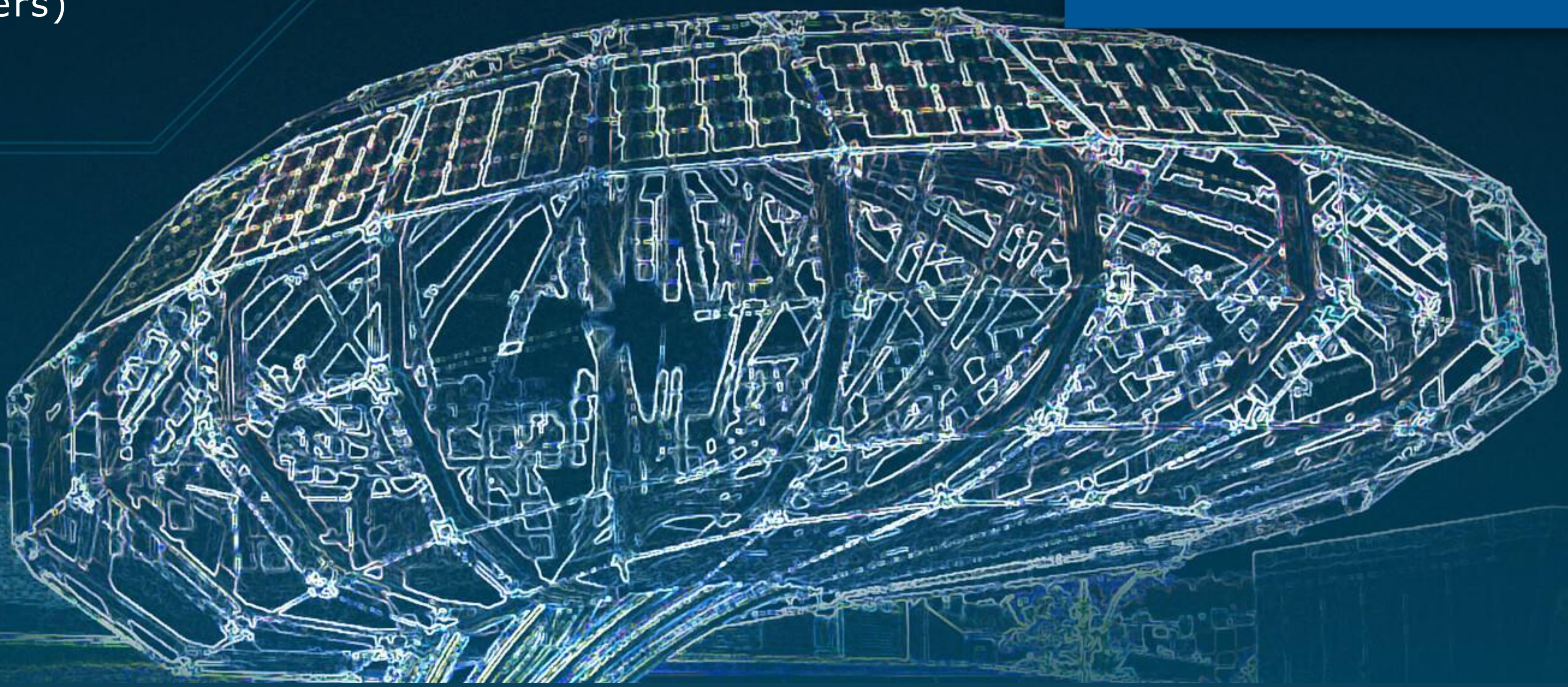
AVL List GmbH (Headquarters)



Battery Simulation

Battery Performance, Thermal and Safety from Component to System

Juergen Schneider

Public

Introduction to the Solution Area

"Batteries are the key differentiator between the various EV manufacturers"

Source: Coffin, David, and Jeff Horowitz. "The Supply Chain for Electric Vehicle Batteries.
" Journal of International Commerce and Economics, December 2018. https://www.usitc.gov/journals

Warm Up - **Current Market:**
Measurements in AVL Series Battery Benchmarking

		Audi e-tron	NIO ES8	Tesla Model 3 LR
Performance	Battery Heating	4.8 kW	5 kW	~2.5 kW from e-Drive Unit
	Power @ -20 °C	70 %	40 %	5 %
Thermal	Battery Temp. START OPERATION	-30 °C	-30 °C	-20 °C
	Battery Temp. END of DERATING of Discharge	-15 °C	0 °C	20 °C
Electrical	Recuperation Power @ -5°C	70 kW	15 kW	0 kW
	Recuperation Power @ 0 °C	100 kW	20 kW	0 kW

Strongest low Temperature derating

Battery Development

Electric Performance

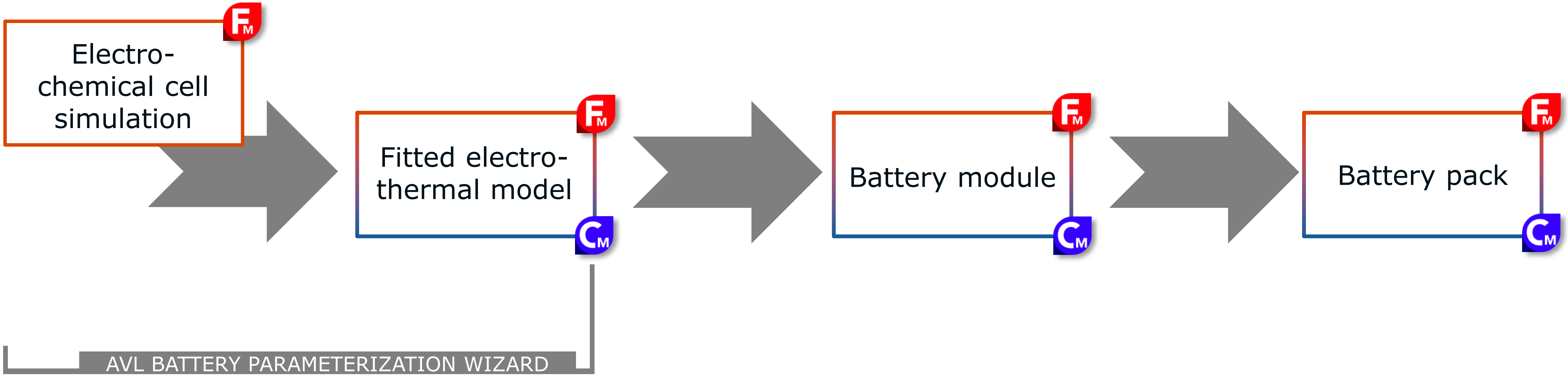
Component Lifetime

Component Safety

Battery electric & thermal management

Optimization of in cell thermal distribution

Thermal Analysis Workflow



Electro-chemical modelling
1D←→3D Workflow

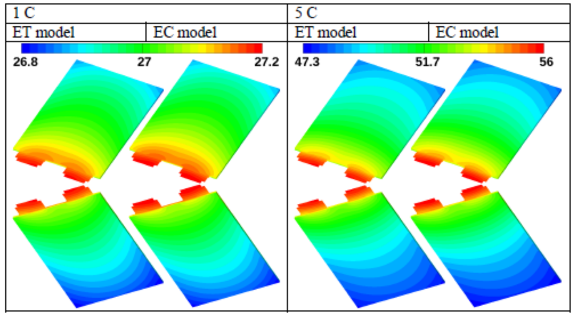
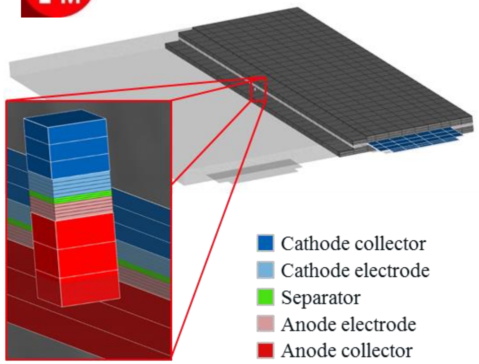


Figure 6. Surface temperature (°C) in both models for a discharge rate of 1 C (left) and 5 C (right) and an ambient temperature of 25 °C at a capacity of 11.5 Ah; top: view of battery center, bottom: view of battery boundary.



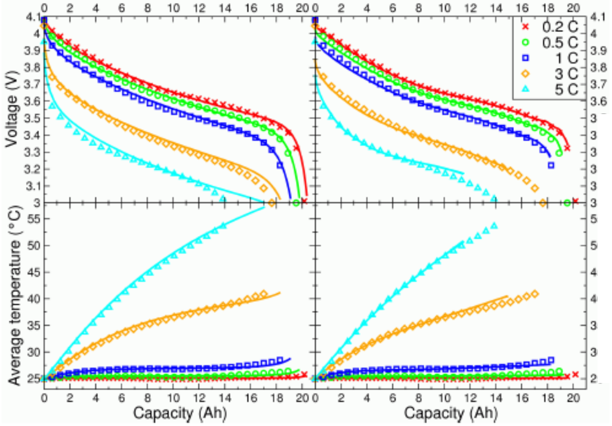
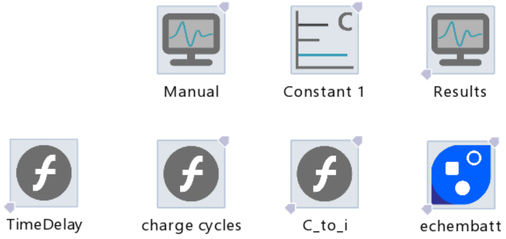


Figure 4. C-rate variation for an ambient temperature of 25 °C: voltage (top) and average temperature (bottom) vs. capacity in experiment (symbols) and simulation (lines) with ET model (left) and EC model (right).



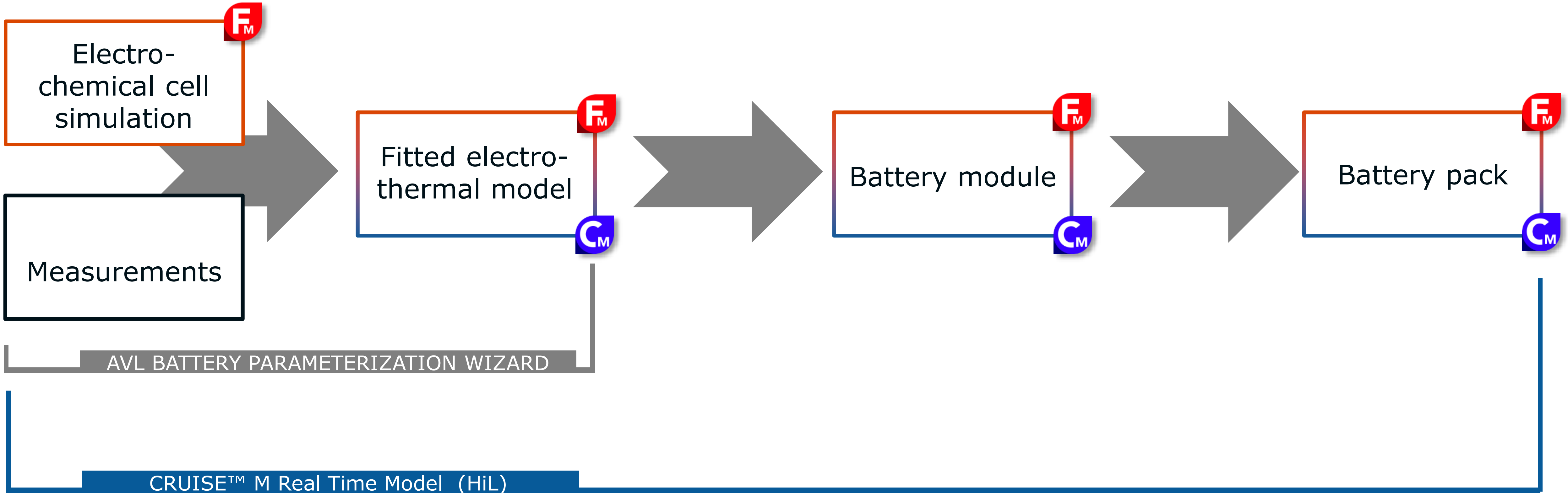
Summary

- AVL CRUISE™ M* and AVL FIRE™ M
- Both tools sit in one common simulation environment, sharing
  - Usability
  - Parameter
  - Material data base
  - Optimization tools, post-processing, model data base …
- The battery models share model parameters
  - Workflow: experiment → 1D → 3D
  - Workflow: 3D → 1D → Vehicle simulation

Fink, C., and Kaltenegger, B., "Electrothermal and Electrochemical Modeling of Lithium-ion Batteries: 3D Simulation with Experimental Validation", ECS Transactions. 61(27):105-124, 2014.

* to be released with upcoming version v2020.1

Thermal Analysis Workflow



Series Battery Benchmarking: Vehicles

2014

Tesla Model S

Renault Zoe

Mitsubishi Outlander

2016

2017

Tesla Model X

Chevrolet Bolt

2018

Tesla Model 3

Hyundai Kona

Nio ES8

2019

Audi e-tron

JLR iPace

2020

Taycan

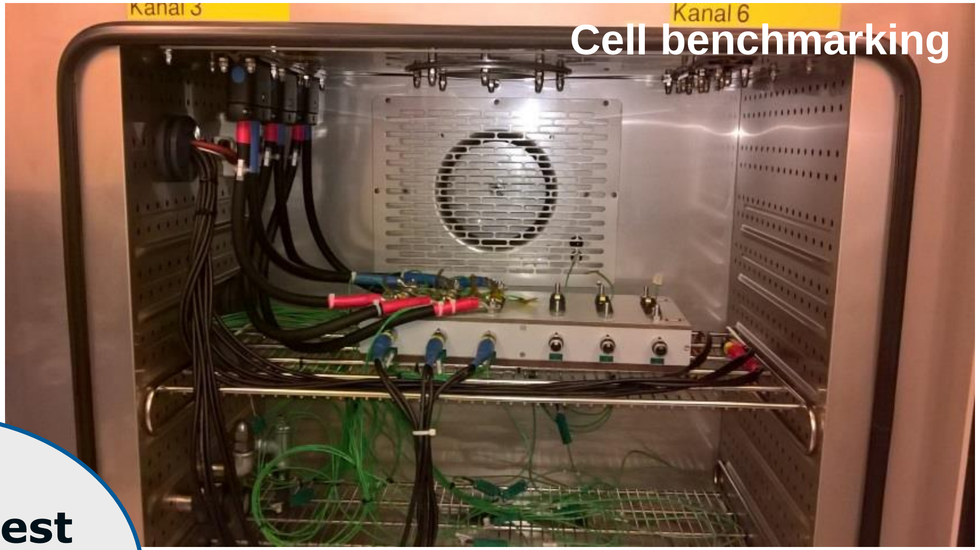
Vehicle Ordered

In Progress

BM Finished

Testing of Battery Systems at AVL


e-mobility test center @ AVL Graz



Cell benchmarking

Battery test facilities at AVL

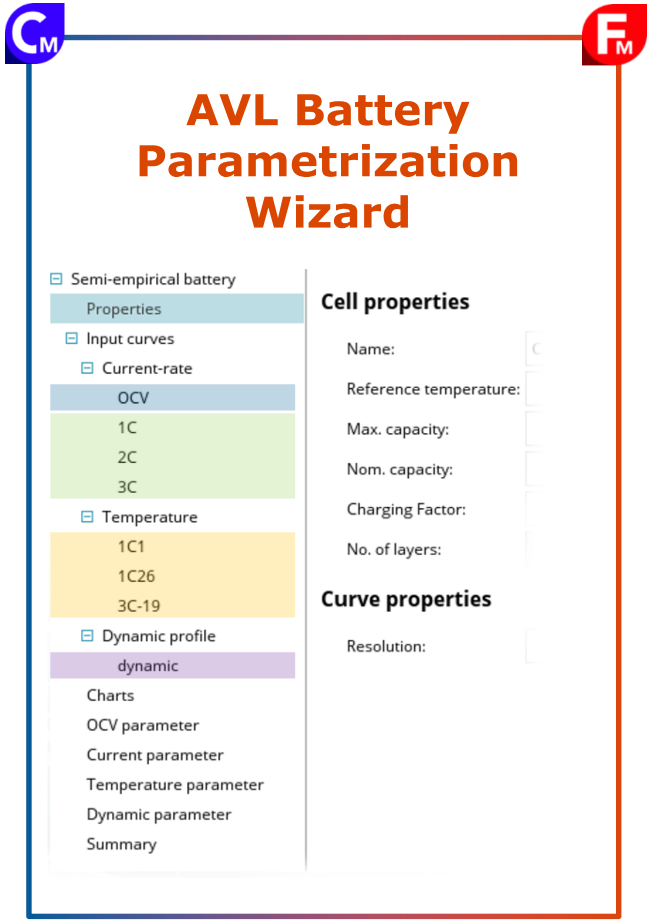

battery test cell

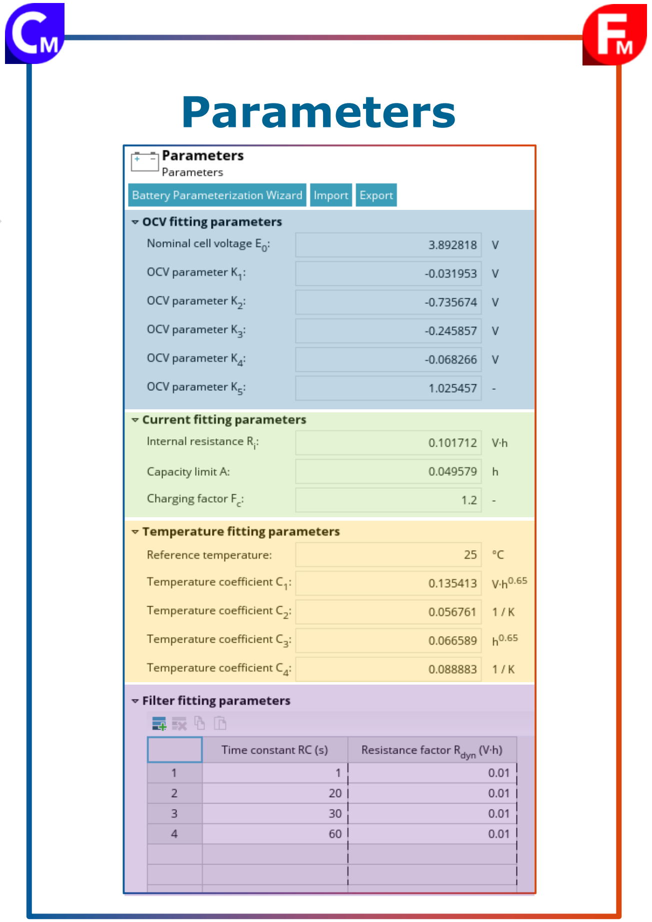
durability and calendaric ageing test cells

Battery Parametrization Wizard

Measurement

- Pre-Conditioning
- Hybrid Pulse Power Characterization
- C-Rate Capability
- Driving Cycles





Automatic calibration of parameters for electro-thermal model available in FIRE™ M and CRUISE ™ M

3D Simulation Applications

Typical AVL FIRE™ M simulation tasks for battery application

Single Cell	Battery Module	Battery Pack	Power electronics
✓ Electro-chemical analysis ✓ Cell calibration ✓ Short circuit investigation ✓ Venting	✓ Transient electrical and thermal behavior ✓ Cooling assessment ✓ Short circuit investigation ✓ Thermal Runaway ✓ Venting and melting	✓ Transient electrical and thermal behavior ✓ Cooling assessment ✓ Short circuit investigation ✓ Thermal Runaway ✓ Venting and melting	✓ Transient electrical and thermal behavior ✓ Cooling assessment

Automatic extraction of model + parameters for 1D System simulation tool AVL CRUISE™ M

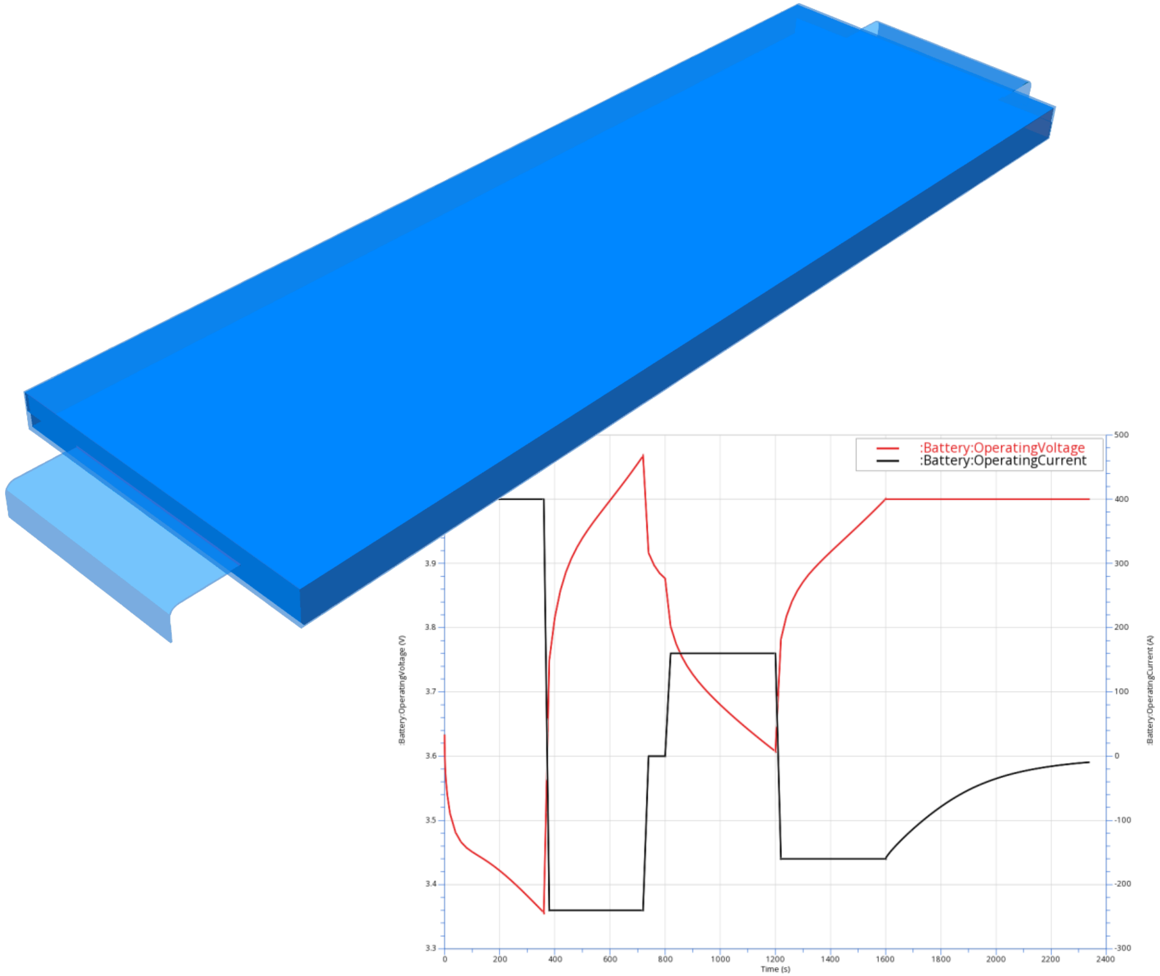
2D and 3D Simulation Results

2D Results (global and local)

Temperature, Pressure, Heat Flux, **Operating Voltage/Current**/Power,
OCV, SoC/DoD, Capacity, Ohmic/Reaction heat source, etc.

3D Results

Temperature, Pressure, Flow Structure (Velocitiy), SoC/DoD, Electric Potentials, **Current density (Vectors),** Current Density, OCV, Melting location, etc.



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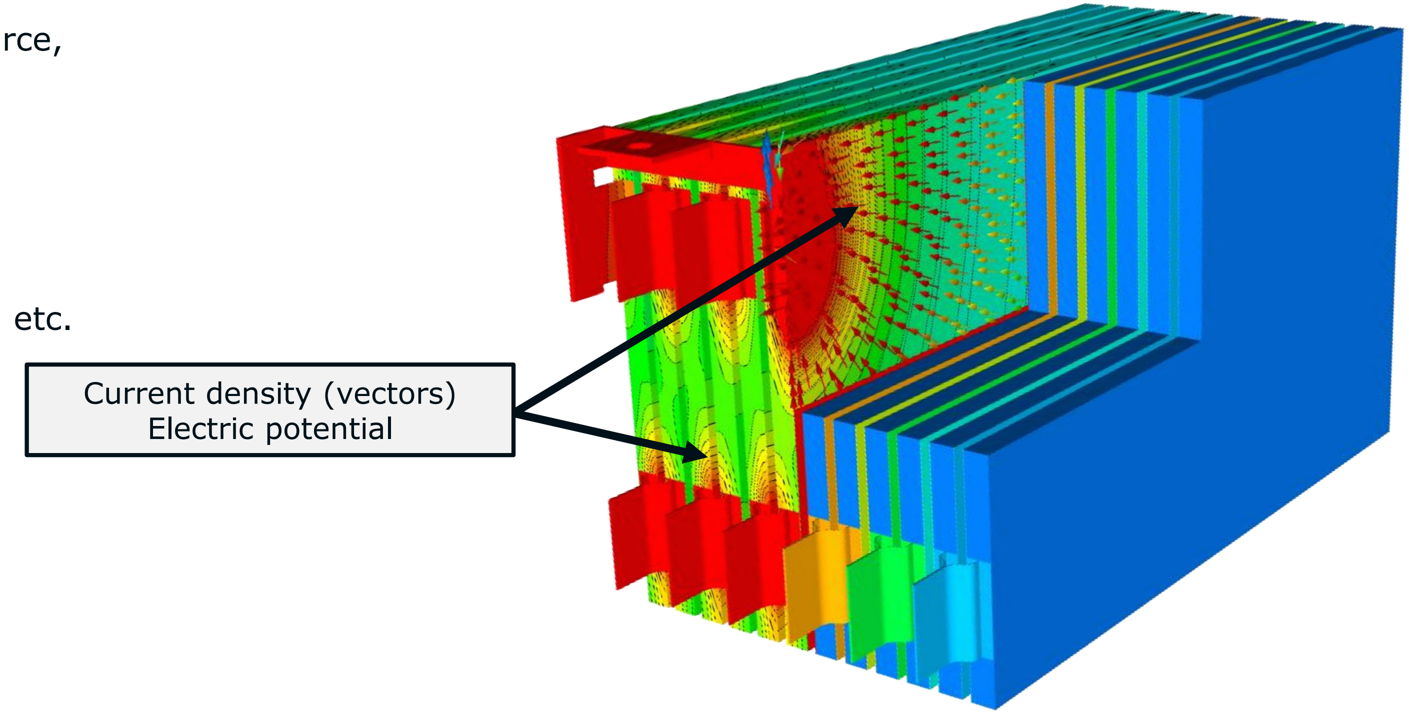
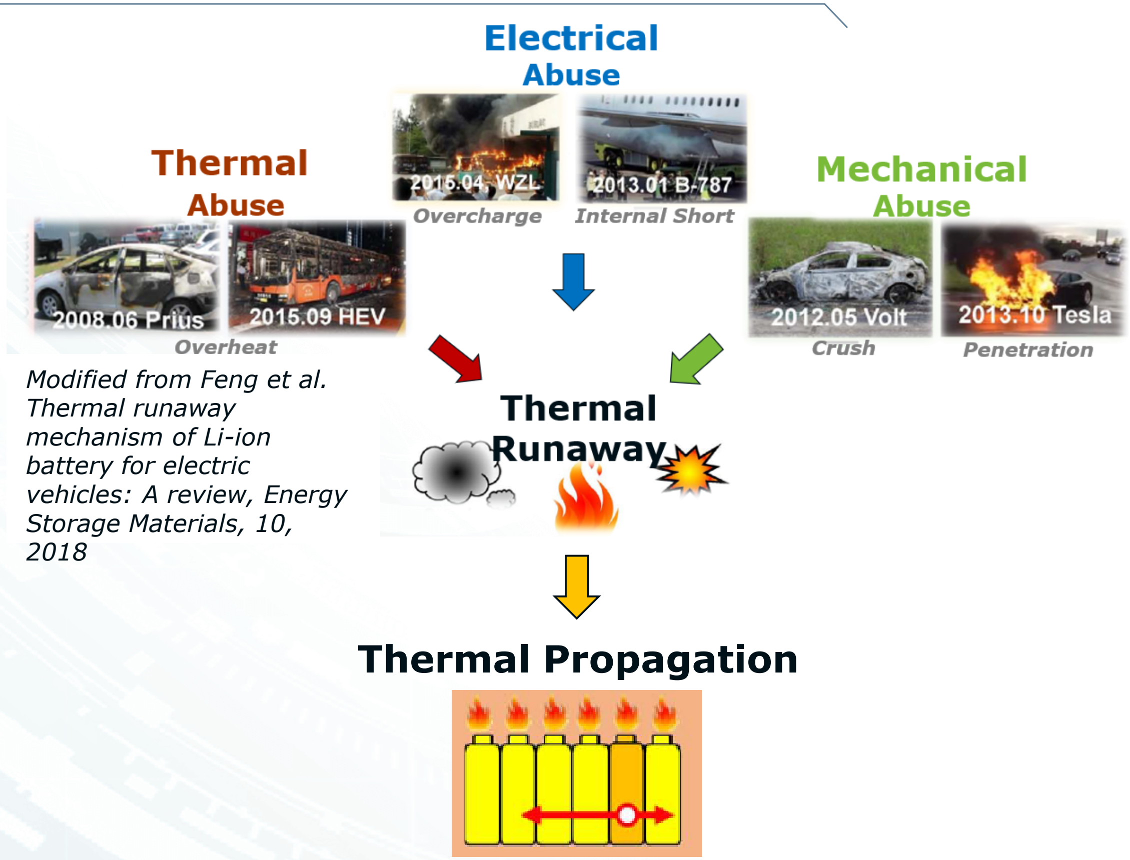
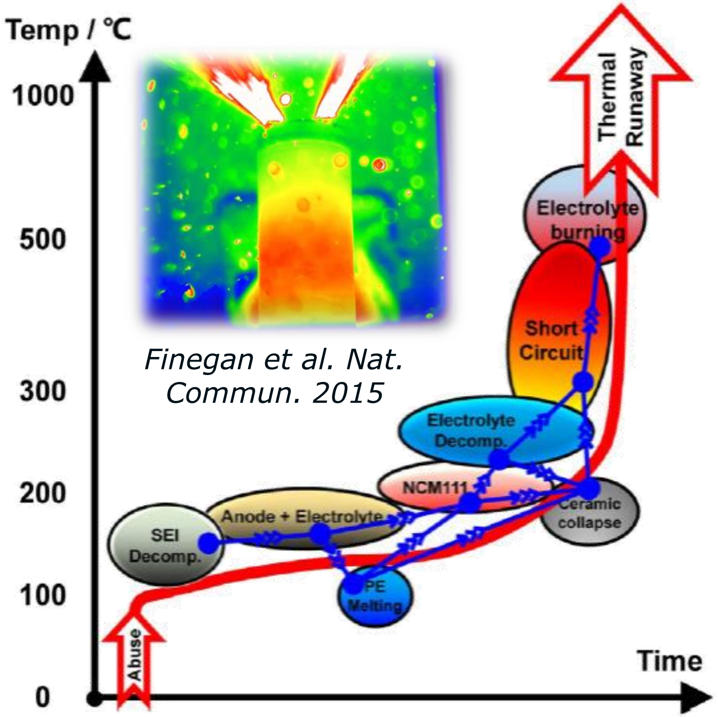


Thermal Runaway, Propagation



Modified from Feng et al. Thermal runaway mechanism of Li-ion battery for electric vehicles: A review, Energy Storage Materials, 10, 2018



Feng et al. Energy Storage Materials, 10, 2018 NMC/graphite chemistry

- ❑ Cell surface temperature increases up to <u>~ 1000°C</u> within few seconds
- ❑ Cell venting with gas volume of <u>~ 100l</u> and temperatures up to <u>1400°C</u>
- ❑ Venting gas has certain concentration of flammable/explosive/toxic species (CO_2, CO, H_2, HF, …)
- ❑ Typical propagation cell-to-cell propagation times are <u>10-30 seconds up to minutes</u>, heavily depends on cell format, capacity, module design, electrical connections, thermal barriers and more

Thermal Runaway, New Regulation

EU*	Japan	Korea	USA	China	India
UN GTR No.20					

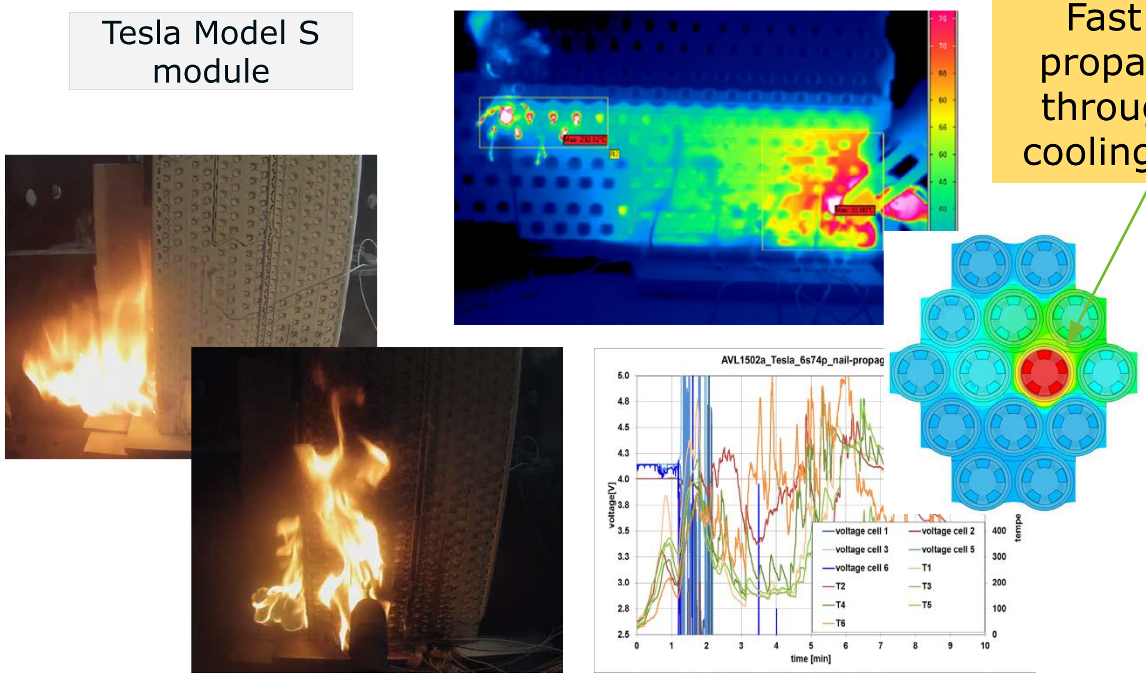
New regulations **GTR20** that requests a duration of 5 min between the warning of thermal runaway and safe escape of passengers

Thermal Runaway, Industry Example

Tesla Model S vs Model 3

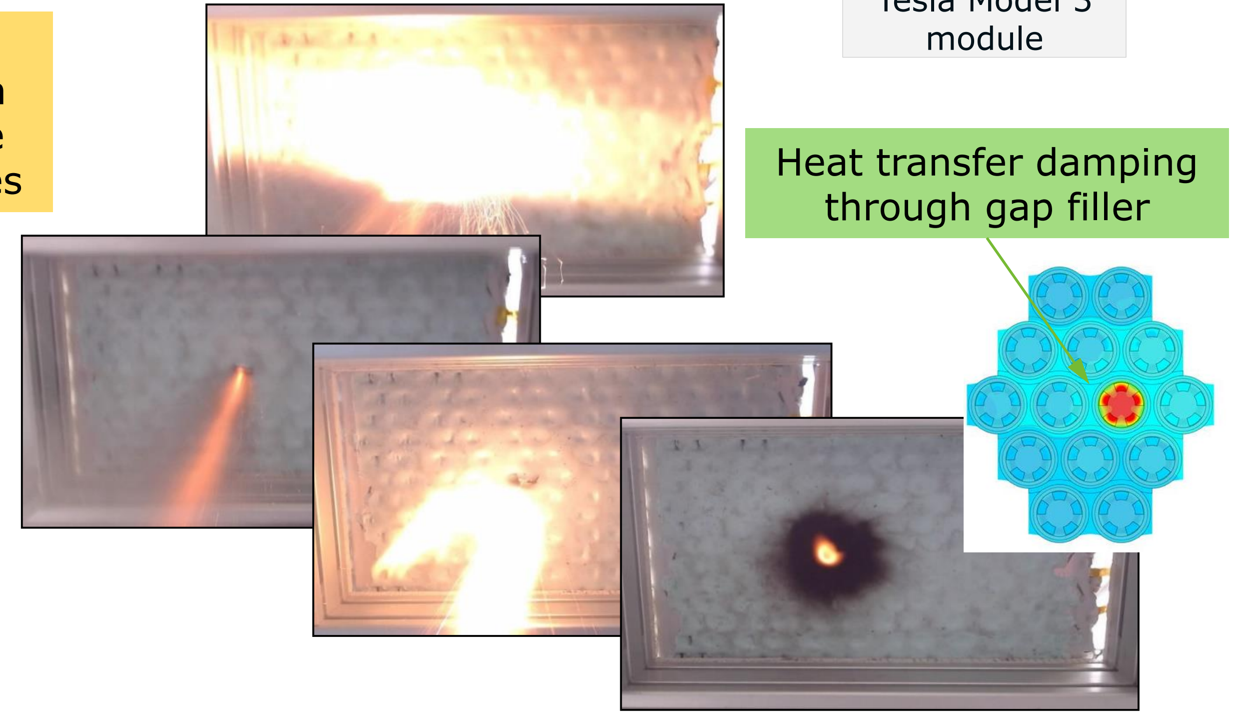
- Two tests performed in AVL benchmarking program
- Countermeasures have been improved in newer design
- In our module test scenario (nail penetration), fast propagation and fire was detected for Model S, while in Model 3 only one cell vented and no propagation was detectable

Tesla Model S module



Fast heat propagation through the cooling plates

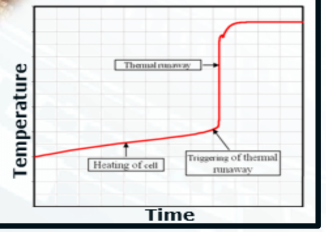
Tesla Model 3 module



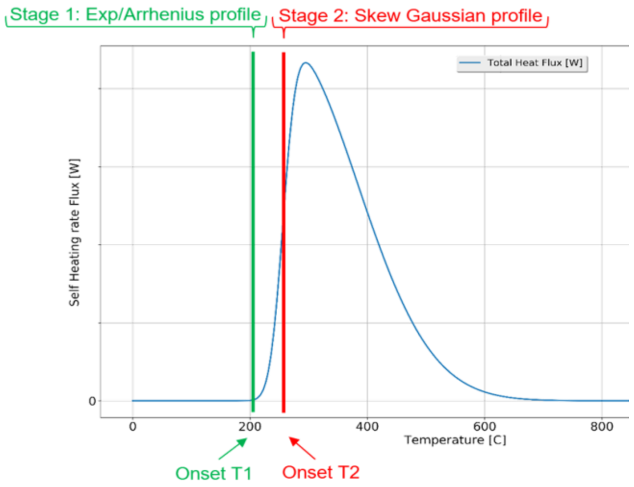
Heat transfer damping through gap filler

From Cell Test to Simulation Input

Measurements
Battery Abuse Test Database

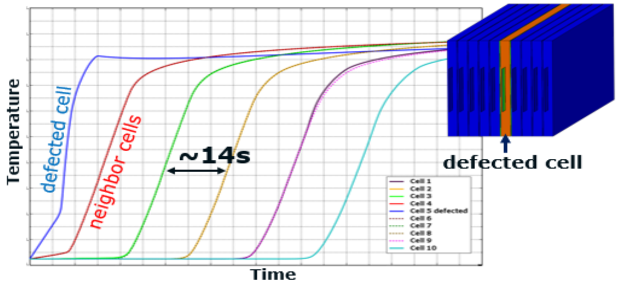


Heat input
Self heating rate



- Obtain **Temperature** Dependent **Body Heat Flux** representing Exothermic reaction during Thermal Runaway

3D Simulation
Thermal simulation



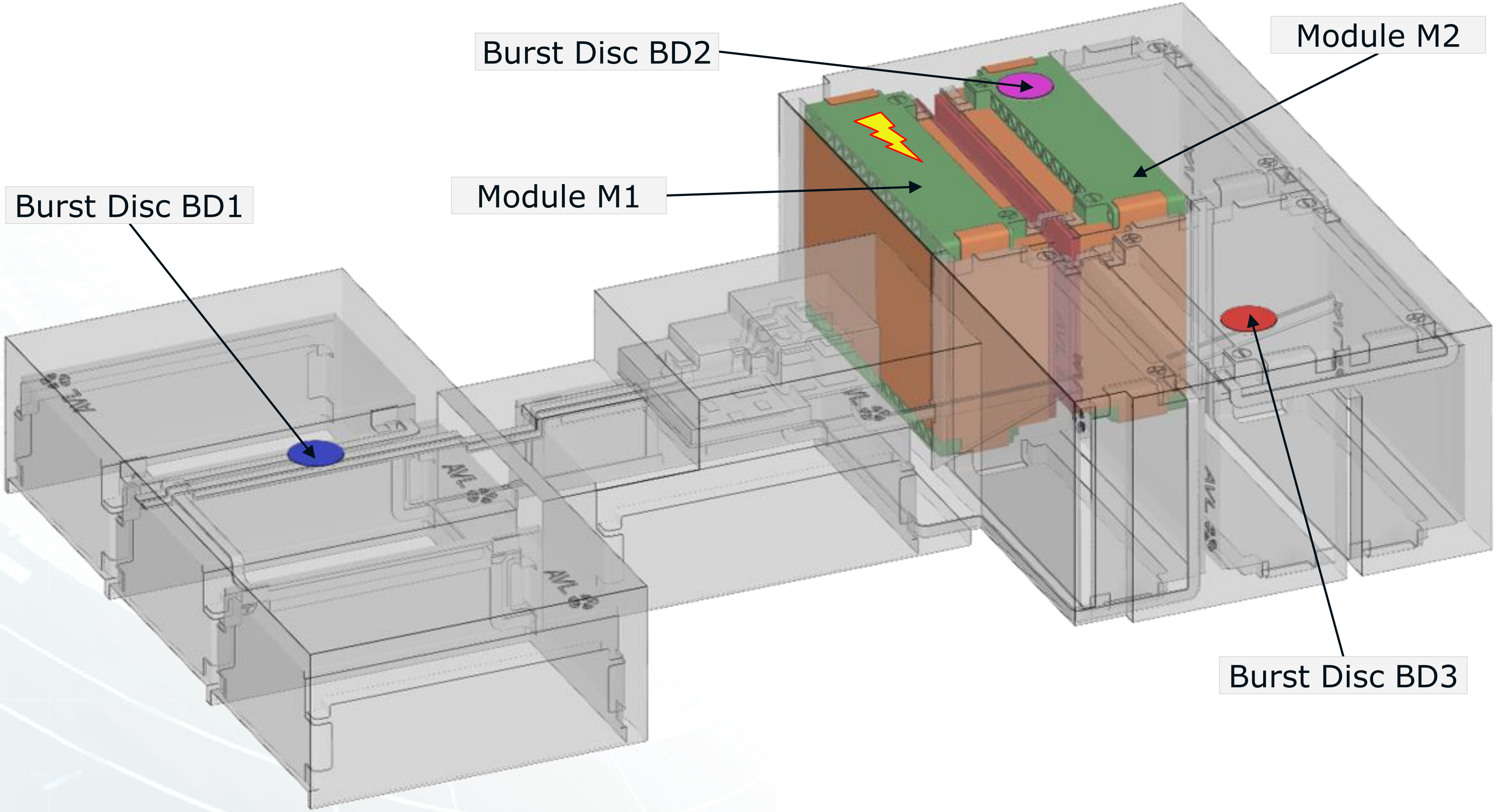
AVL FIRE™ M

- Transient CFD (Electro-) Thermal Heat Transfer Analysis
- Thermal propagation in battery module/pack

- Observe **if / how** thermal runaway propagation takes place.
- Suggest and develop strategies to **prevent** thermal runaway.
- Evaluate wave **propagation time** & **velocity** inside the cell and along the module.

Thermal Runaway, Pack setup

Complete pack



2D and 3D Simulation Results

2D Results (global and local)

Temperature, Pressure, Heat Flux, Operating Voltage/Current/Power,
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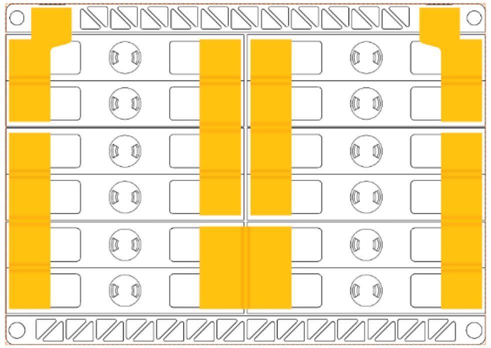
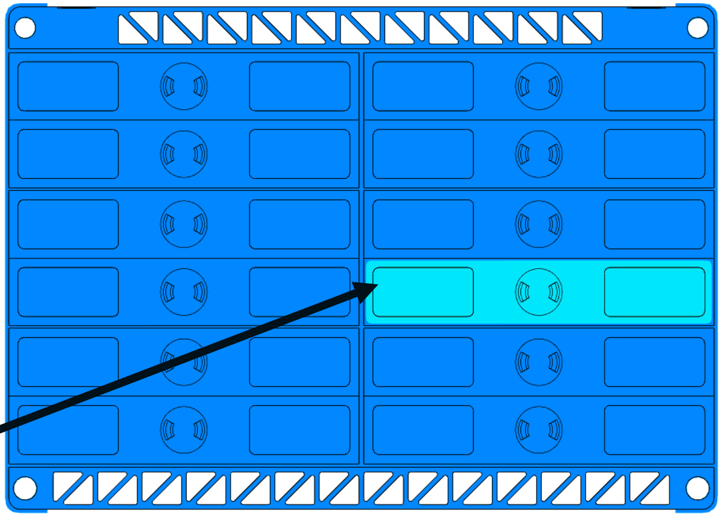
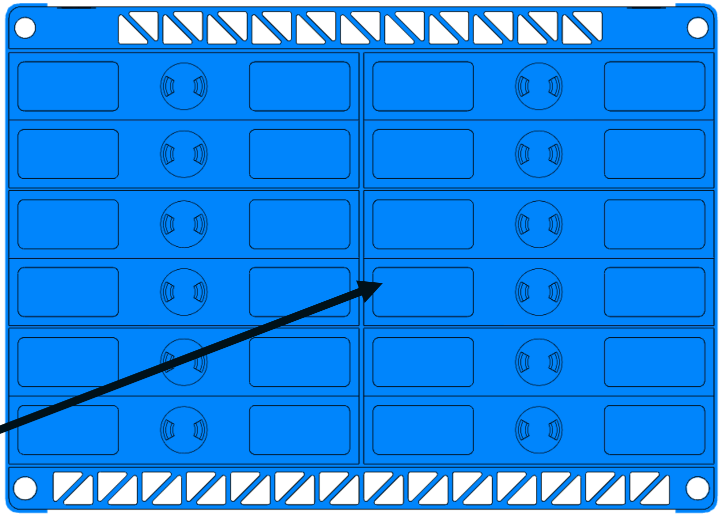
3D Results

Temperature, Pressure, Flow Structure (Velocitiy), SoC/DoD, Electric Potentials, Current Density (Vectors), Current Density, OCV, **Energy content**, Melting location, etc.





Thermal Propagation after Thermal Runaway in cell #3



Energy Content

2D and 3D Simulation Results

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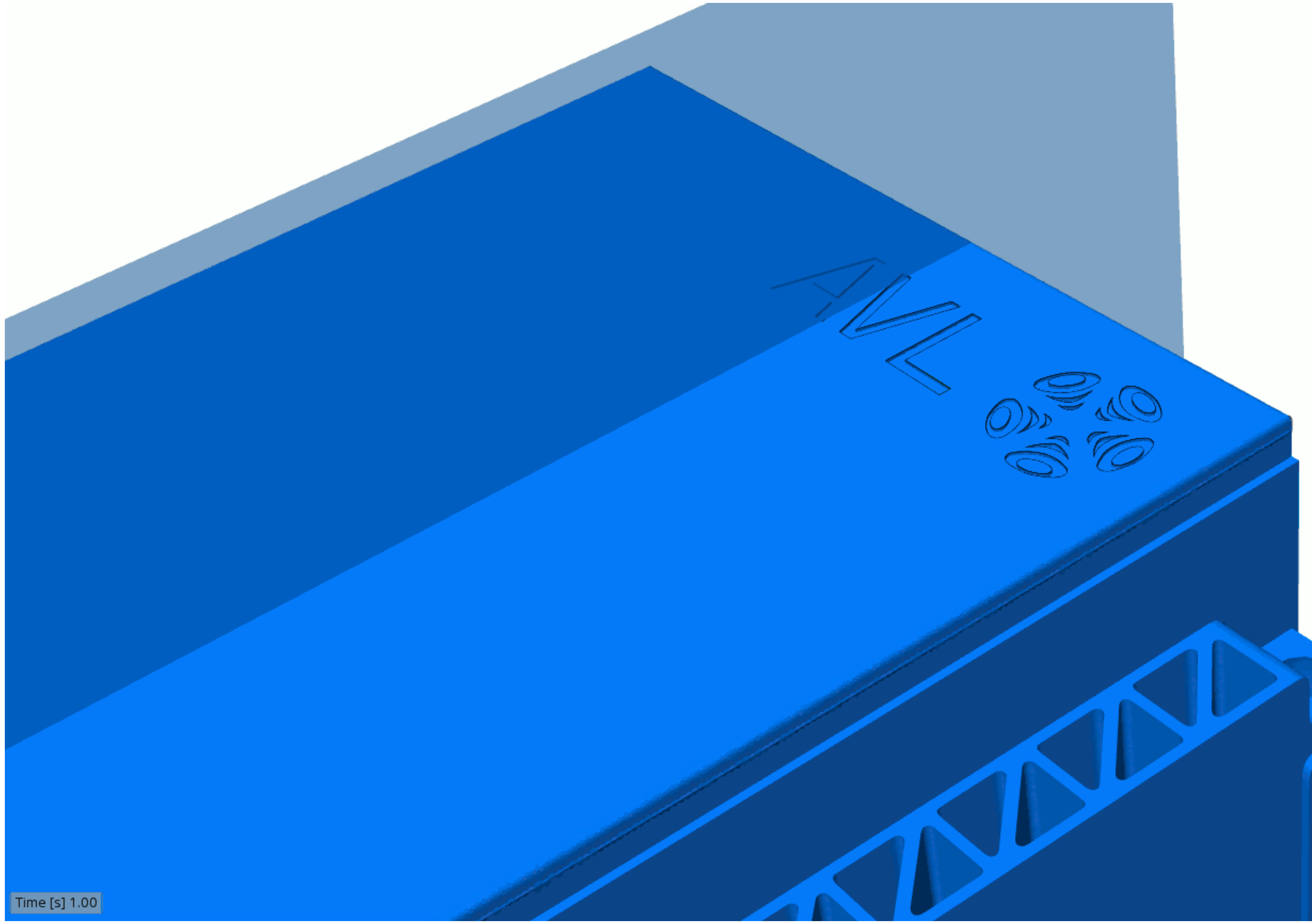

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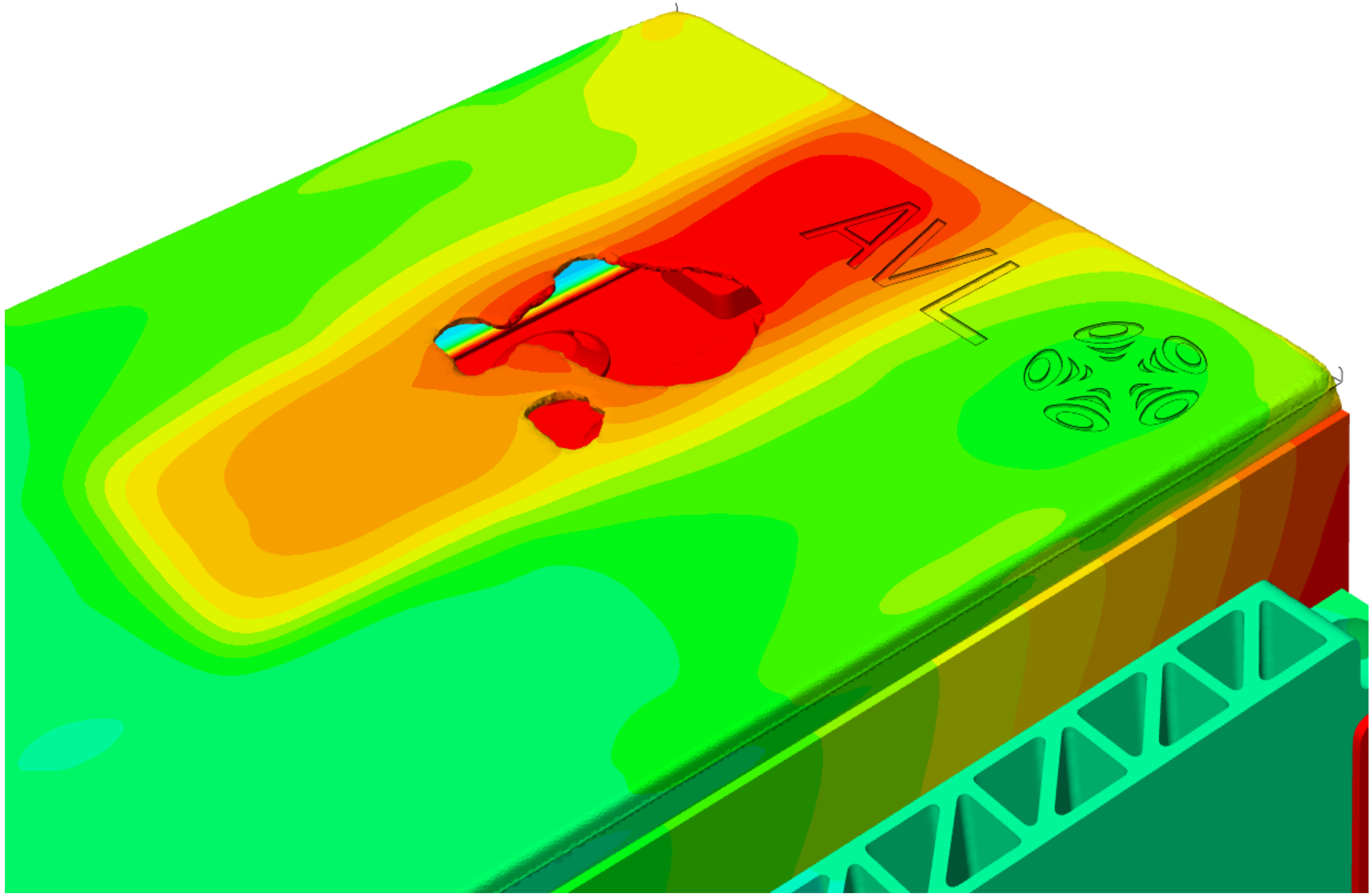

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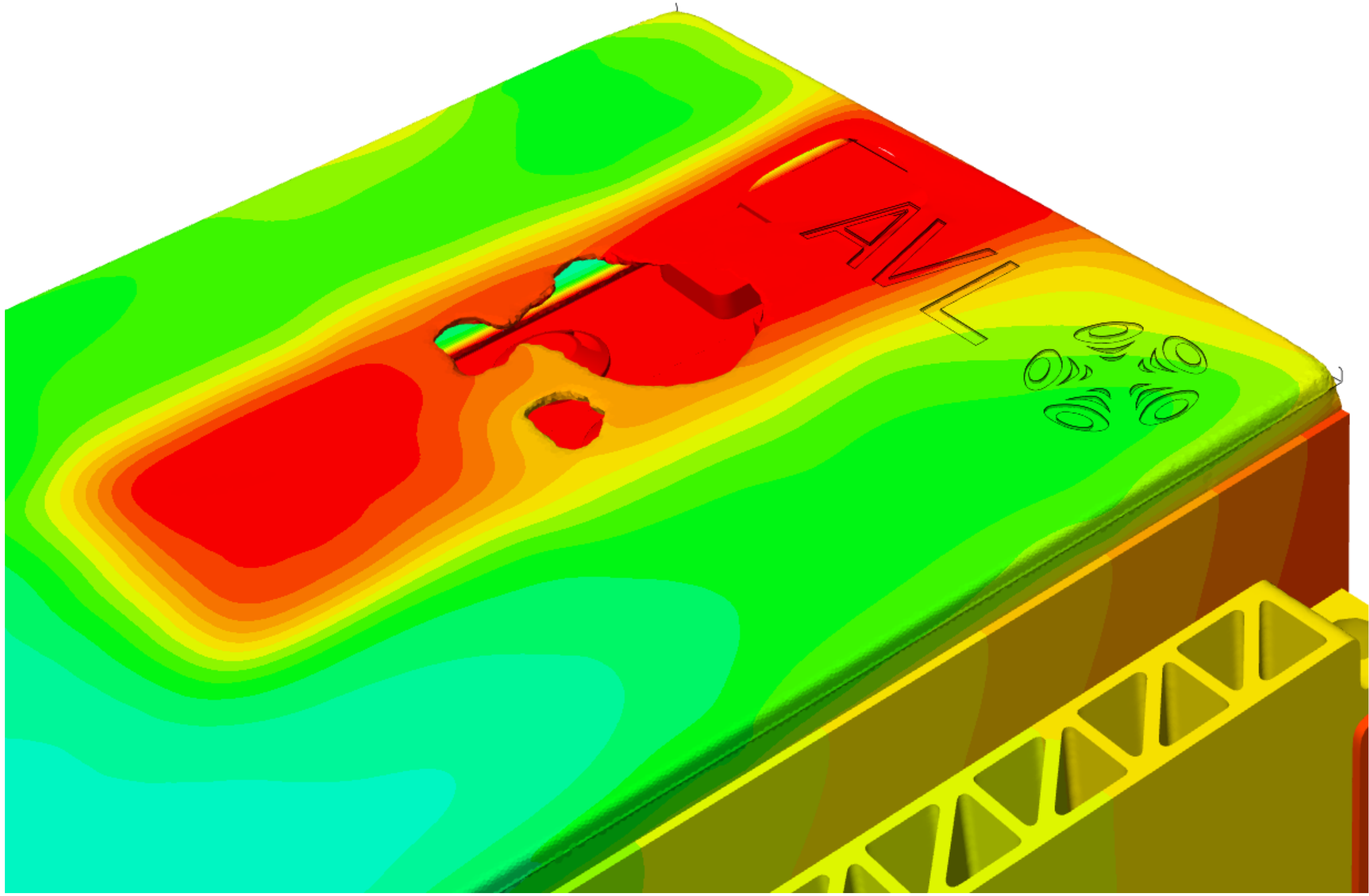
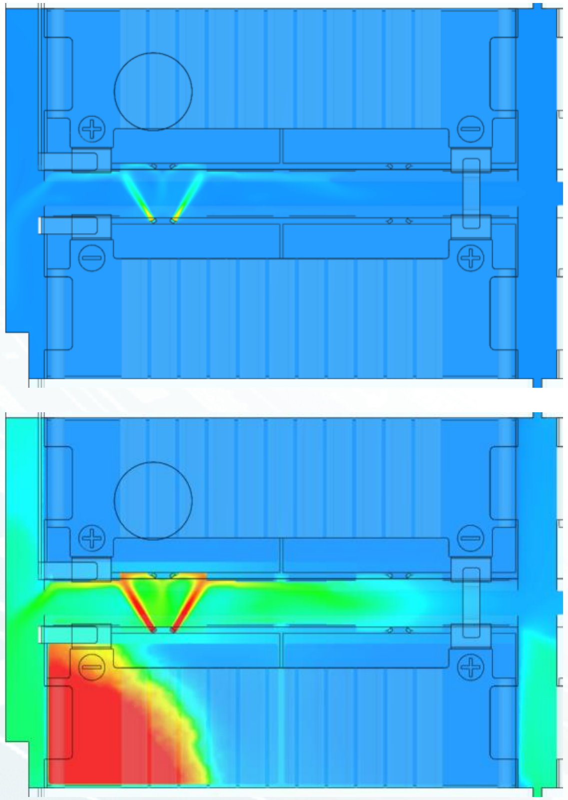
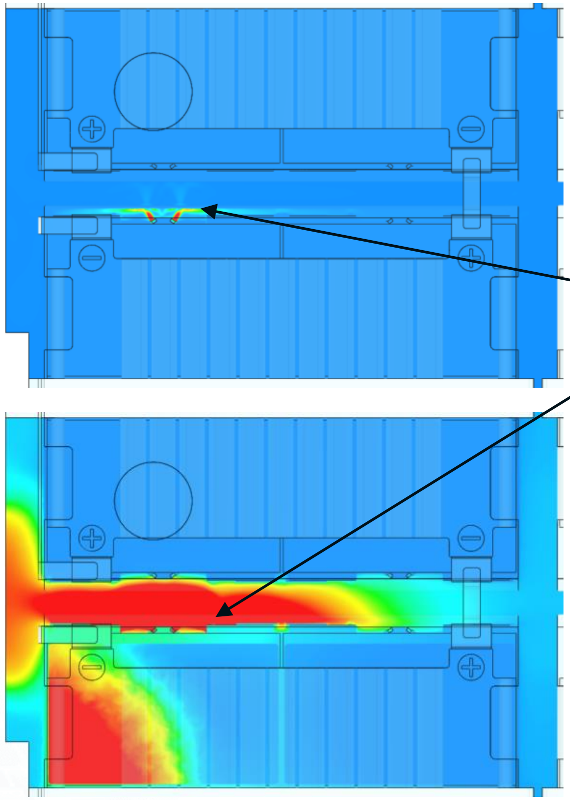


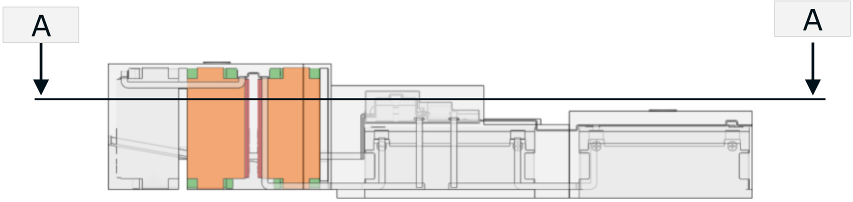
Complete Pack Simulation
Velocity/Temperature – BD and FB Comparison

BD2 | **BD2 + FB**





- Instead of directly hitting module M2, hot venting gas stopped by the module cover
- Venting gas pushed towards the sides of the modules

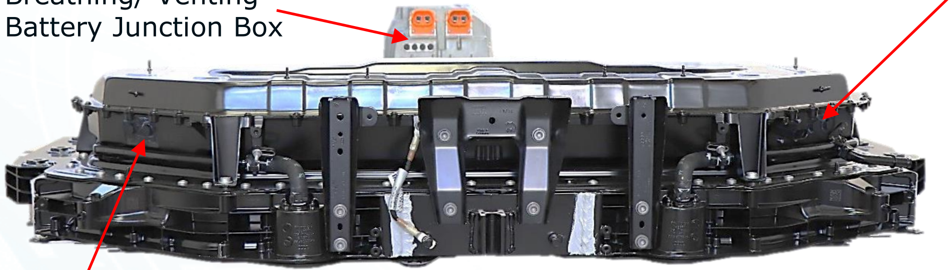


Flame Barrier → Prevents triggering of module M2

Venting Strategy, AVL Benchmarking

Audi e-tron

Breathing/ Venting
Battery Junction Box



Breathing/ Venting

Gegenüberliegende
Seite,
Überdruckventil?

Breathing
device

NIO ES8

Breathing/ Venting

Venting unit

Tesla Model 3

Breathing
E/E Section

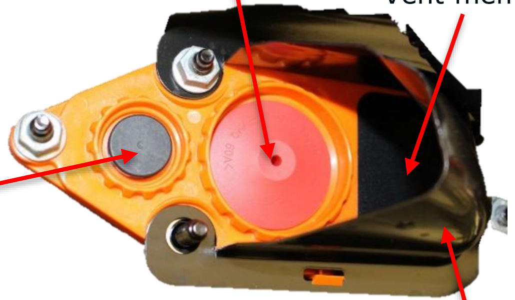
Breathing/
Venting

Breathing/
Venting

Vent plug

Vent membrane

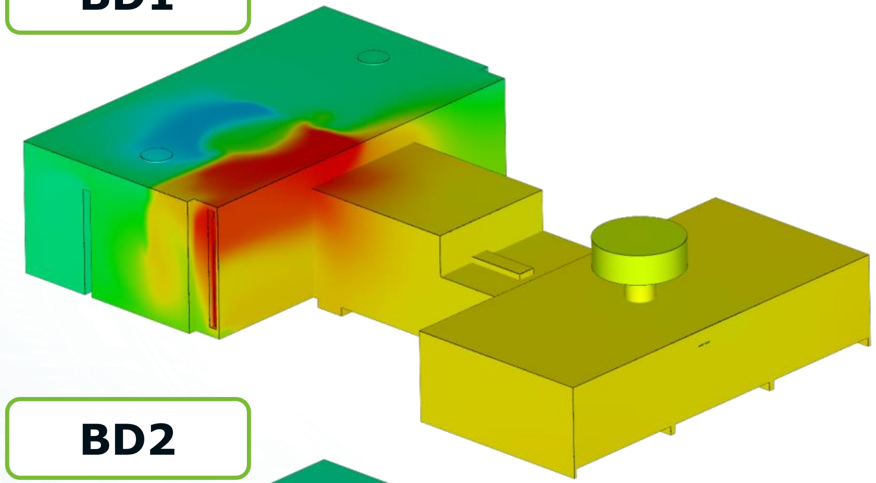
Breathing
device



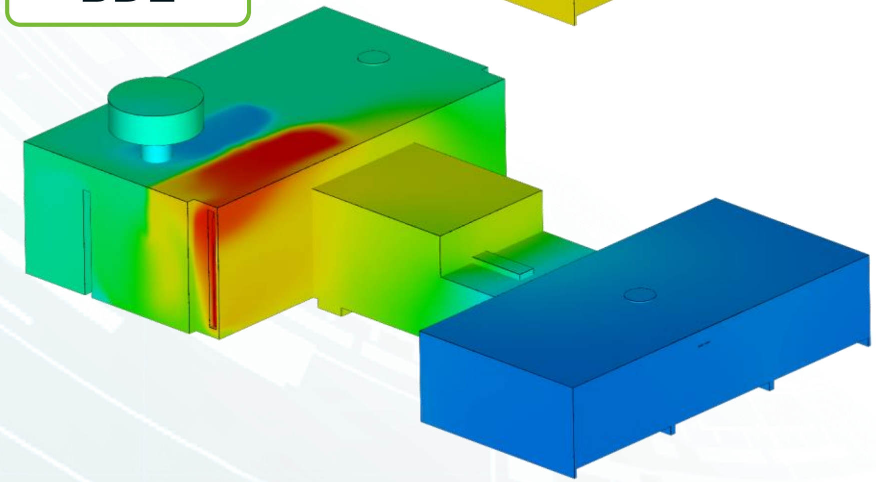
Guiding sheet metal

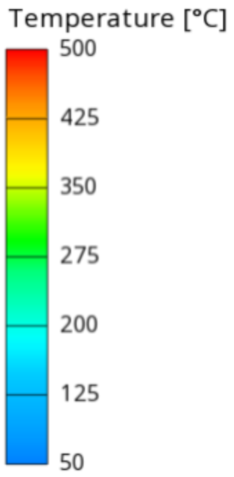
Complete Pack Simulation
Pack Temperature – BD Comparison

BD1

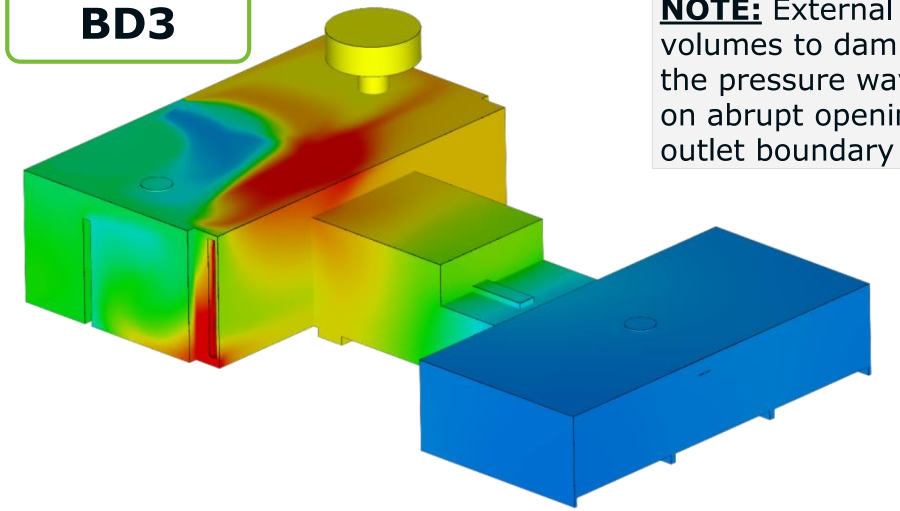


BD2





BD3



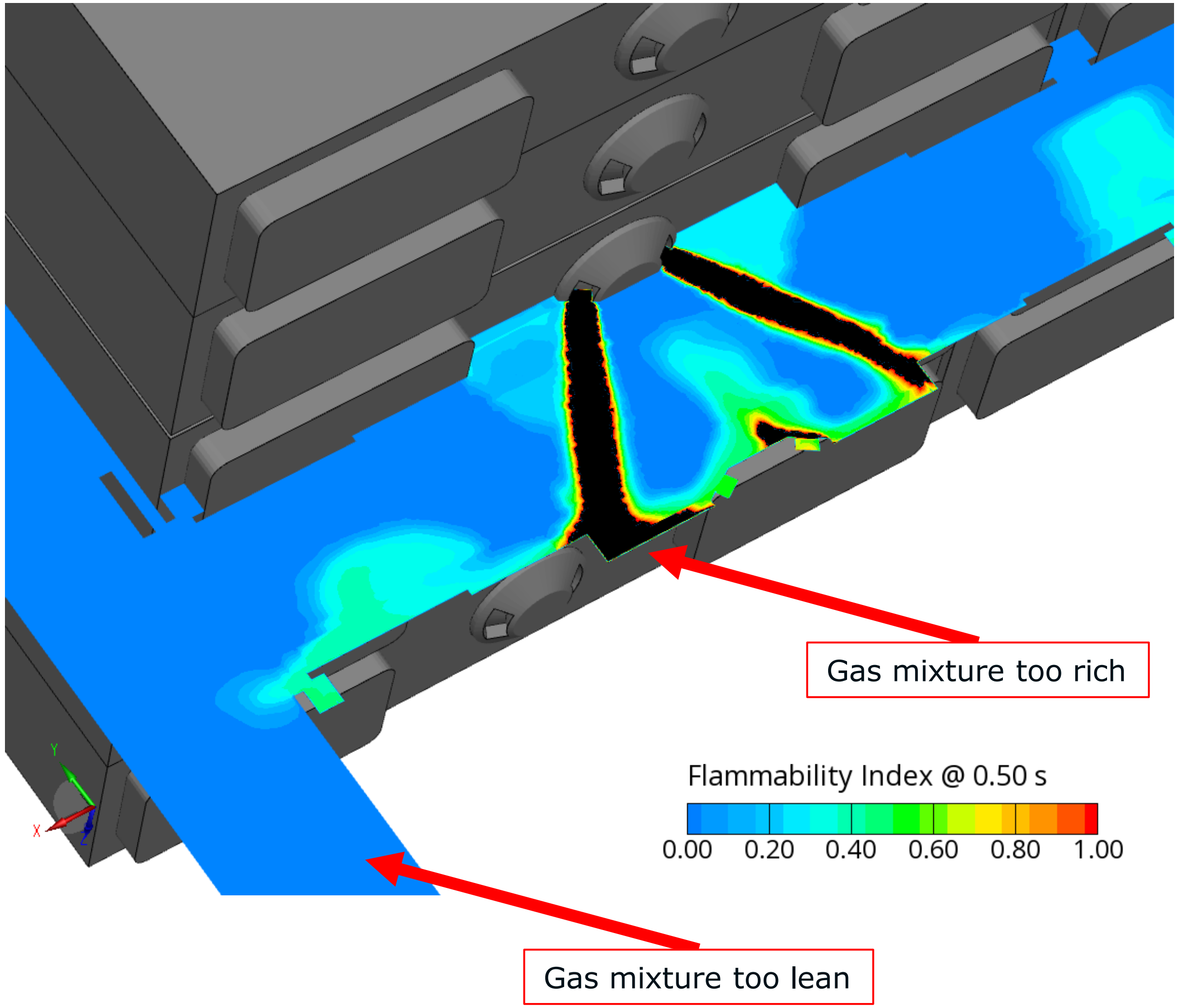
NOTE: External volumes to damp the pressure waves on abrupt opening outlet boundary

- The position of the burst disc strongly affects the pack cover temperature evolution → Important for sealing and structural integrity!
- Coupling to FE analysis required in battery pack development

Advantages and disadvantages of Burst Disc Position strongly dependent on the triggered module
→ More than one venting plug should be available

Use Case: Venting Gas Combustion

The Flammability Index indicates the propability of ignition of venting cases, if a suitable ignition source is available (e.g. hot metal particles)



2D and 3D Simulation Results

2D Results (global and local)

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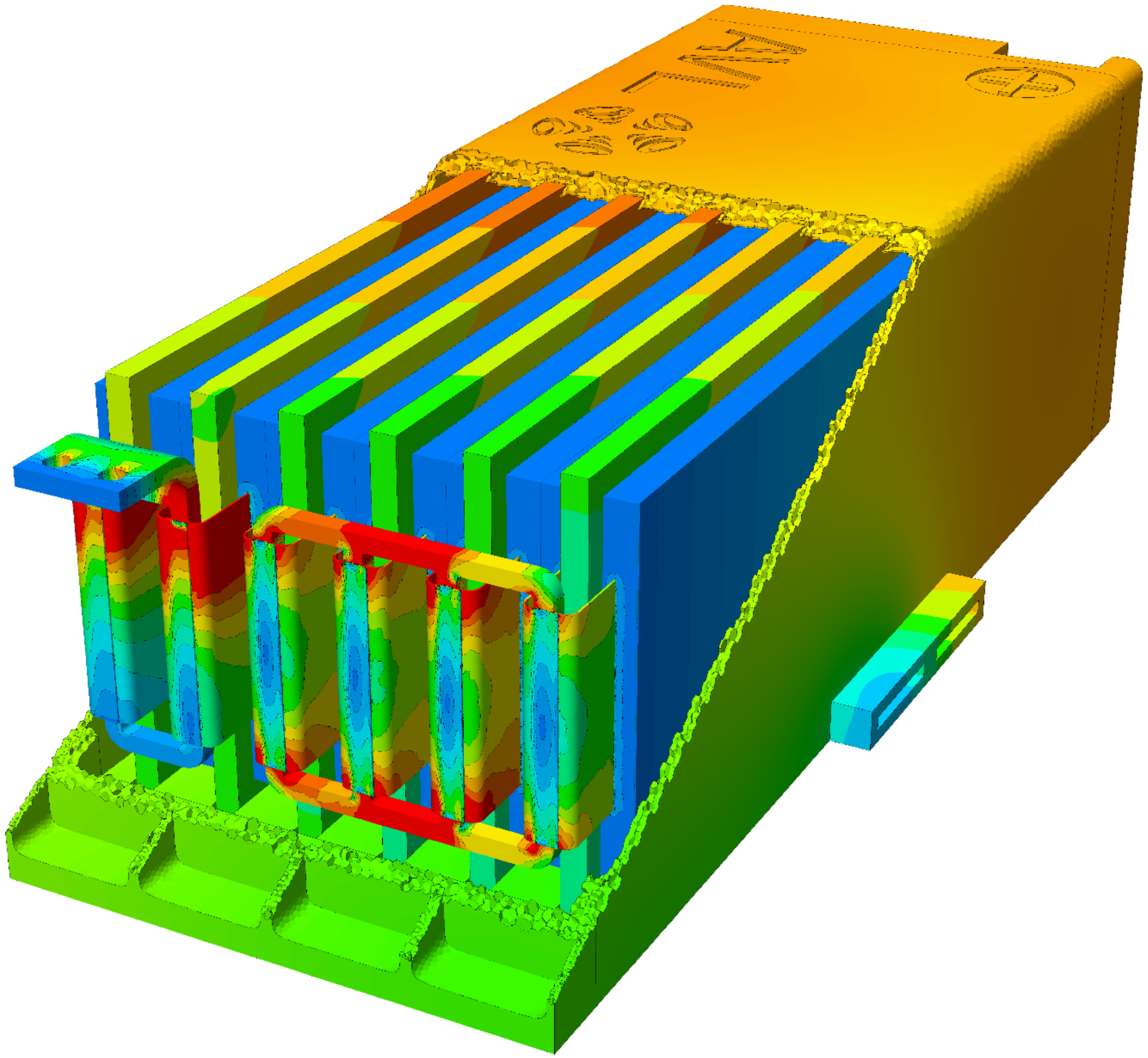
3D Results

Temperature, Pressure, Flow Structure (Velocitiy), SoC/DoD, Electric Potentials, Current Density (Vectors), Current Density, OCV, Energy content, Melting location, etc.

CRUSE™ M model input

Material and Geometry **information**, **Heat Transfer Coefficient**, Boundary Conditions, etc.



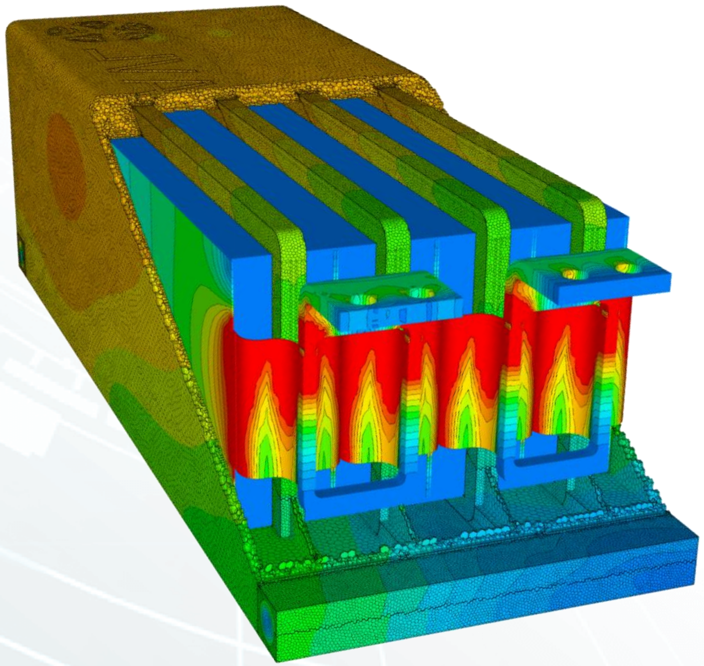
Model Compression and Handover

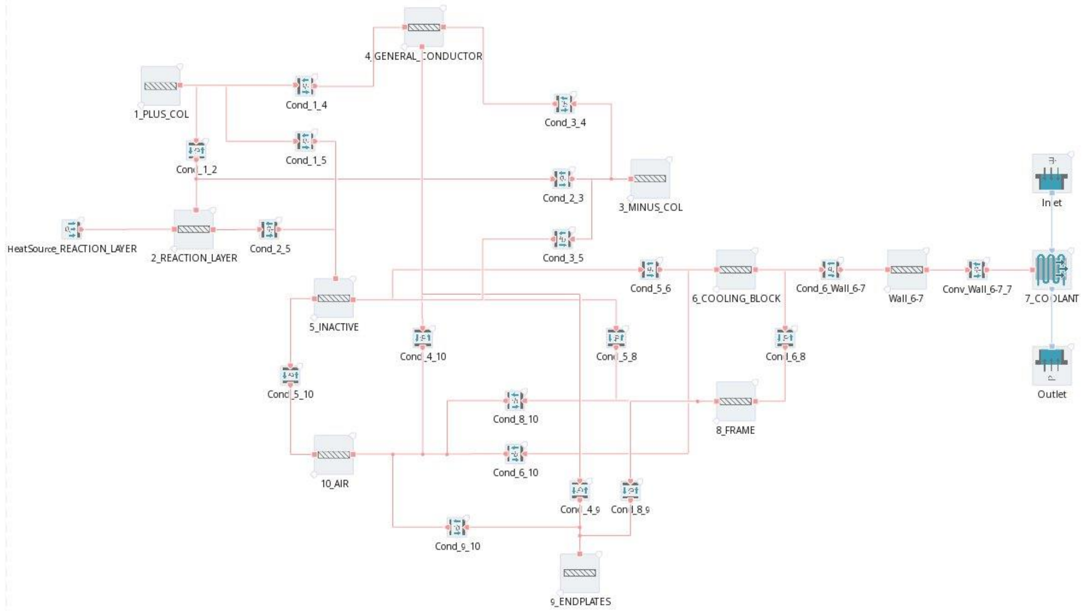
3D Simulation

AVL FIRE™ M

1D System

AVL CRUISE™ M





Model Compression and Handover

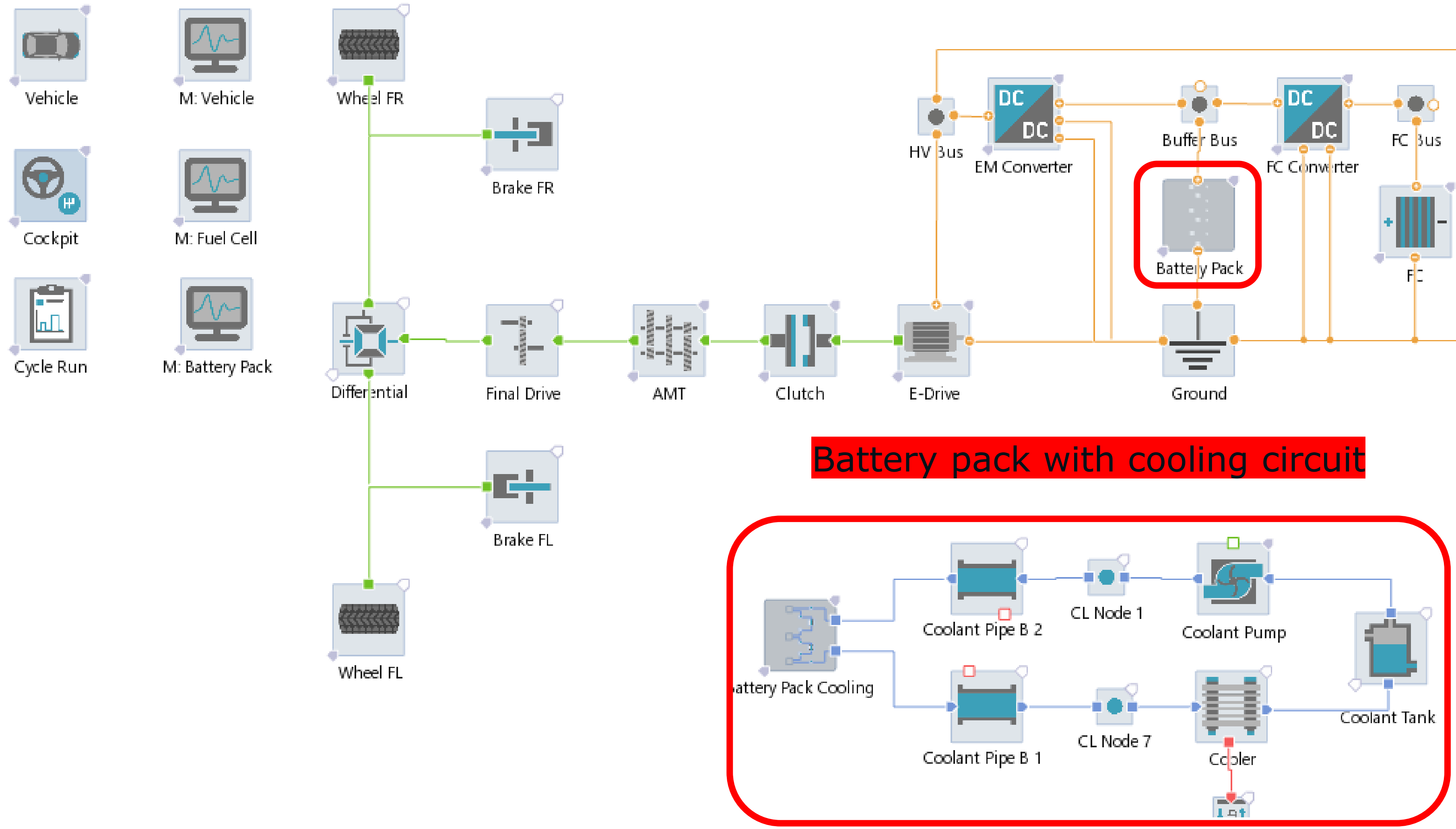
3D CFD Results

AVL FIRE™ M

CRUISE M

Battery Model

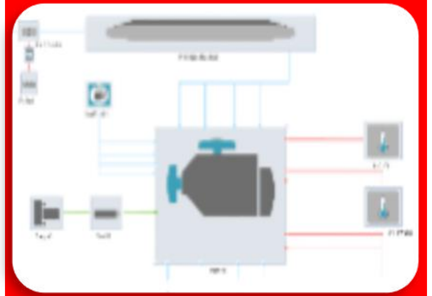
Vehicle Model – Overview



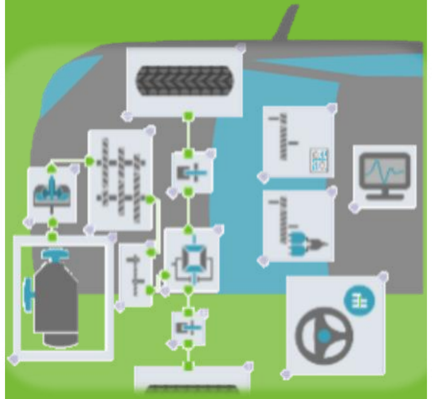
System Simulation

Handling multiple domains

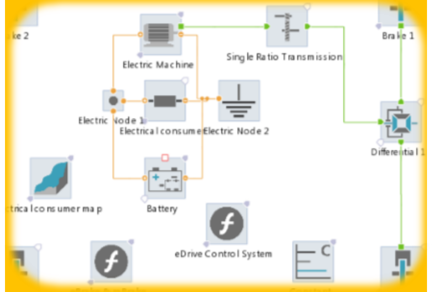
Thermal



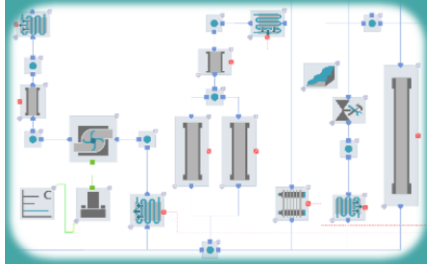
Mechanical



Electric



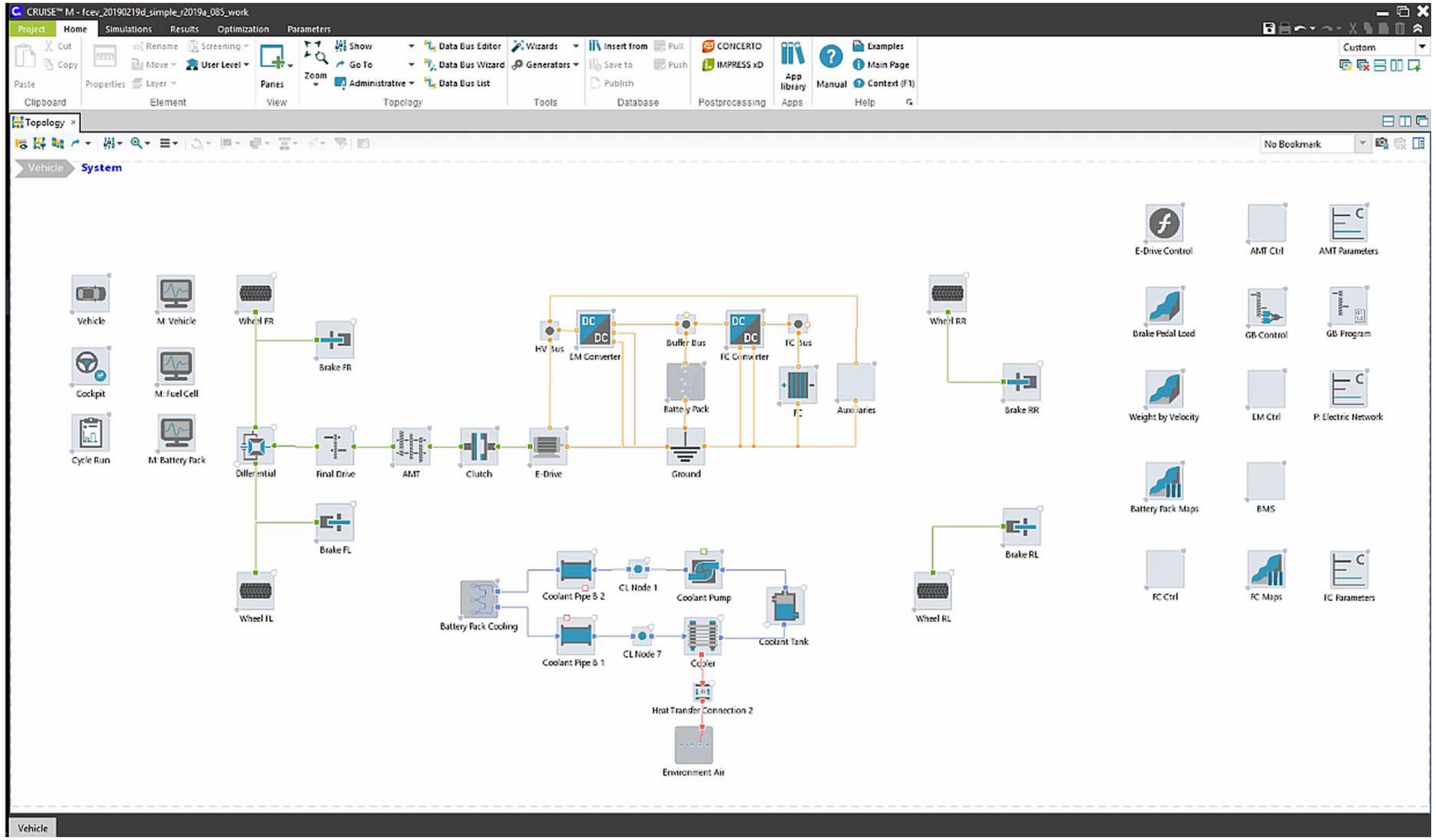
Fluid



Control

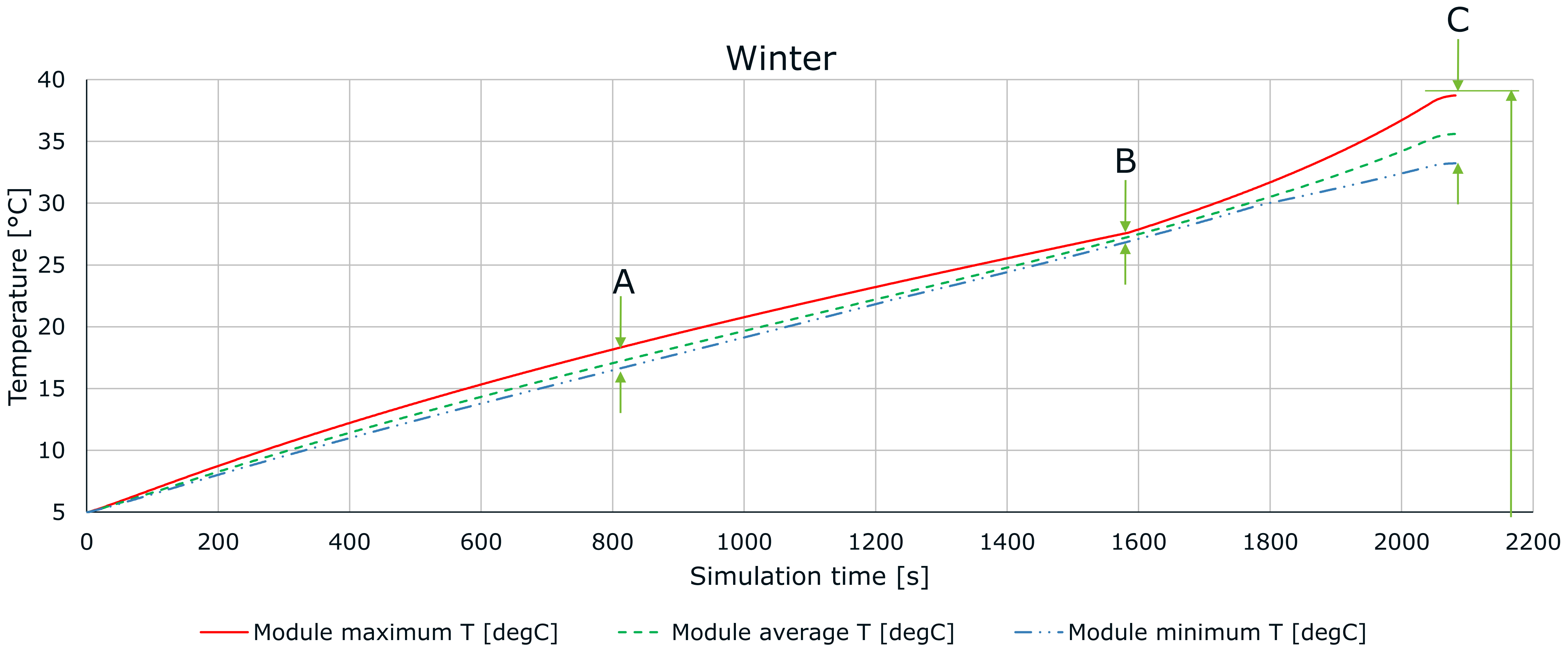
Vehicle Simulation

Complete model overview and run



Use Case – Season Sensitivity

Module temperatures: minimum-maximum-average



Use Case – Season Sensitivity

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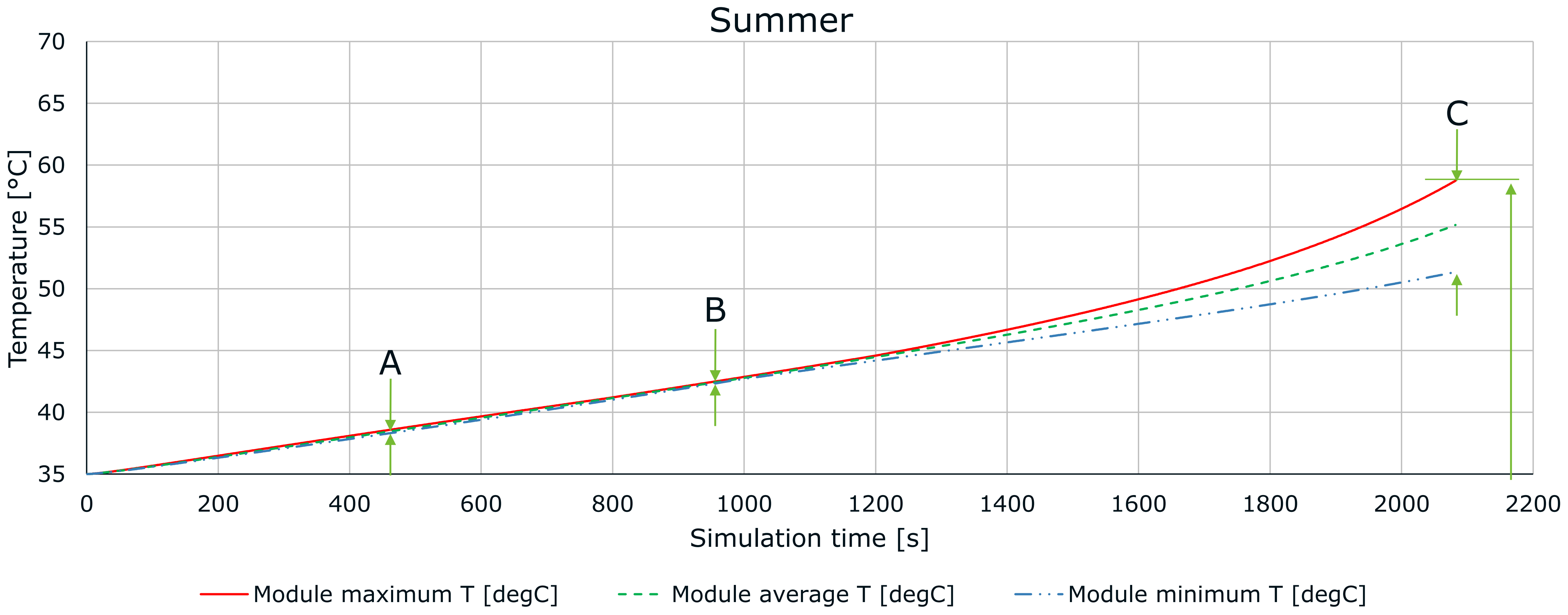

1D Vehicle System Analysis

Benefits

- **Virtual testing of components and control strategies** – controllable components during run-time
- Support of „**digital twin**" generation
- **Integration with real and virtual equipment** – component, system and controls
- **Flexible** choice of **missions** – stationary and transient multi-physical analysis
- **Concept comparison** considering physical properties, e.g.:
  - Module and/or pack **electric layout**, e.g. 180s1p vs 90s2p
  - Module and/or pack **cooling layout**, e.g. air vs liquid coolant
  - Driveline with **different** number and position of **electric machines**

Summary

At a glance

- ✓ **Fully scalable solution** from cell level to module to battery pack
- ✓ **Integrated solution** that covers entire range **from cell testing to vehicle integration** – and back to test bed (CRUISE™ M, HiL)
- ✓ **Automatic** battery **parametrization**
- ✓ Electro-thermal and **electro-chemical** model
- ✓ **Thermal and electrical network** in one tool
- ✓ **Automatic model compression and handover** from FIRE™ M to CRUISE™ M vehicle model
- ✓ **Easy** exchange of cells or battery layouts for **concept comparison**

Thank You

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