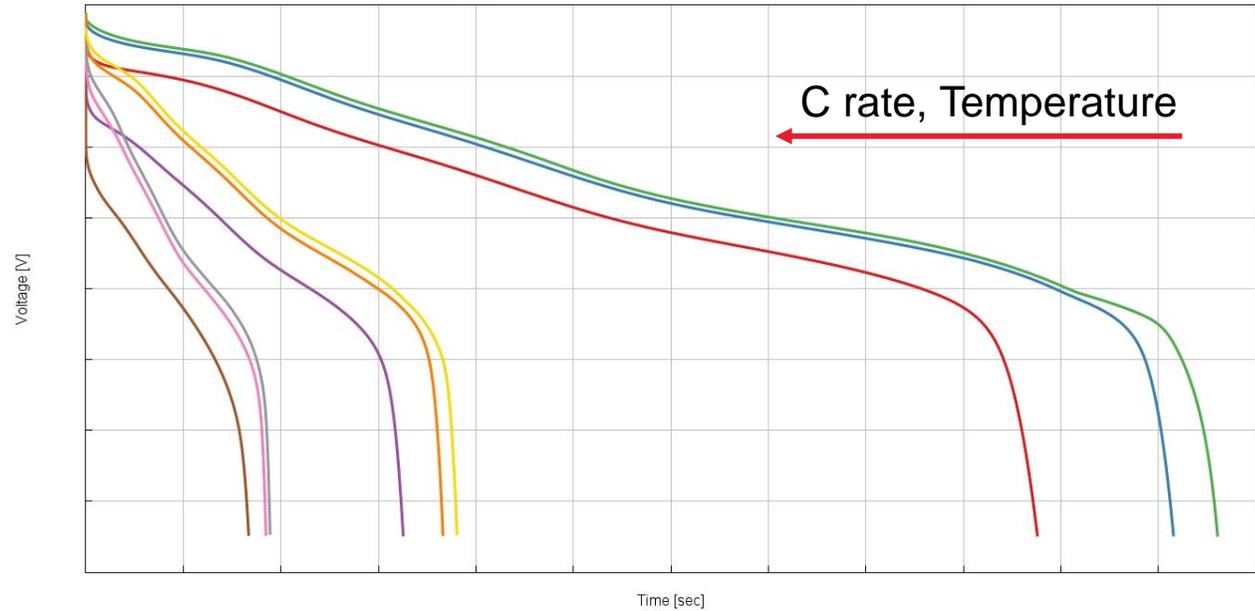
Cell teardown

Capacity tests

Rate tests

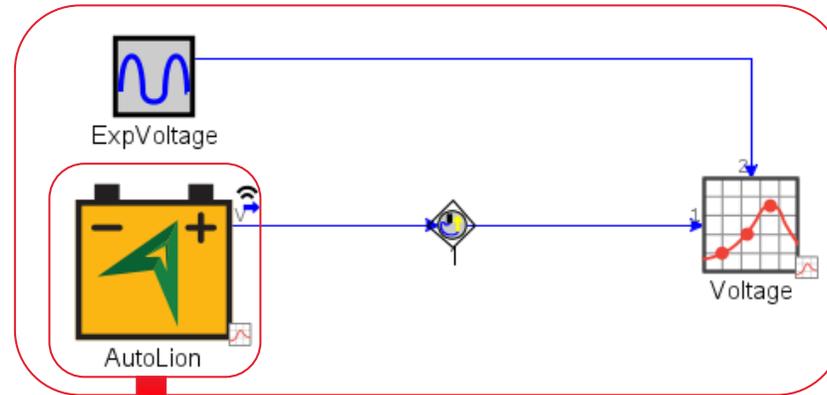


Capacity tests and rate tests - different C rates and Temperatures



# AutoLion Single Cell Model

## Model building and calibration

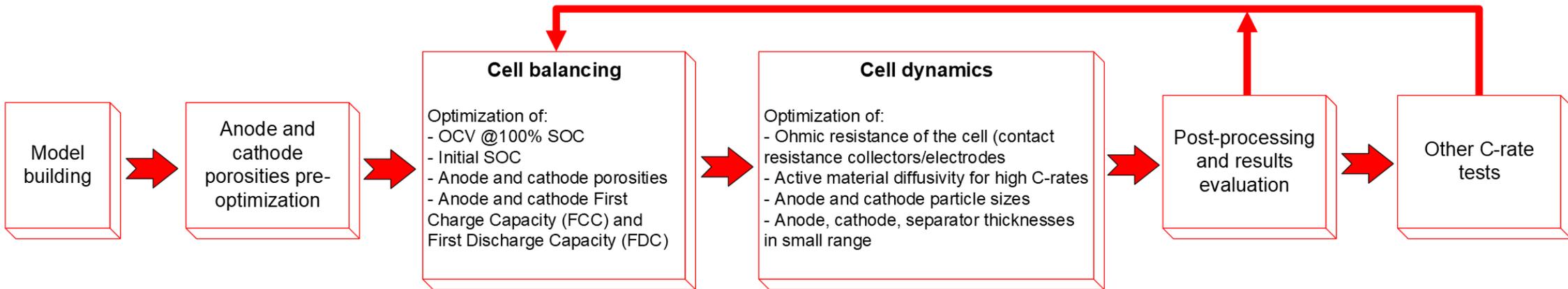


✓ Main ✓ Model Setup ✓ Cathode ✓ Anode ✓ Assembly ✓ Thermal Behavior ✓ Advanced ✓ Mechanical Plots

- Cell Geometry
- Load request and initial state of the cell (initial SOC)
- Model setup (cell operating conditions)
- Cathode/anode active materials and porosities/loading
- Foil materials, separator layer material, electrolyte
- Imposed experimental temperature

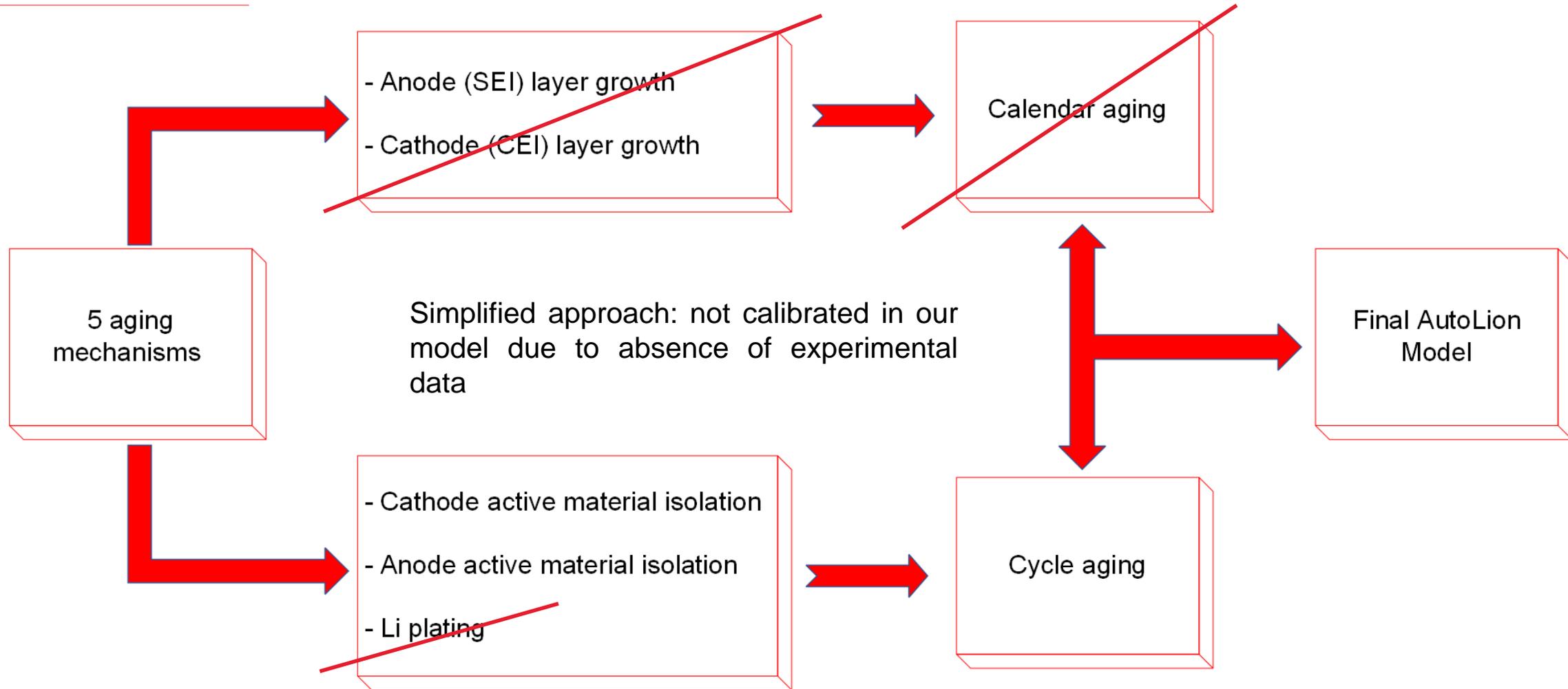
# AutoLion Single Cell Model

## Model building and calibration



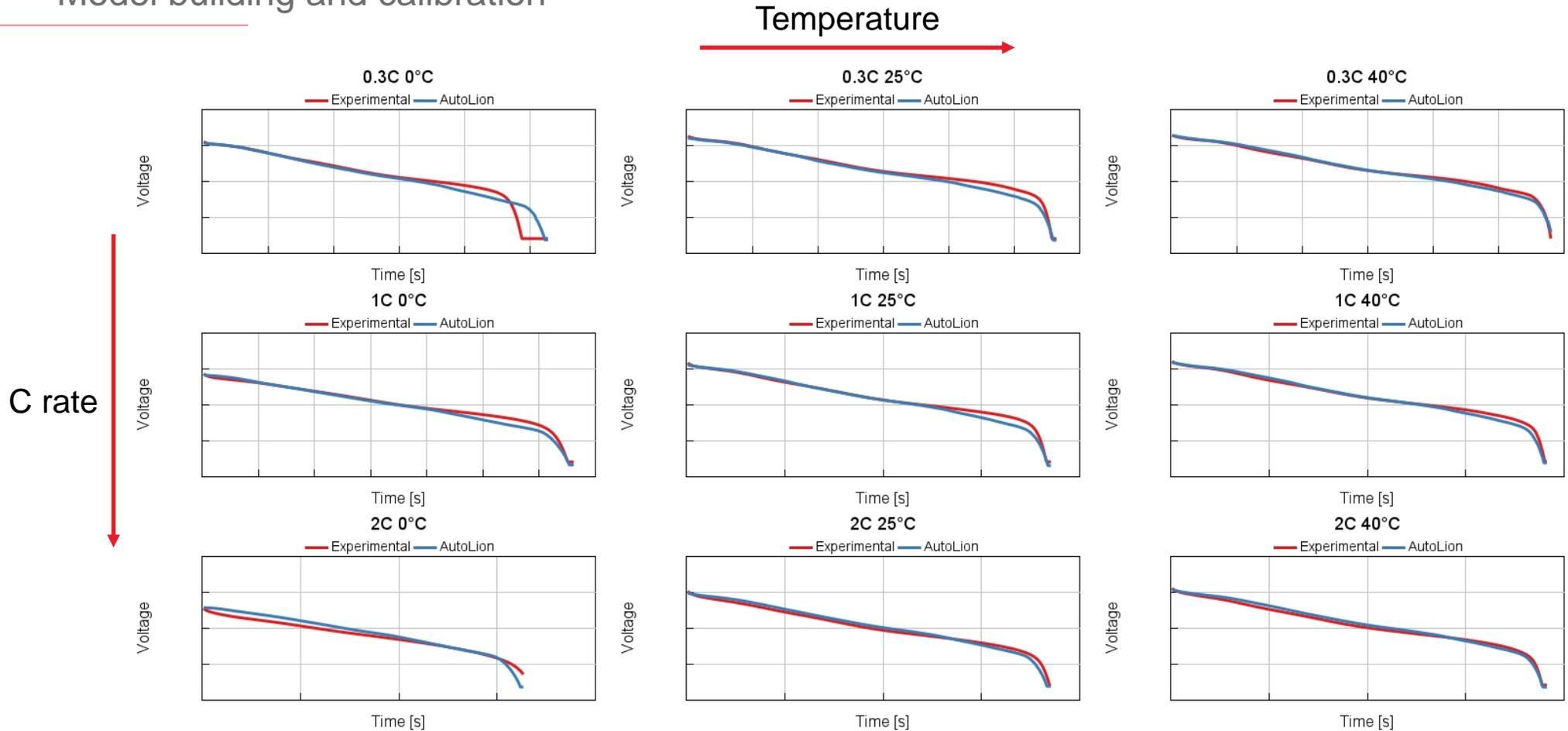
# AutoLion Single Cell Model

## Model building and calibration



# AutoLion Single Cell Model

## Model building and calibration



- Good matching both for low and high temperatures and C-rates tested
- Future developments may aim to improve the values for solid diffusivities, electrolyte ionic diffusion and terminal to foil resistances

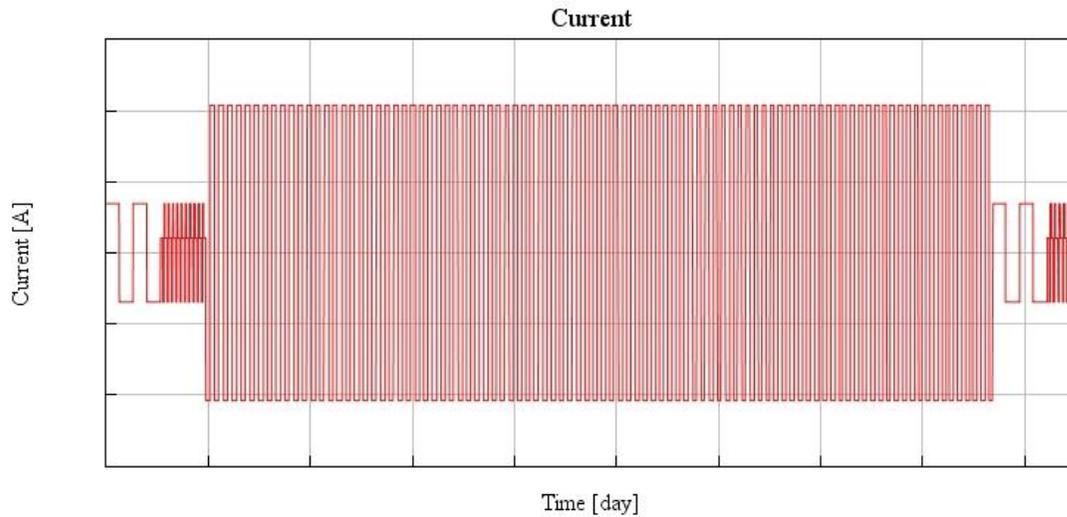
# AutoLion Single Cell Model

Model building and calibration

## Single cell cycle aging calibration – simplified approach

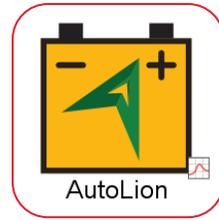
Test procedure

Qualitative results

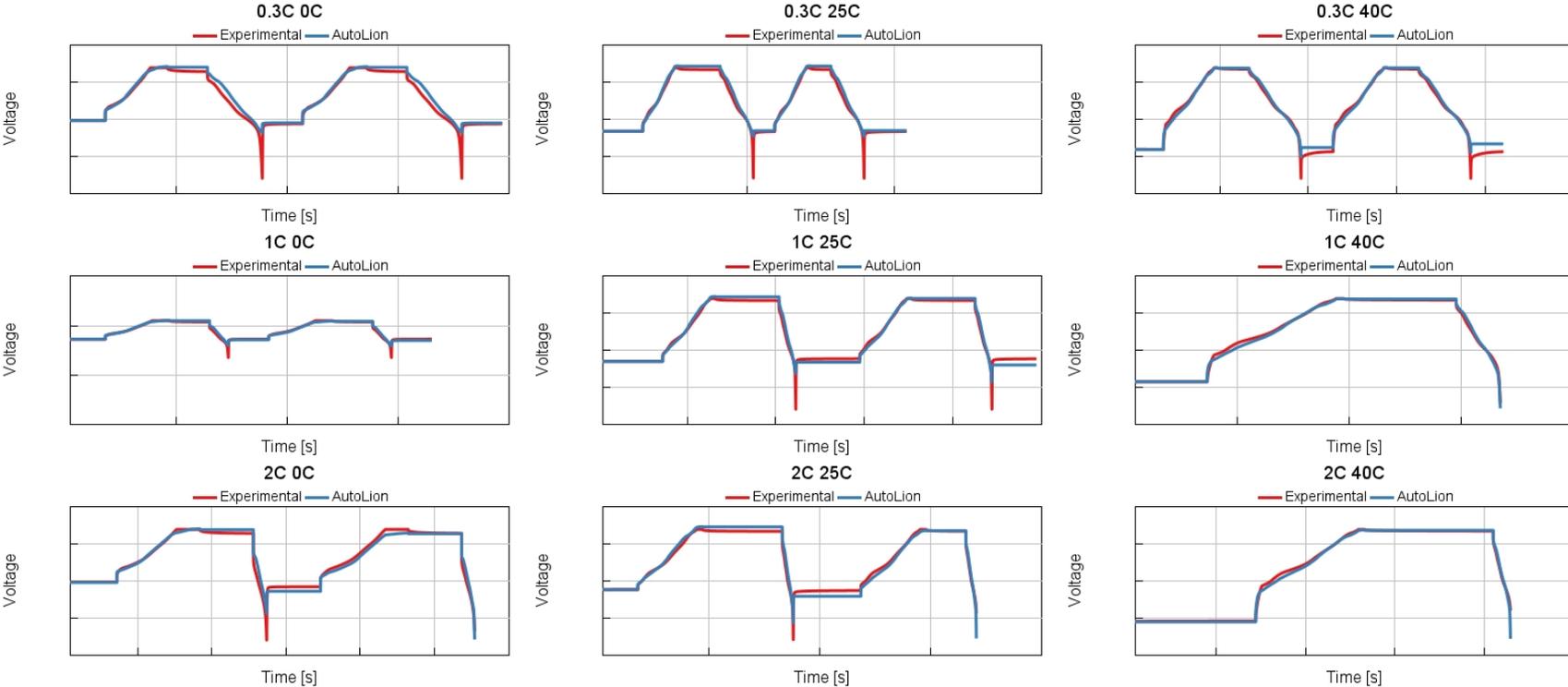


# AutoLion Single Cell Model

Applications at cell, module and full battery pack levels



## AutoLion single cell

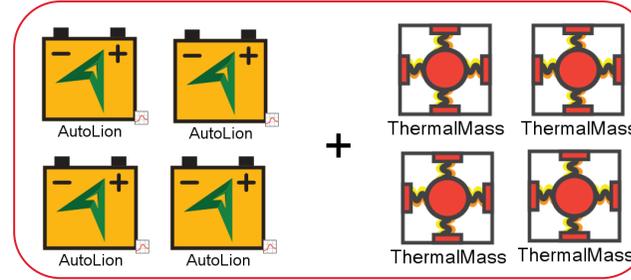
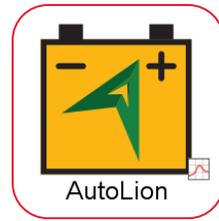


- Very good predictive results are reached for all the simulations, considering both lower and higher C-rates and different temperatures

# AutoLion Single Cell Model

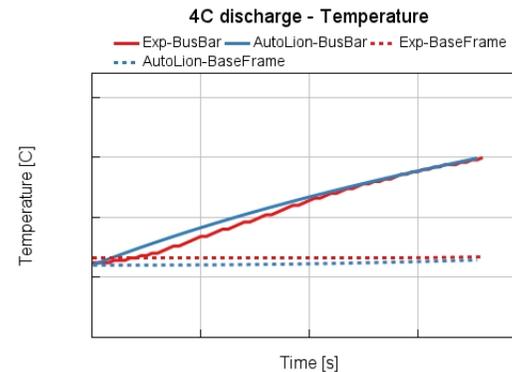
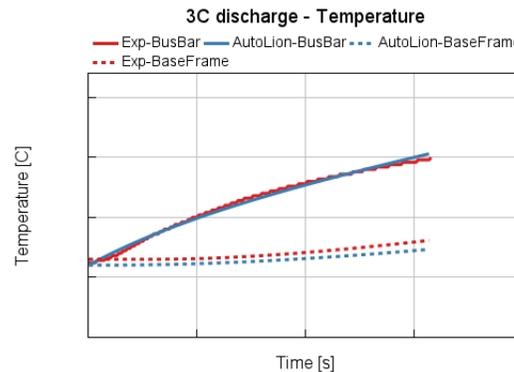
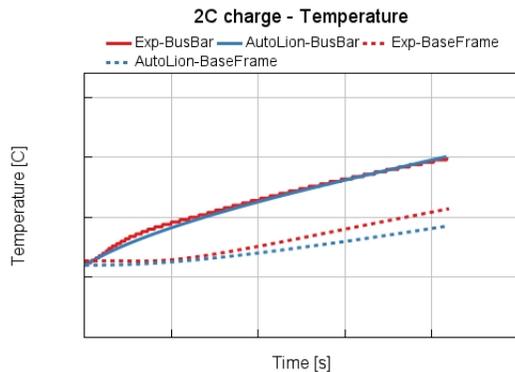
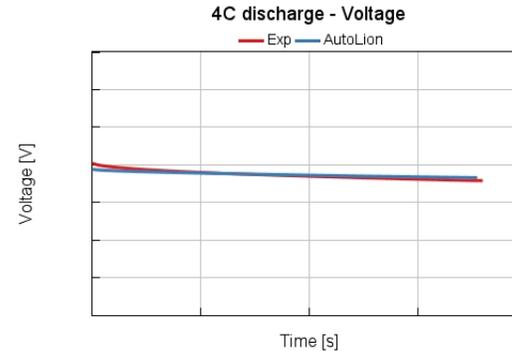
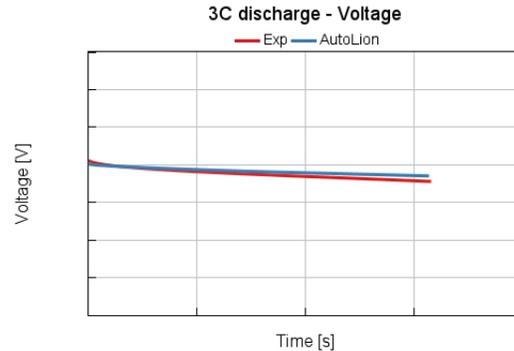
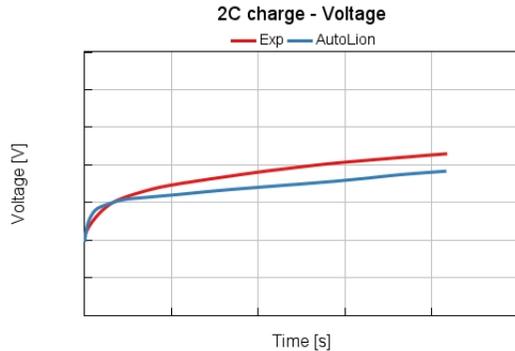
Applications at cell, module and full battery pack levels

Module creation =



AutoLion single cell

Module

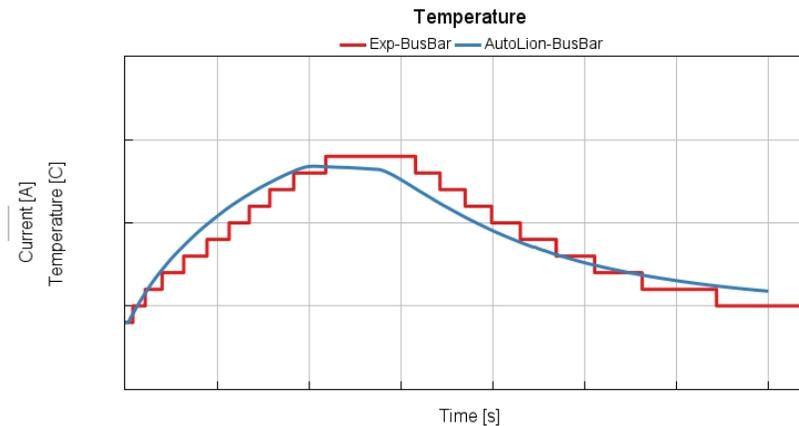
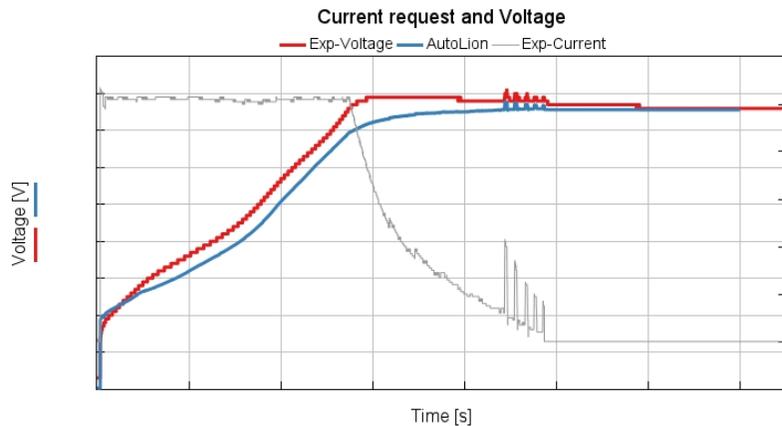
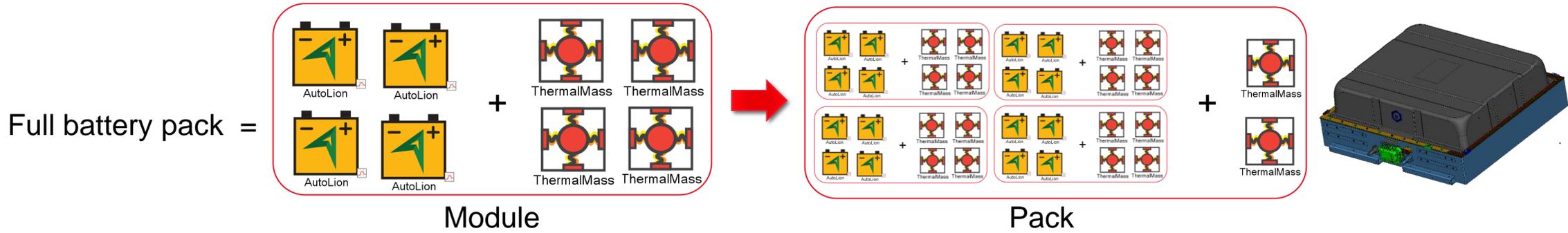


- Electrical behavior:
  - Starting phase is slightly mismatched
  - Satisfying overall behavior

- Thermal behavior:
  - strictly dependent on thermal masses and conductances
  - Satisfying overall behavior

# AutoLion Single Cell Model

Applications at cell, module and full battery pack levels



- Electrical behavior:
  - Small differences and overall behavior very good matched
- Thermal behavior:
  - strictly dependent on thermal masses and conductances
  - Satisfying overall behavior

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# Phase Change materials (PCM) for battery thermal management

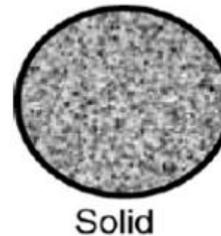
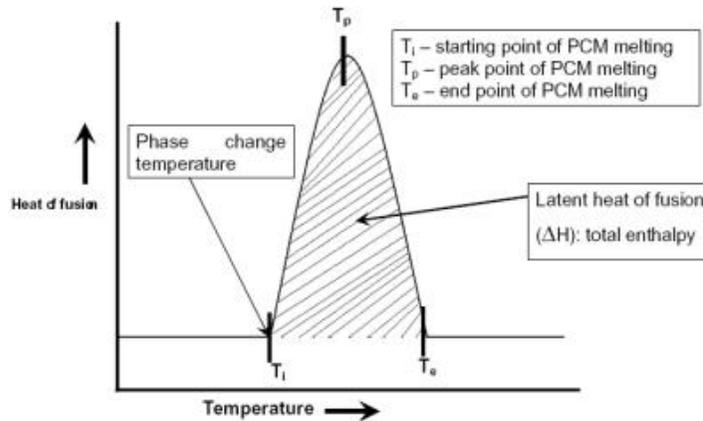
## PCM introduction

Phase Changing Materials (PCM) are substances able to release and absorb heat (energy) thanks to their phase transition. By melting and solidifying, they can store and release this energy fulfilling the function of passive thermal management

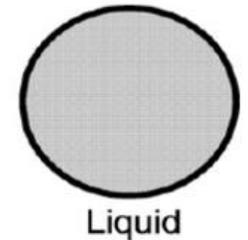
Specific characteristics

Benefits

Drawbacks



Melting (heat goes into the solid as it melts)  
Solidification (heat leaves the liquid as it solidifies)



Scope of the activity is to evaluate the benefits of the introduction of Phase Changing Materials (PCM) inside the battery pack in terms of thermal management and aging

# Phase Change materials (PCM) for battery thermal management

PCM effects thanks to AutoLion simulations

Full battery pack temperature behavior with and w/o PCM for different cases

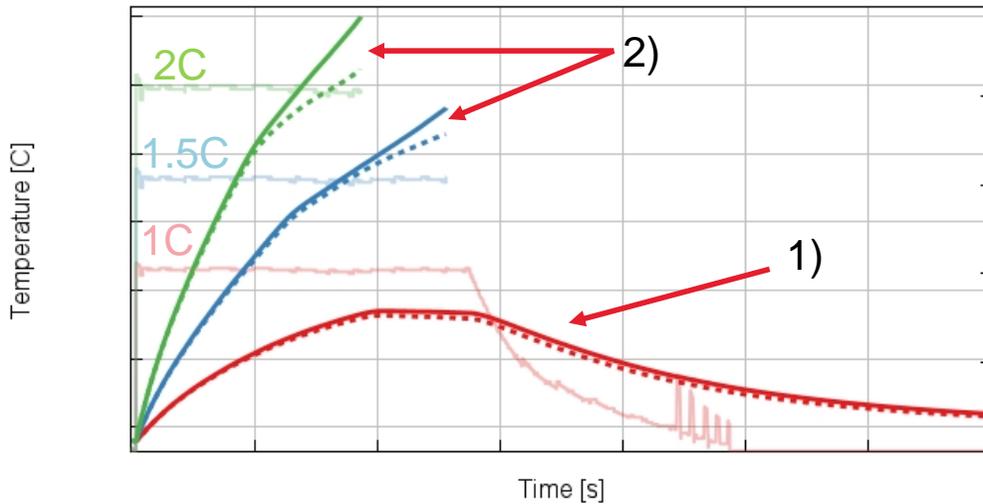
1) For  $T < T_{\text{melting}}$  : only thermal conductivity influence

2) For  $T > T_{\text{melting}}$  : benefits of the melting effect

3) Solidification: latent heat released (drawback)

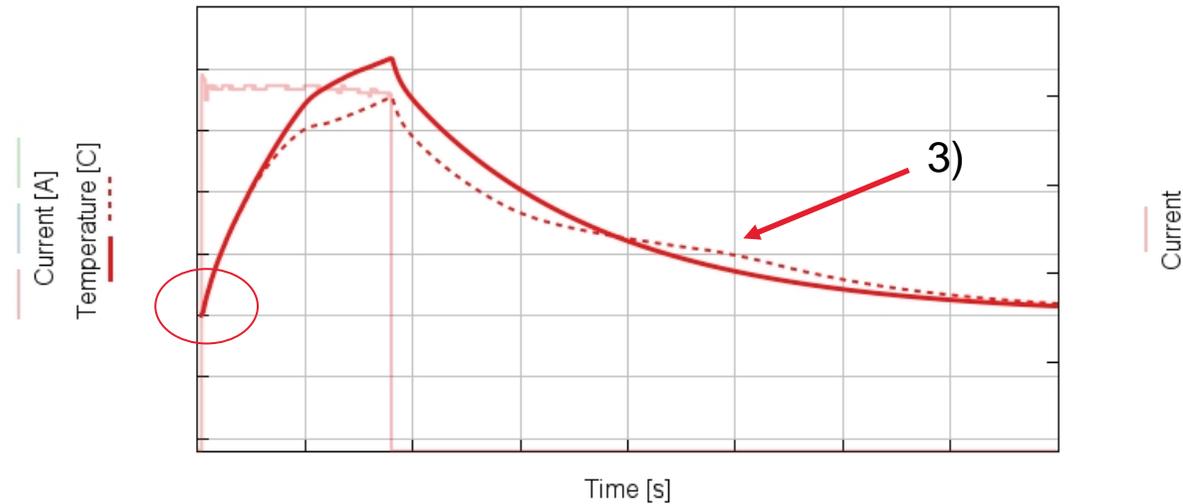
Temperature - Charging

— 1C — 1.5C — 2C — NO PCM-4 L/min - - - PCM-4 L/min  
— NO PCM-0 L/min-1.5C - - - PCM-0 L/min-1.5C — NO PCM-ZeroFlow-2C  
- - - PCM-ZeroFlow-2C



Temperature - Charging + switch off + T amb35°C

— 2C — NO PCM-4 L/min - - - PCM-4 L/min



# Phase Change materials (PCM) for battery thermal management

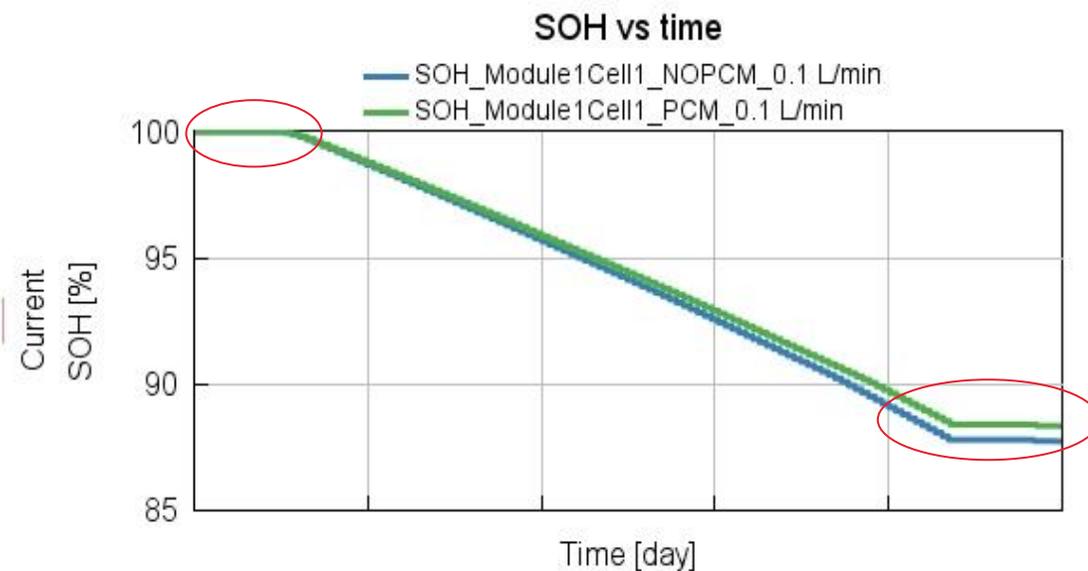
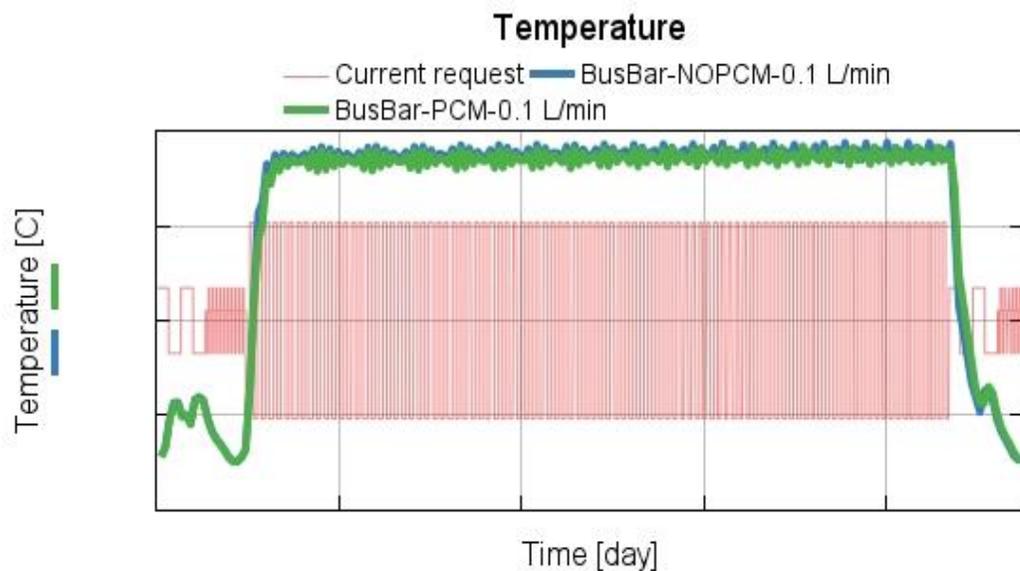
Simple application of full battery pack aging simulations with and without PCM

Full battery pack aging with and w/o PCM for different cases

Test procedure

Temperature behaviour

Qualitative results



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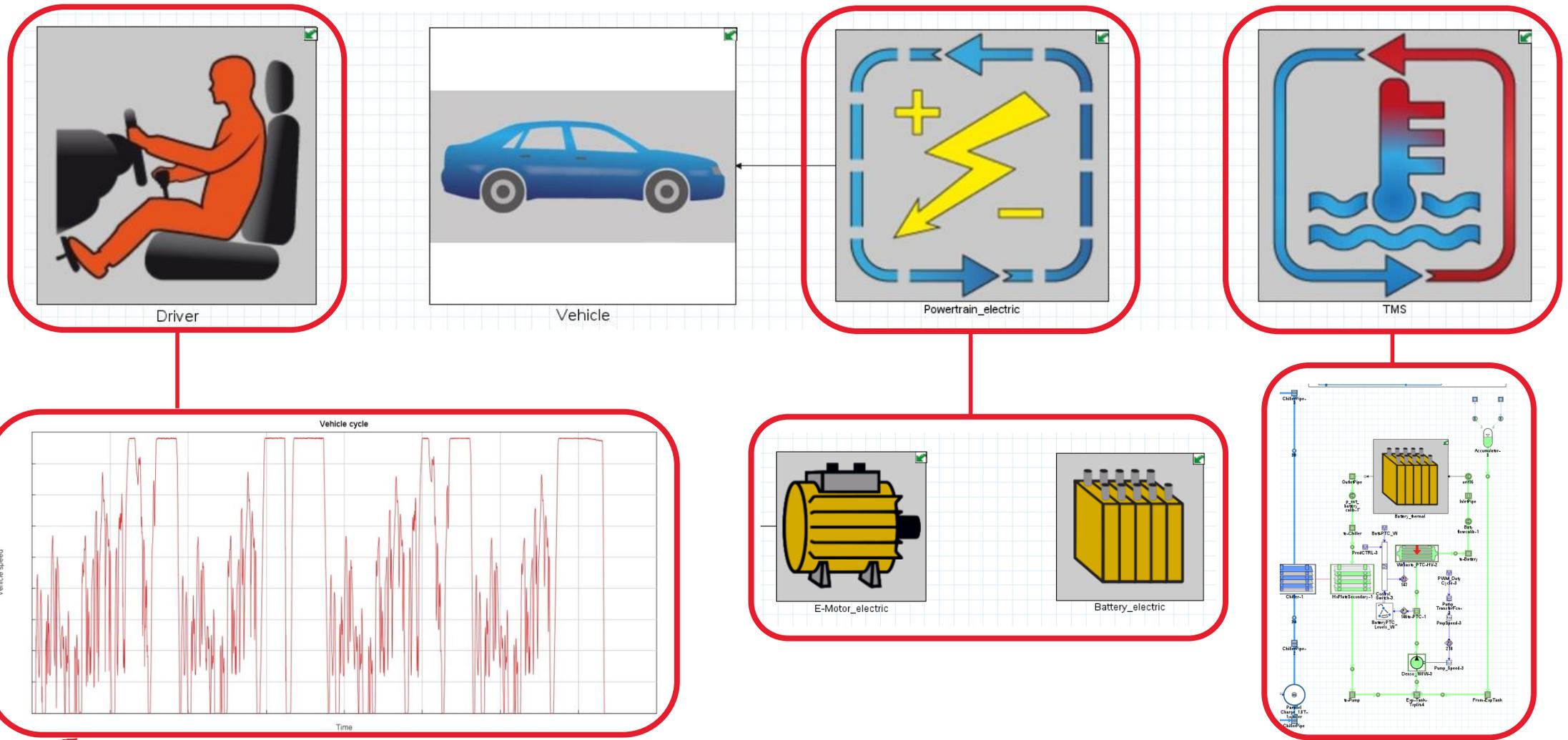
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# Full vehicle model implementation

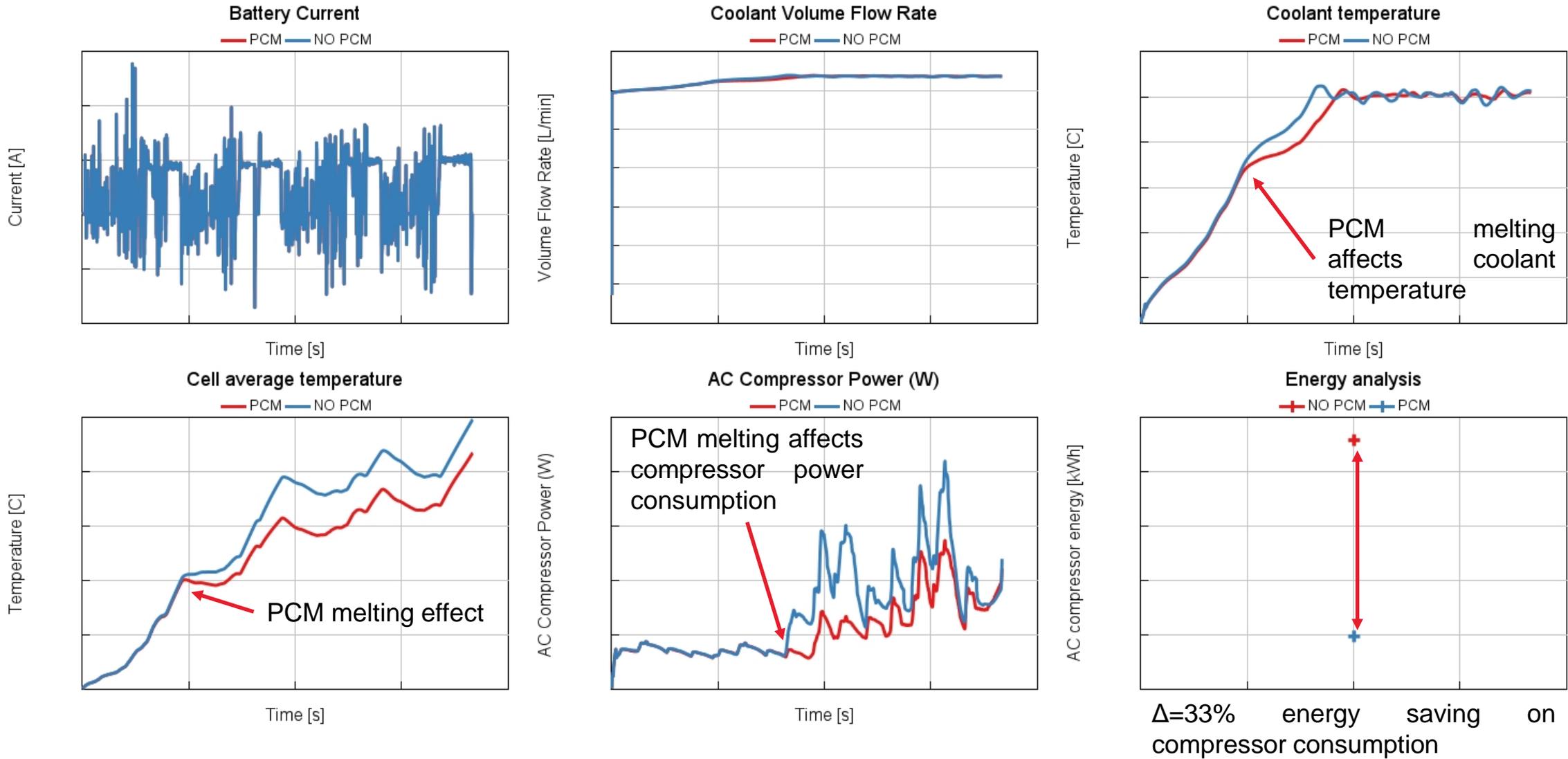
Simplified approach to evaluate chiller-compressor energy saving with PCM

Vehicle simulations performed to understand the effects of PCM at system level with a **simplified control approach**



# Full vehicle model implementation

Simplified approach to evaluate chiller-compressor energy saving with PCM



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# Conclusions and acknowledgements

## AutoLion cell model

- The activity has shown a repeatable and reliable methodology for building and calibrating an AutoLion P2D electrochemical model for Lithium-ion batteries
- The model was tested for different conditions and level of detail (cell, module and pack), showing excellent performance

## PCM effects evaluation

- GT-AutoLion was an essential tool for assessing the effects of PCM on battery thermal behavior and aging
- The capabilities of AutoLion have been tested in a simplified vehicle model to assess the effect of PCM implementation on compressor energy saving

## Future developments

- Refine the model calibration
- Introduce the other aging mechanisms
- Implementing and calibrating the effect of thermal runaway reactions

# Acknowledgements

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I would like to express my gratitude to my colleagues for their invaluable contributions to this project. A special thanks to Lorenzo Bianchi, Matteo Scialabba, and Amalia Gouzounis for their dedication, expertise, and support

# Thank you for your attention!

