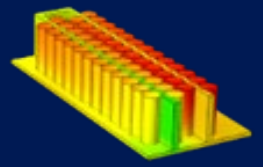


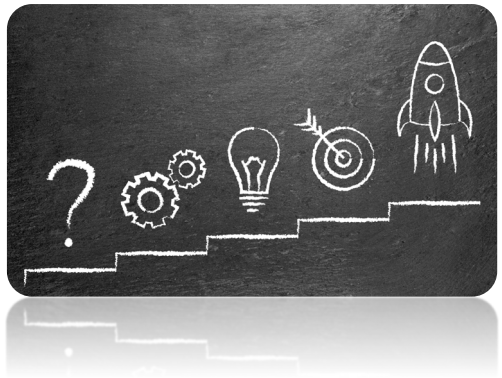
IAV’s multi-purpose 3D coupling solution for electro-physicochemical Battery models via COMSOL-API

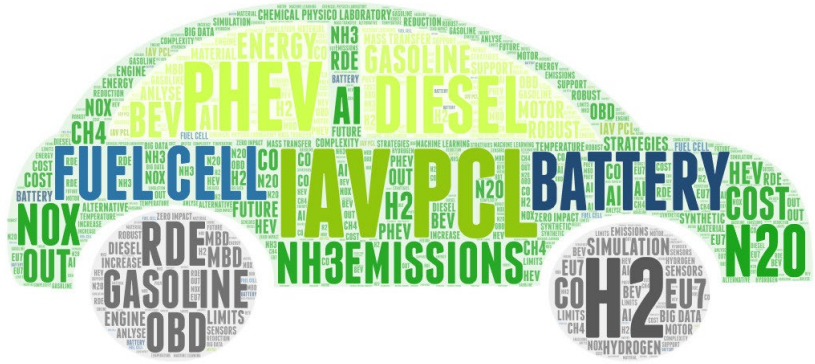
Comsol Conference Munich 2023

Dr. Jakob Hilgert, Jochen Schäffner, Dr. Maria Kalogirou, October 2023

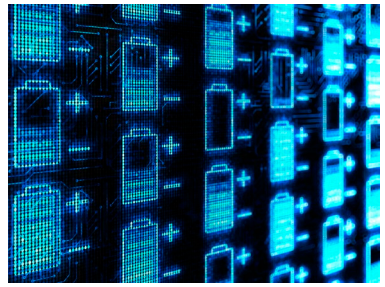
Introduction

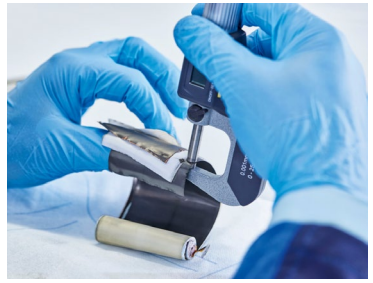
- **IAV** – A Tech Solution Provider
  - 40 Years of engineering experience
  - Global operation (24 location)
  - 7600 employees (67% engineers)

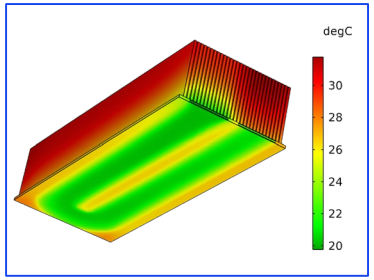




- **Battery and Material Science Lab**
  - Cell investigation, testing, disassembly
  - Small scale cell assembly
  - Physical characterization and parameter identification
  - Model development and calibration



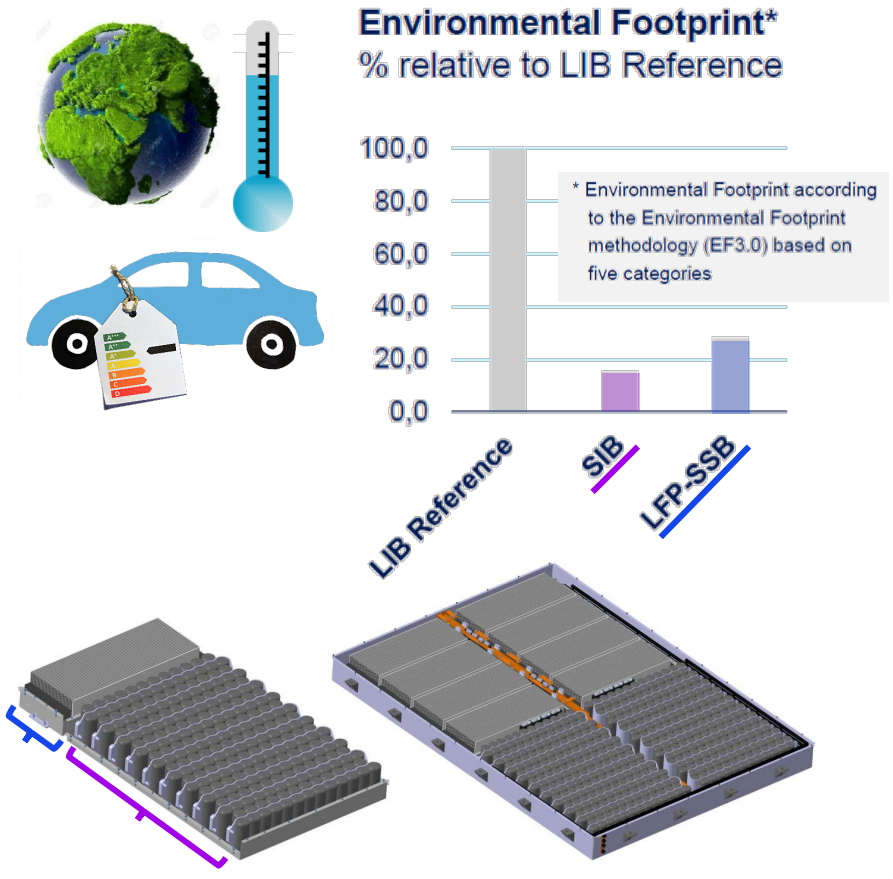




The Task

- Develop a Battery concept
  - that is environmentally friendly ➔ SIB, SSB
  - making use of novel battery cell technology potentials
    - quick-charge, low temperature operation, long life, safety
  - with individual demands and limits of application
    - low energy density, high temperature needed
  - by applying virtual engineering methods

  ➔ Novel Approach: The IAV **Twin Battery**



→ in this Presentation: design of thermal management and cooling system using coupled battery models

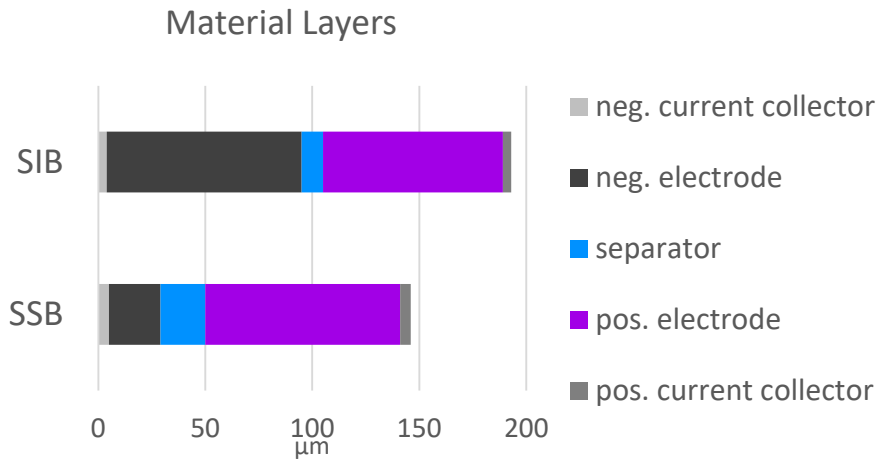
Cell Models

Comsol: Battery Design Module

- Two P2D cell models are implemented using COMSOL Battery Design Module

- A Sodium-ion technology
  - HC anode / PBA cathode
  - binary 1:1 liquid electrolyte
  - Representing cylindrical cell (H: 120 mm, D: 46 mm) ➔ ~19Ah
  - Energy density (cell level) 142 [Wh/kg]; 282 [Wh/l]

- A solid-state Lithium-ion technology
  - Lithium metal anode / LFP cathode
  - single-ion conductor electrolyte
  - Representing pouch cell (L: 600 mm, W: 115 mm) ➔ ~61Ah
  - Energy density (cell level) 300 [Wh/kg]; 600 [Wh/l]

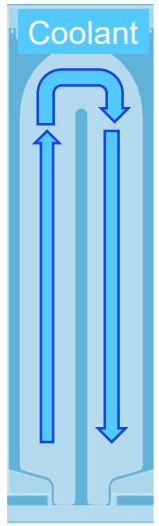


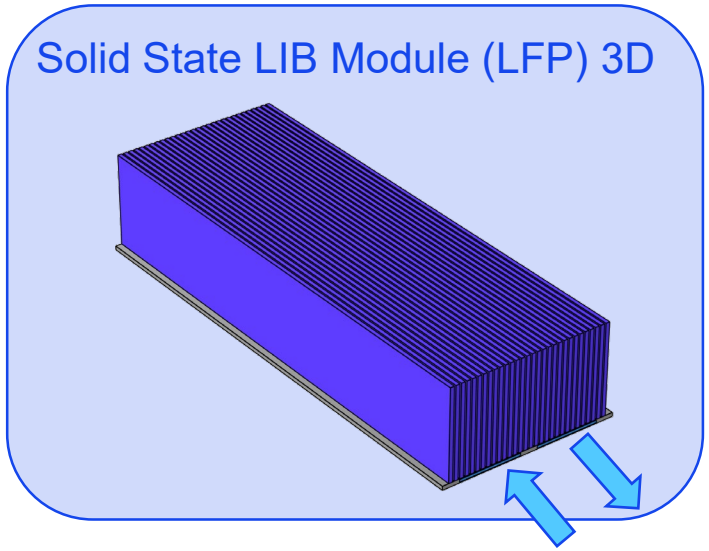
- Cell design based on simulation studies and calculations for capacity, energy density, quick-charge and internal resistance targets
- Material parameters from libraries & literature

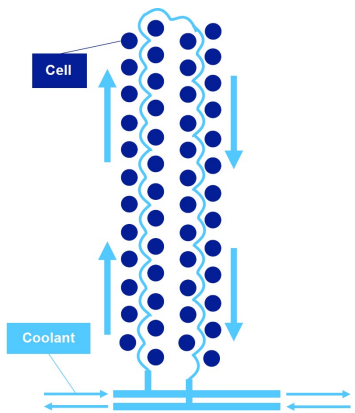
From Cells to Modules

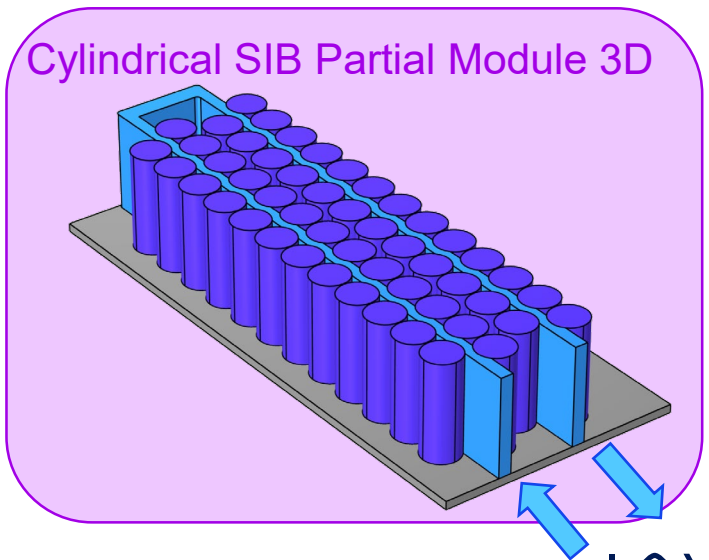
Comsol: API, Heat Transfer, CFD

- The cell-models are abstracted to JAVA code and multiplied using COMSOL API to generate a representative population of individual cells
- These are coupled into simplified 3D partial battery pack thermal models using COMSOL Heat Transfer Module to account for dissipated Energy and Heat conduction
- Cooling circuits are implemented using COMSOL Multiphysics CFD capabilities
- The electrochemical performance is investigated at vehicle level to account for system interactions over varying boundary conditions (e.g., temperature).





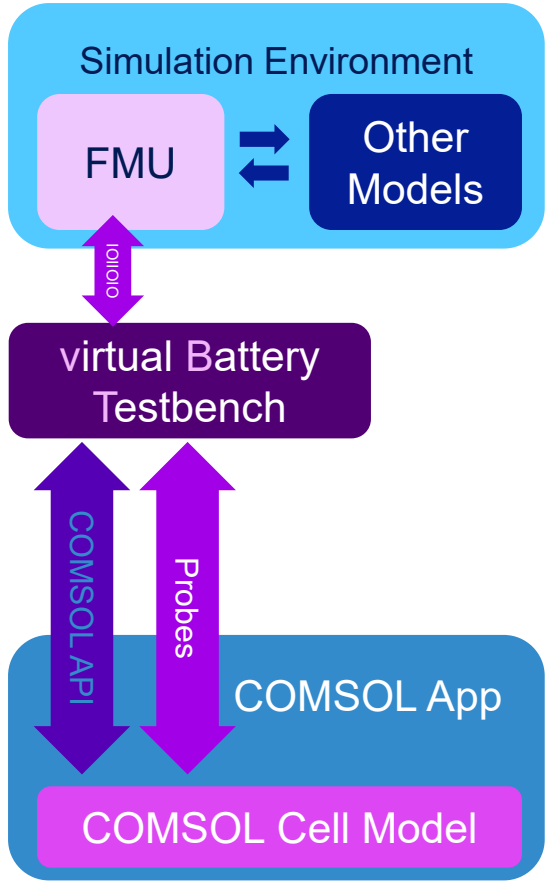




Coupling
Comsol: Application Builder, API

- The Module Models are packaged into Apps using the COMSOL Application Builder
- Interfacing Java code (COMSOL API) is used to provide remote control abilities
  - Initialize individual cells (temperature, capacity, SOC, SOH, …)
  - Control and input signals (current, ambient and coolant temperature, coolant flow)
  - Read probes during simulation (cell voltages, temperatures, power dissipation, coolant outlet temperature)
- FMU Frontends are implemented to interface with the COMSOL Apps

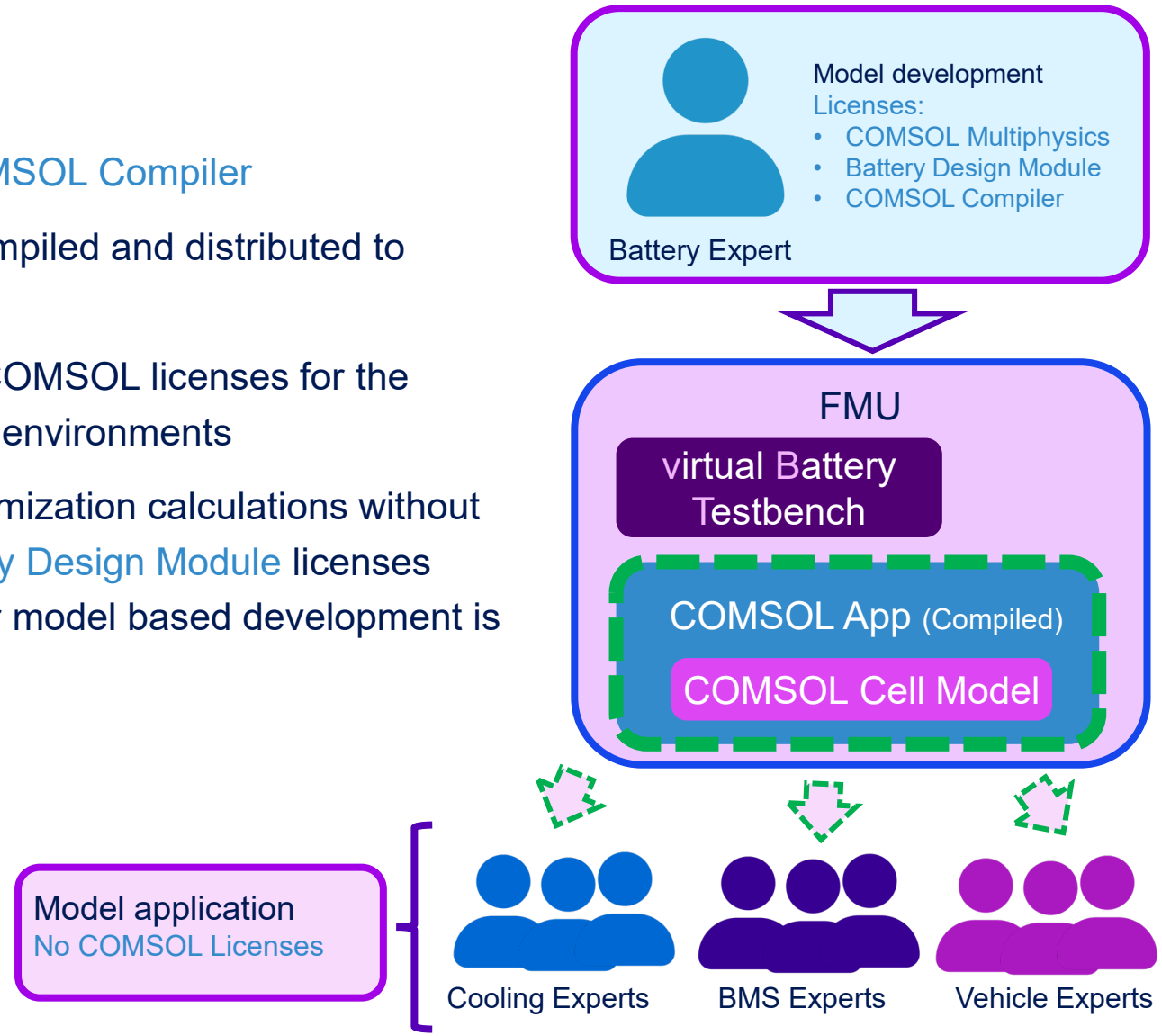
- These FMUs are then coupled to vehicle simulation environments in 3rd party software (e.g., INCA-FLOW™, GT-SUITE™, SIMULINK® etc.) for Co-simulation.



Compile and Distribute

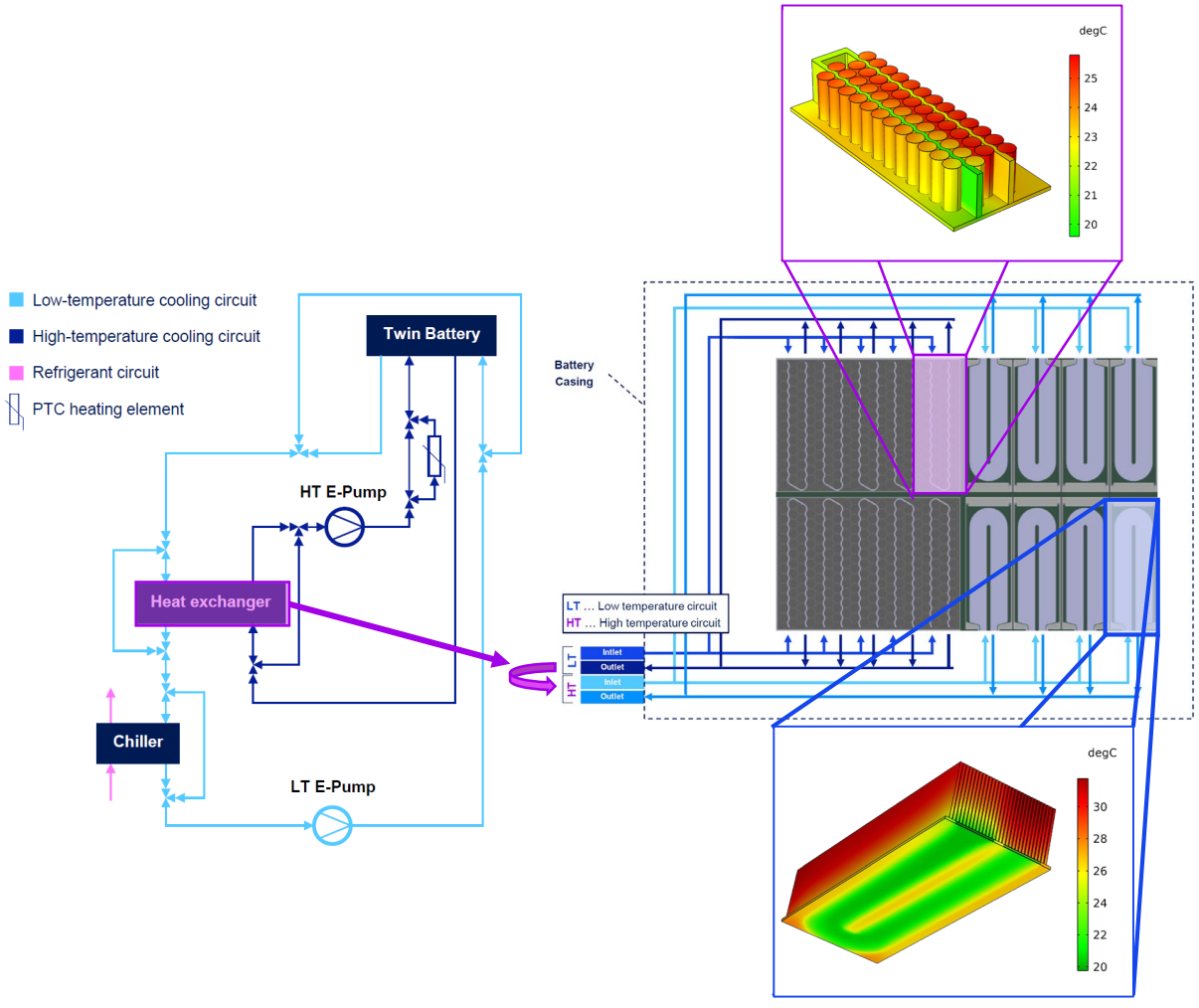
Comsol: Compiler™

- A very beneficial option at this point is the COMSOL Compiler
- The battery module COMSOL Apps can be compiled and distributed to specialists in other fields
- Using compiled Apps eliminates the need for COMSOL licenses for the application of models in distributed developing environments
- Cooling system engineers can run parallel optimization calculations without access to any COMSOL Multiphysics or Battery Design Module licenses within their usual tool chains ➔ acceptance for model based development is greatly improved



Integration and Application

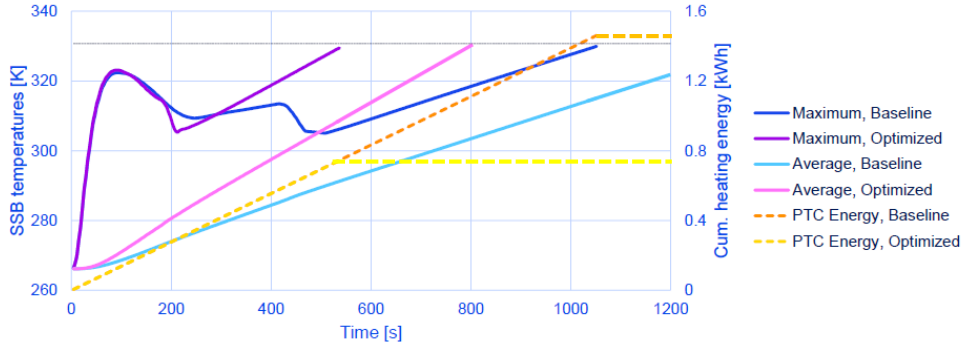
- Simulation environments runs coupled vehicle, cooling system, BMS and battery models
- The COMSOL Apps return voltage, SOC, temperatures, and power dissipation as inputs to BMS and cooling system
- All internal cell states are available for interpretation to the design engineer
- Impact of cooling system design choices on battery performance can be evaluated immediately
- Advanced heat management concepts can be evaluated ➔ e.g. SIB waste heat used for SSB conditioning at cold start



Results

- Verification of concept performance by coupled multiscale and multi domain simulation
- Coupled 3D cell temperatures, distributed P2D chemistry and 1D cooling circuits in an electric powertrain model
- Very fast on-demand activation of solid state cells can be achieved with partial pre-conditioning with SIB waste heat
- Optimized thermal management contributing to shortening the time and energy input needed for SSB activation at cold conditions
- **Demonstration of the twin battery concept overcoming major disadvantages of single battery technologies**

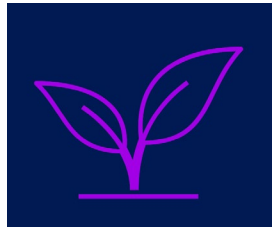
SSB heat-up w/wo optimized thermal management



Coupled 1D-3D-EPCM WLTC simulation result: Thermal management concept optimization for active SSB heating with PTC, -7°C [1]

[1] Dipl.-Ing. M. Sens, Dr.-Ing. A. Fandakov, Dipl.-Ing. M. Clauß, Dr.-Ing. J. Werfel, P. Tourlonias, M.Sc. M. Prüger, M.Sc. E. Özkan, Dr.-Ing. C. Danzer, Dr. rer. nat. C. Kruschel, Dipl.-Ing. S. Meyer, Dr.-Ing. A. Joos, Dipl.-Ing. M. Kratzsch, "*Towards a Sustainable Vehicle Concept Part 1: The High-Voltage Battery - Technologies and Methods*"

Summary and Conclusion



- IAV has established a holistic development process for batteries
  - design optimization of future battery concepts utilize EPC battery models and coupled simulation environments
  - A multi-purpose 3D coupling approach greatly extends the applicability of COMSOL battery models in automotive system development
  - Model-based development becomes readily available within many existing toolchains using COMSOL Application Builder in conjunction with COMSOL Compiler

- The **Twin Battery** concept combines advantages of SIB and LFP-SSB within one battery
  - An innovative thermal management concept uses waste heat of the SIB cells to heat LFP-SSB cells to their operational temperature window

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