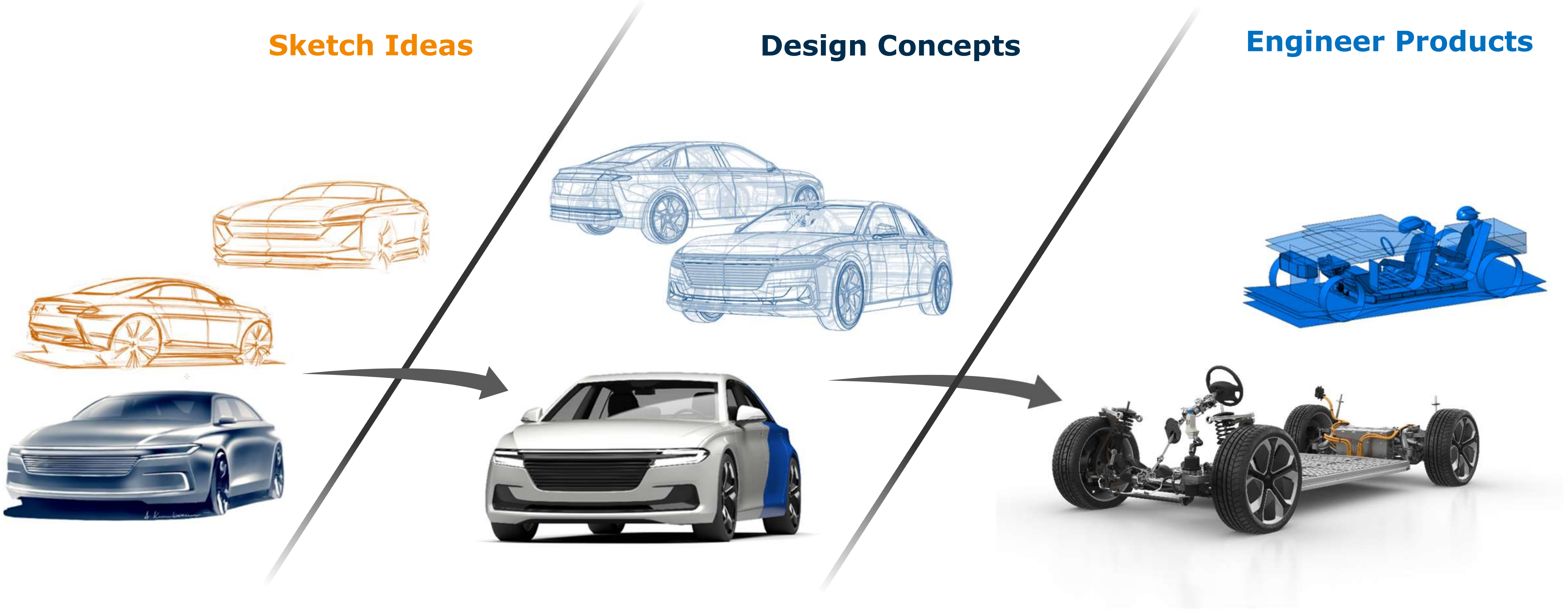
FOR VIRTUAL DEVELOPMENT

AVL Virtual Twin for Battery Energy Assessment

Jürgen Schneider
Advanced Simulation Technologies

From Vision to Product



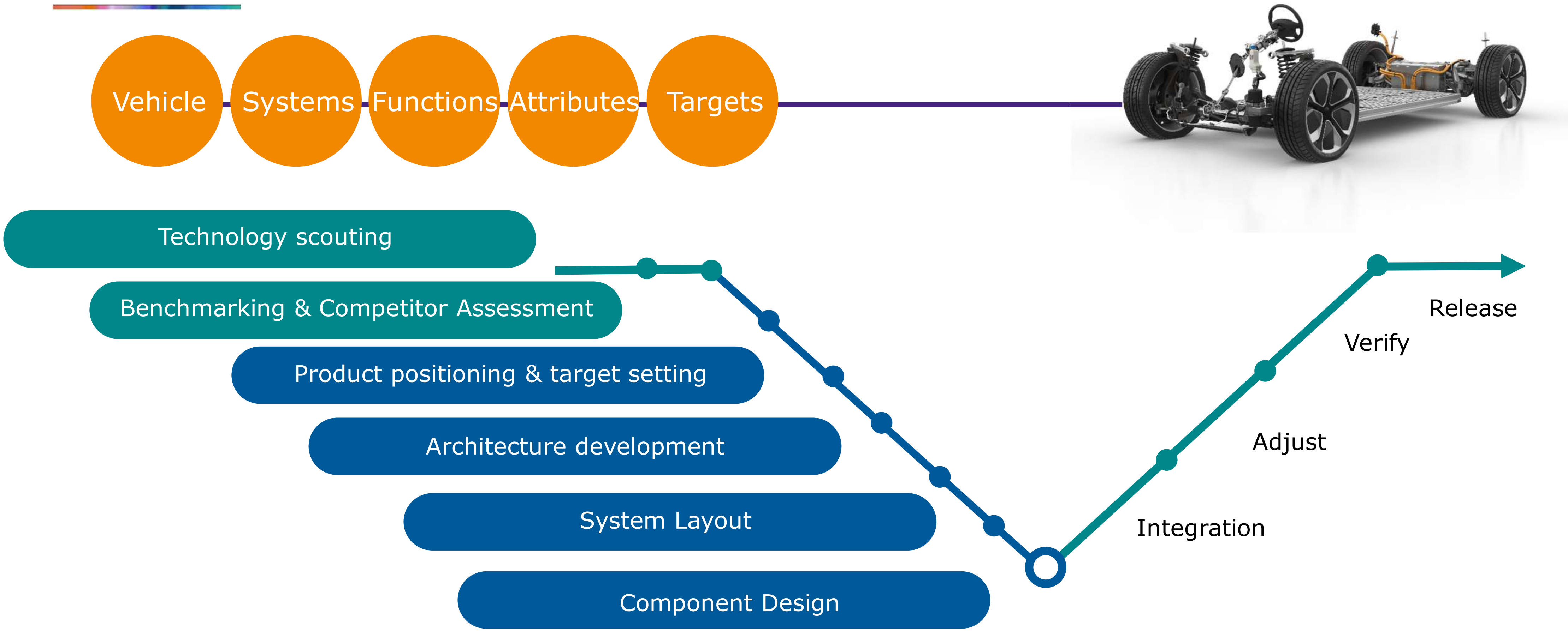
Sketch Ideas

Design Concepts

Engineer Products

Reimagining motion/mobility required a smooth process from great ideas to successful products

Product Specification



Vehicle

Systems

Functions

Attributes

Targets

Technology scouting

Benchmarking & Competitor Assessment

Product positioning & target setting

Architecture development

System Layout

Component Design

Integration

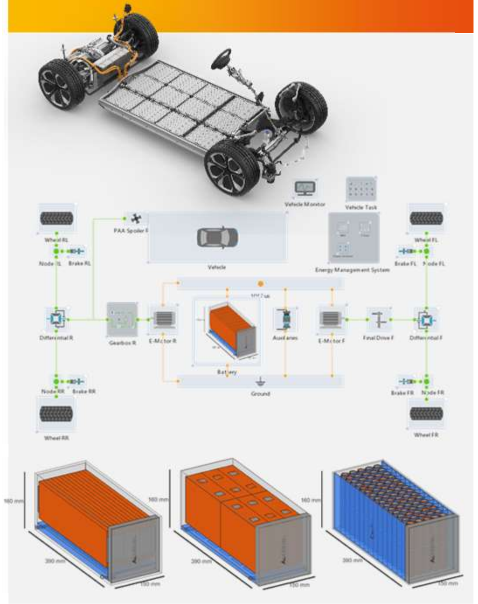
Adjust

Verify

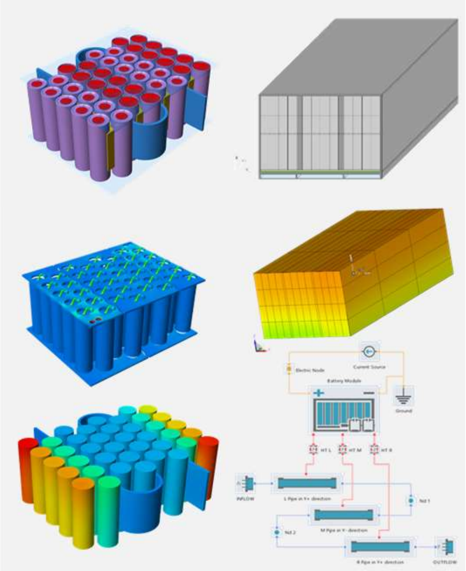
Release

Battery Modelling

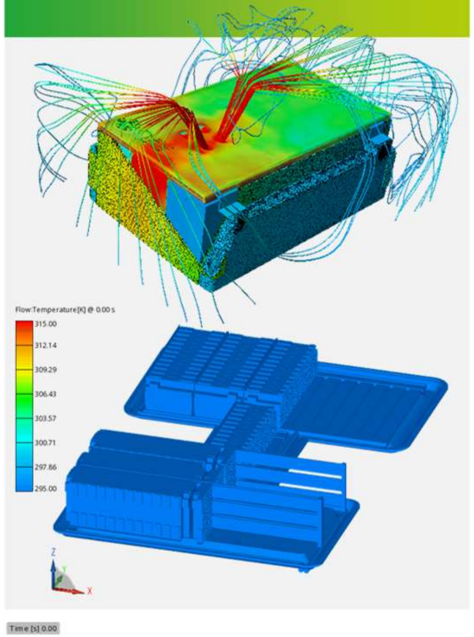
Concept and Layout



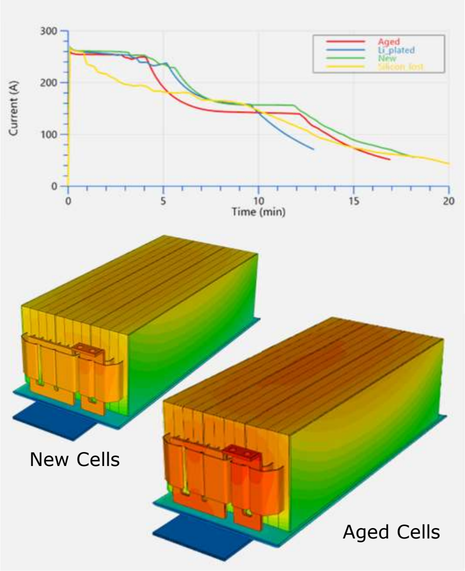
Active Safety



Passive Safety



Battery Life



Master battery development through virtualization with AVL CRUISE™ M and AVL FIRE™ M

AVL’s Simulation Solutions for E-Mobility

CRUISE™ M

- **Multi-physics system simulation tool**
- **Real-time capable/direct Simulink interface**
- Vehicle and powertrain concept analysis
- Sub-system layout
    - Mechanical driveline, Electrical network an Thermal system, Control signals

⇩

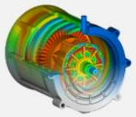
- E-drive performance and efficiency
- Battery cell (equivalent circuit, electrochemical DFN, BATEMO, FMU support)
- Cell to Module to Pack, Cell to Pack
- Module/Pack cooling, thermal safety
- Fast-charging optimization
- Battery ageing and lifetime assessment

⇩

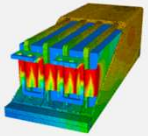
- Virtual Integration
- Virtual Calibration

FIRE™ M

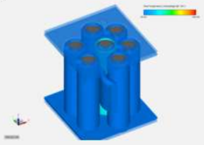
- **3D CFD simulation tool**
- **Workflow based modelling**



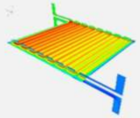
- EM forces
- E-motor cooling



- Electro-chemical cell
- Battery module/pack cooling
- Thermal runaway (melting/propagation, flammability, particle release, etc.)



- Battery venting gas (considering burst discs)



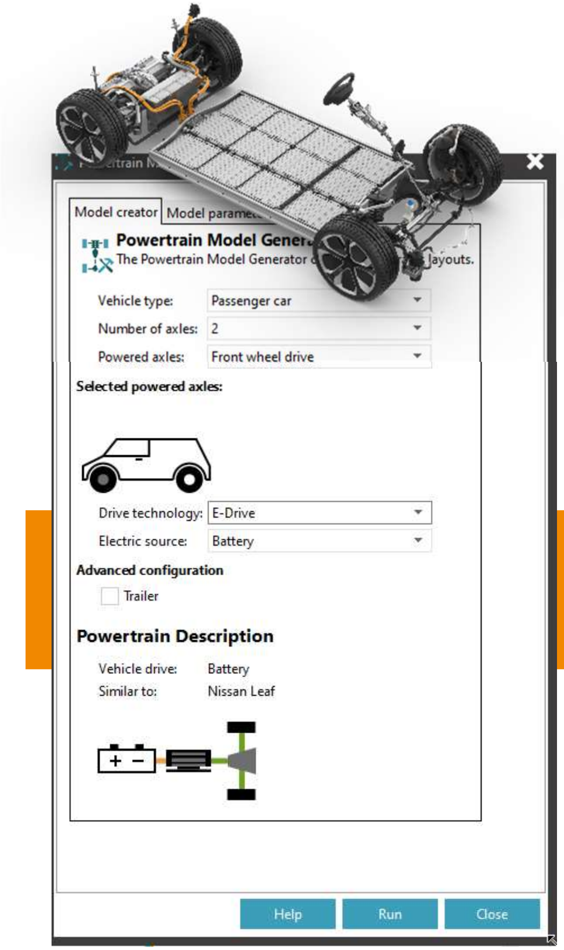
- Fuel cell/stack design
- Electro-chemical, thermal

AVL VSM™

- **Simulation tool for accurate prediction of the vehicle behaviour and improvement of vehicle systems from the concept to the testing phase**
- **Real time capable**

- Balancing of the vehicle efficiency & driving attributes
- Virtual vehicle concept definition, RDE cycle simulation
- Vehicle dynamics (handling, agility, body motion,…)
- Drivability prediction
- Chassis control development
- High performance vehicle & lap time optimization
- Truck & tractor simulation

Concept and Layout



Model creator | Model parame

Powertrain Model Gener

The Powertrain Model Generator c layouts.

Vehicle type: Passenger car

Number of axles: 2

Powered axles: Front wheel drive

Selected powered axles:

Drive technology: E-Drive

Electric source: Battery

Advanced configuration

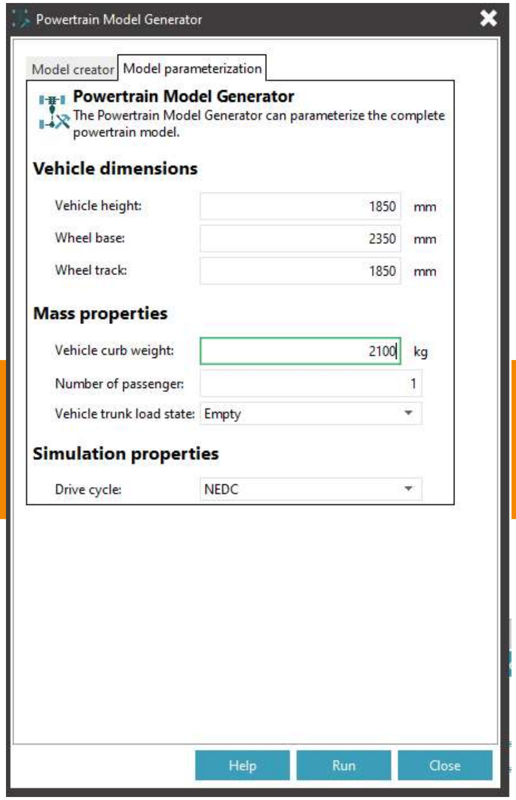
☐ Trailer

Powertrain Description

Vehicle drive: Battery

Similar to: Nissan Leaf

Vehicle Model generation



Powertrain Model Generator

Model creator | Model parameterization

Powertrain Model Generator

The Powertrain Model Generator can parameterize the complete powertrain model.

Vehicle dimensions

Vehicle height: 1850 mm

Wheel base: 2350 mm

Wheel track: 1850 mm

Mass properties

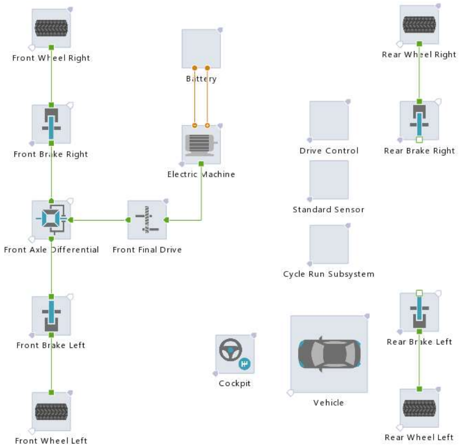
Vehicle curb weight: 2100 kg

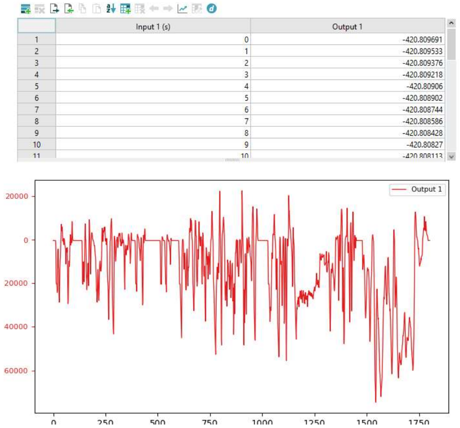
Number of passenger: 1

Vehicle trunk load state: Empty

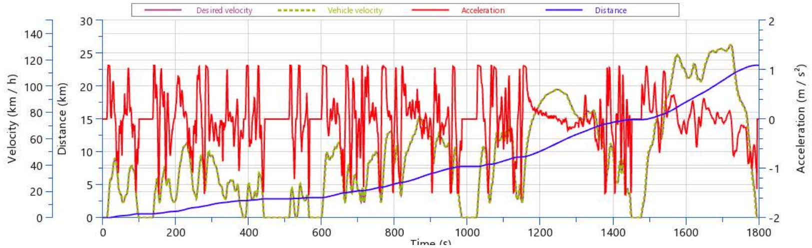
Simulation properties

Drive cycle: NEDC





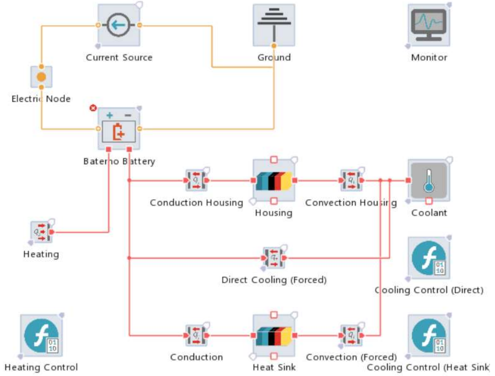
	Input 1 (s)	Output 1
1	0	-420.809691
2	1	-420.809533
3	2	-420.809376
4	3	-420.809218
5	4	-420.80906
6	5	-420.808902
7	6	-420.808744
8	7	-420.808586
9	8	-420.808428
10	9	-420.80827
11	10	-420.808113



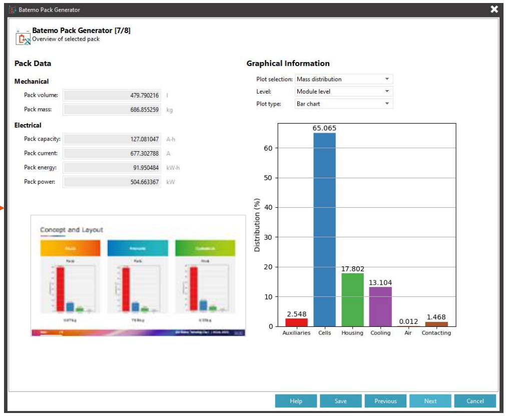
AVL CRUISE™ M

Concept and Layout

Batemo Pack Generator



Batemo Pack Generator



Batemo Pack Generator [7/8]
Overview of selected pack

Pack Data

Mechanical

Pack volume: 479.790216 l
Pack mass: 686.855259 kg

Electrical

Pack capacity: 127.081047 A·h
Pack current: 677.302788 A
Pack energy: 91.950484 kW·h
Pack power: 504.663367 kW

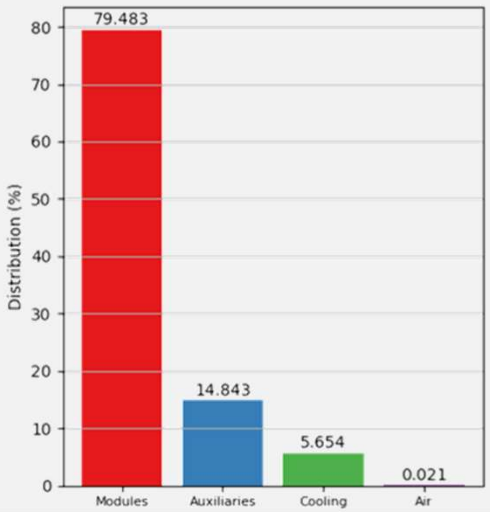
Graphical Information

Plot selection: Mass distribution
Level: Module level
Plot type: Bar chart

- ✓ Module mass and volume distribution
- ✓ Pack mass and volume distribution
- ✓ Pack weight, volume
- ✓ Energy content
- ✓ Capacity
- ect.

Concept and Layout

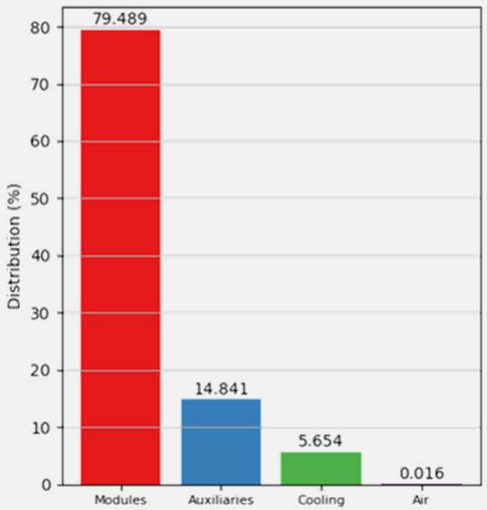
Pouch



Pack

687kg

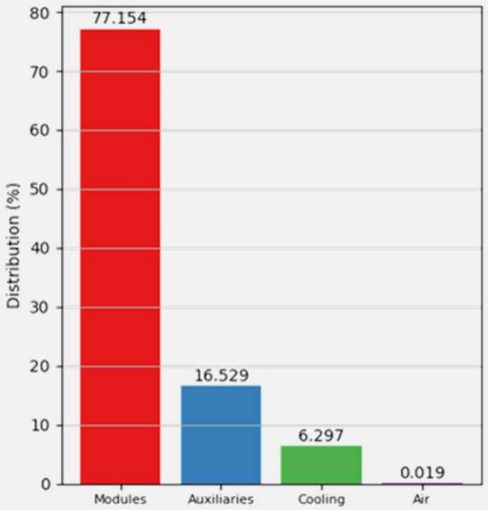
Prismatic



Pack

705kg

Cylindrical



Pack

635kg

Concept and Layout

Pouch

Electrical Summary

Capacity: 127 Ah
Current: 677 A
Energy[1]: 91,9 kWh
Power: 505 kW

Prismatic

Electrical Summary

Capacity: 124 Ah
Current: 773 A
Energy[1]: 90,4 kWh
Power: 498 kW

Cylindrical

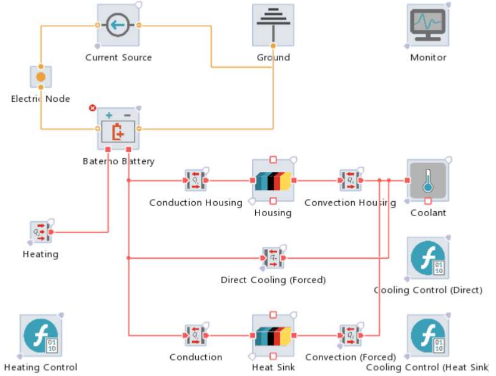
Electrical Summary

Capacity: 117 Ah
Current: 535 A
Energy[1]: 89,9 kWh
Power: 406 kW

[1] We have designed all packs to have the same energy content

Concept and Layout

Batemo Pack Generator



Batemo Pack Generator

AVL CRUISE^{TM} M Simulations
with Batemo Pack Generator

Batemo Pack Generator

Batemo Pack Generator [7/8]
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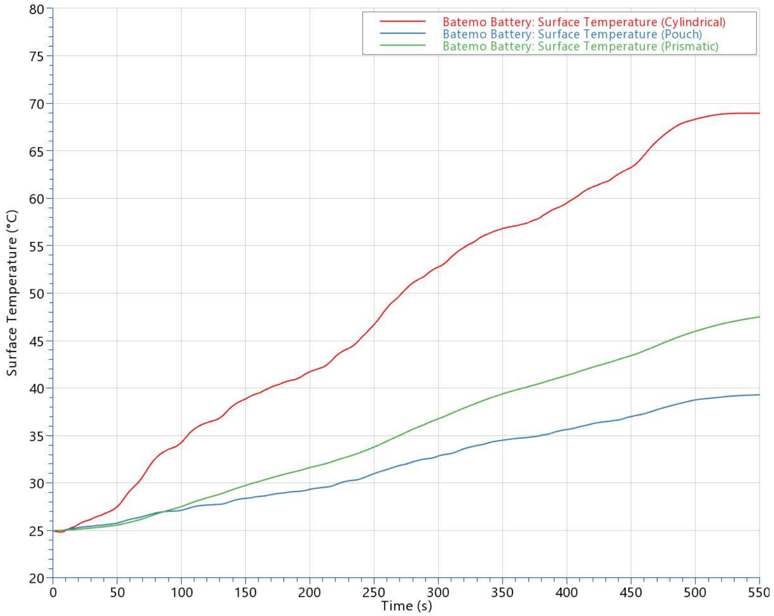
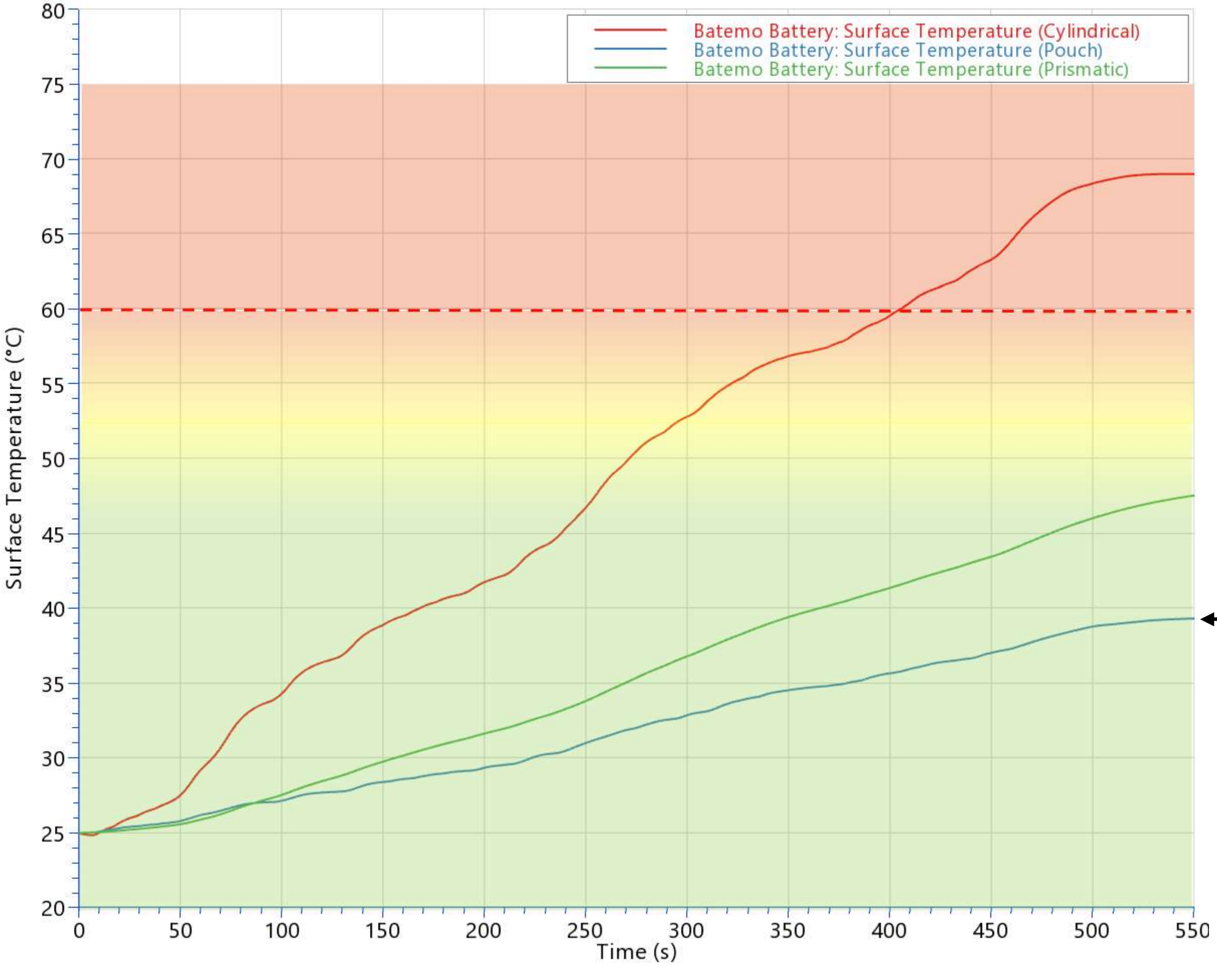


- ✓ Anode/Cathode potential
- ✓ Cell temperature
- ✓ Cell/Module/Pack voltage
- ✓ Cell/Module/Pack current
- ✓ SOC based on real conditions
- ✓ Range estimation
- ✓ Energy flow
- ✓ Fast charging capability

ect.

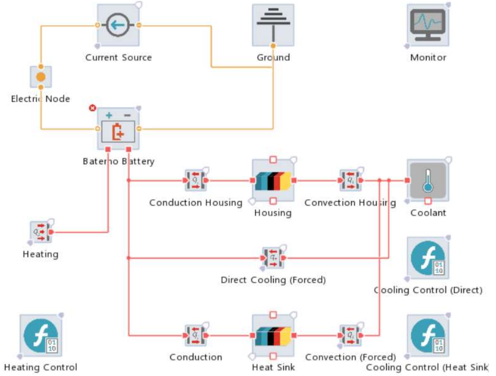
Concept and Layout



Lowest Temp.

Concept and Layout

Batemo Pack Generator



Batemo Pack Generator

AVL CRUISE^{TM} M Simulations
with Batemo Pack Generator

Batemo Pack Generator [7/8]
Overview of selected pack

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Graphical Information

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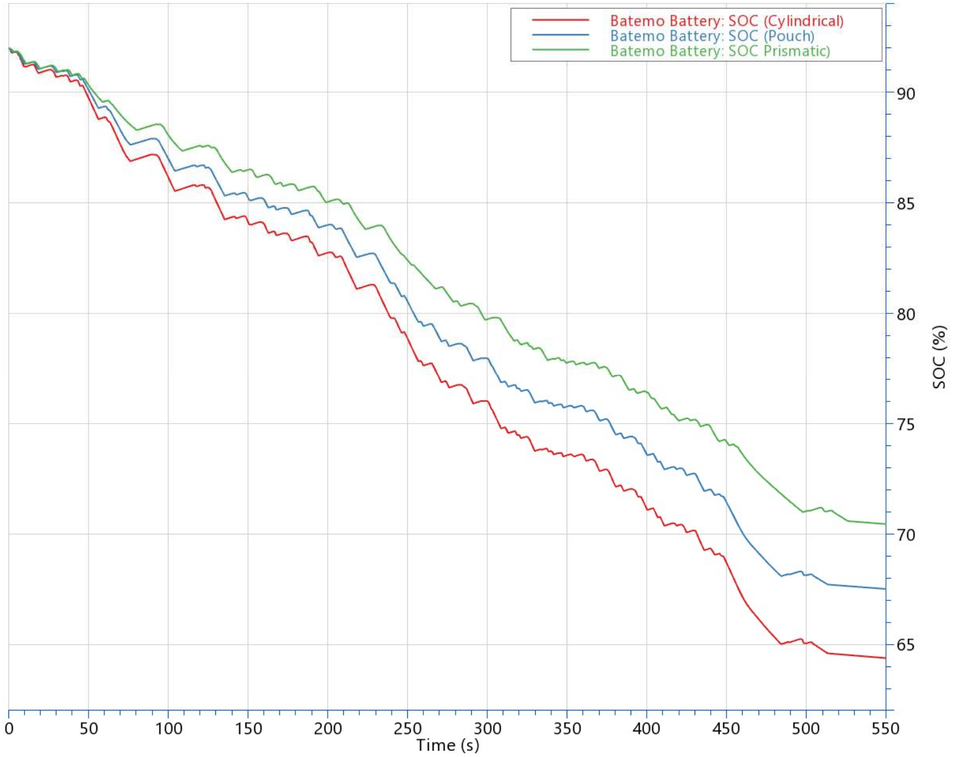
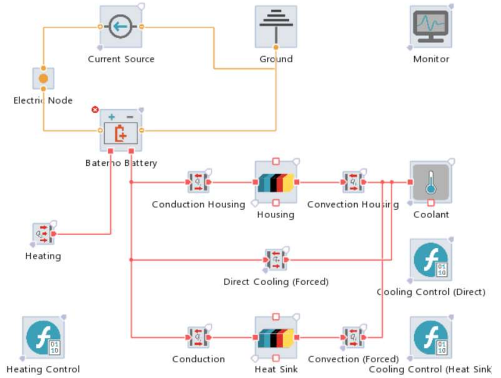
Plot type: Bar chart



Concept and Layout

Batemo Pack Generator



Batemo Pack Generator

AVL CRUISE^{TM} M Simulations

Component Costs


Batemo Pack Generator

Batemo Pack Generator [7/8]
Overview of selected pack

Pack Data

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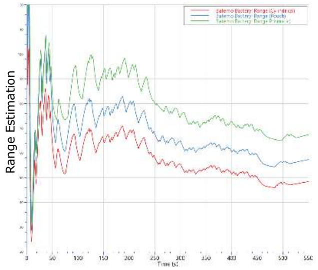
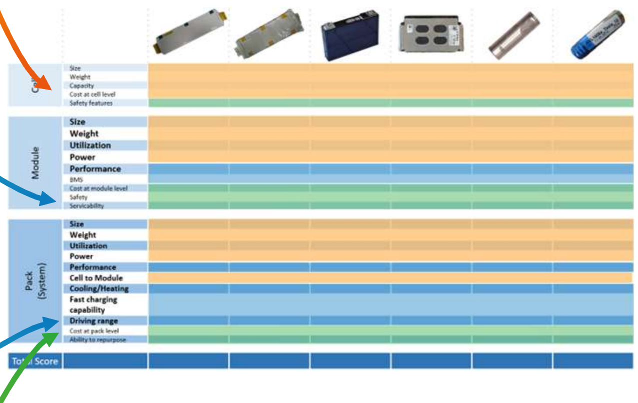


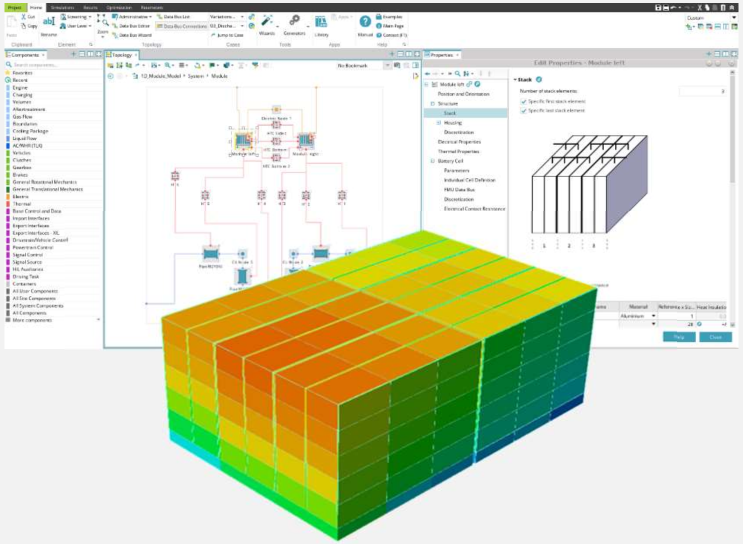
Decision matrix



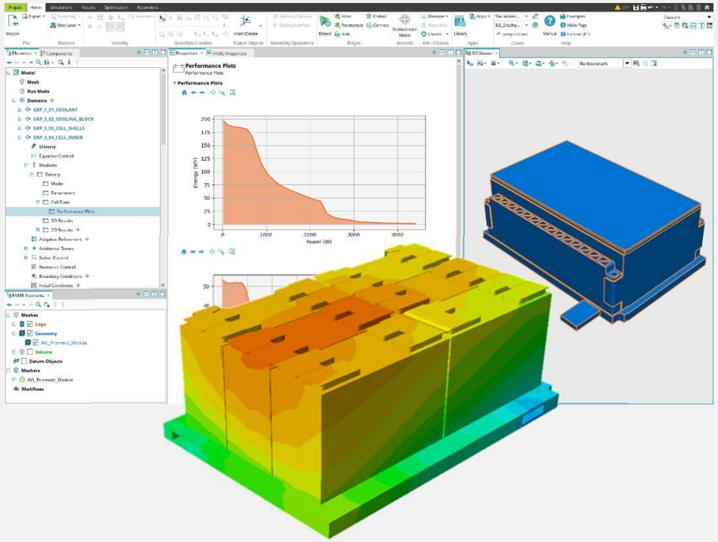
Ce	Size						
	Weight						
	Capacity						
	Cost at cell level						
	Safety features						
Module	**Size**						
	Weight						
	Utilization						
	Power						
	Performance						
	BMS						
	Cost at module level						
	Safety						
	Servicability						
Pack (System)	**Size**						
	Weight						
	Utilization						
	Power						
	Performance						
	Cell to Module						
	Cooling/Heating						
	Fast charging capability						
	Driving range						
	Cost at pack level						
	Ability to repurpose						
Tot l Score							

Component Design Optimization

AVL CRUISE™ M

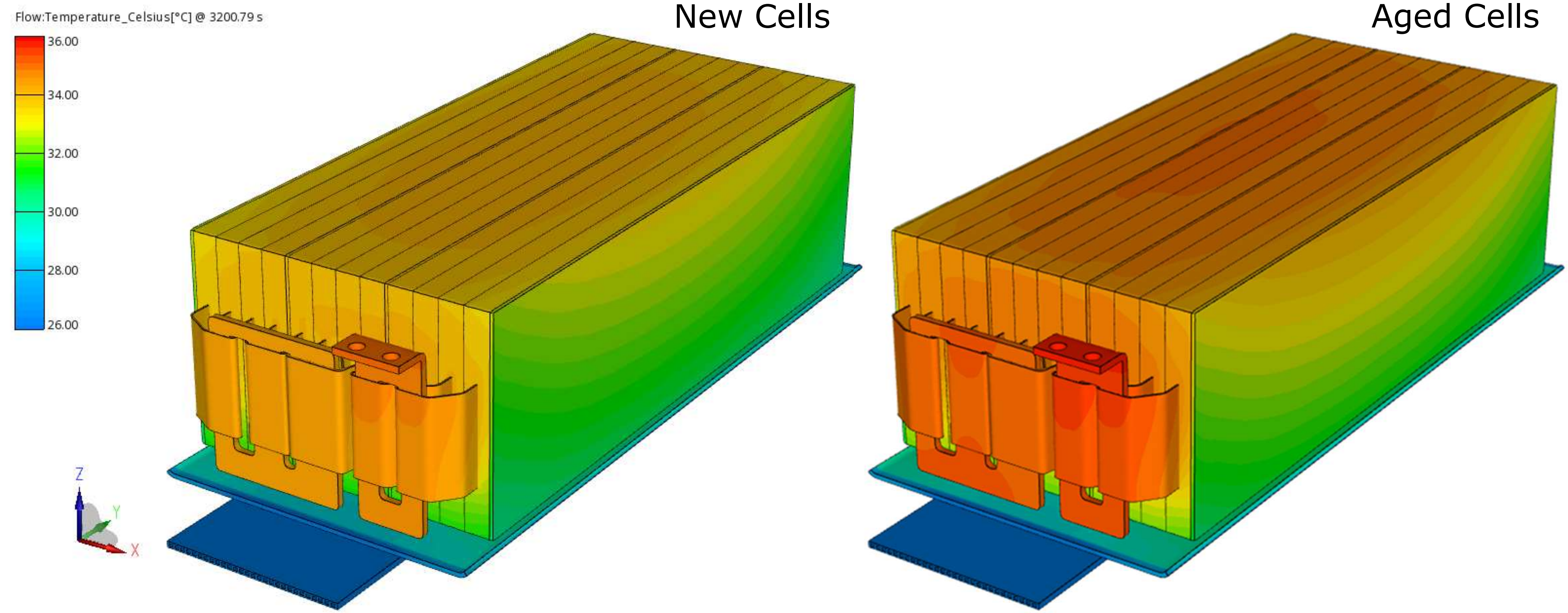


AVL FIRE™ M

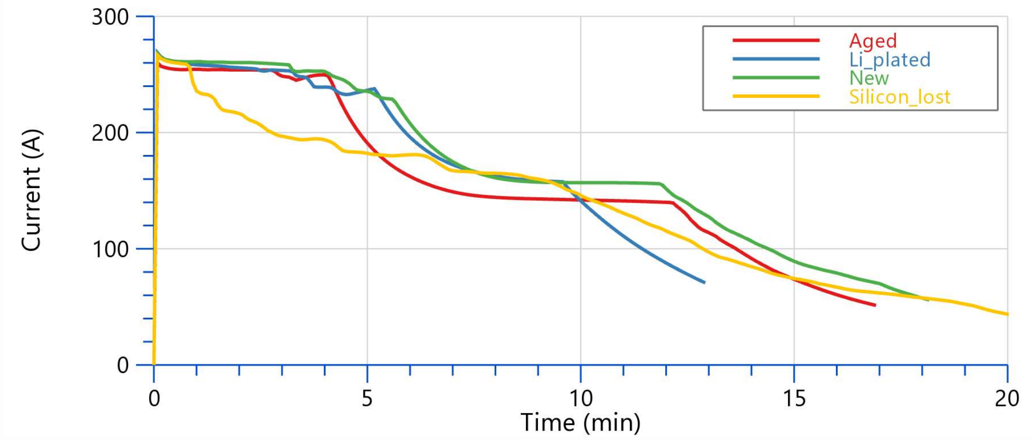


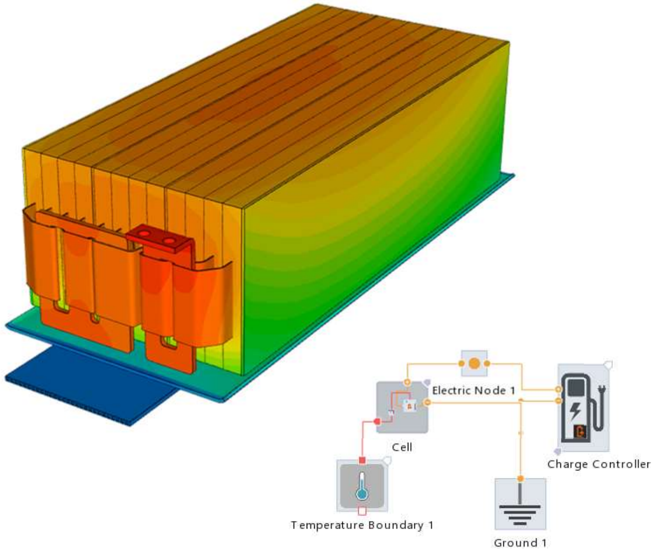
One solution for system and component development with same look and feel, sharing the same material property database and model parameters.

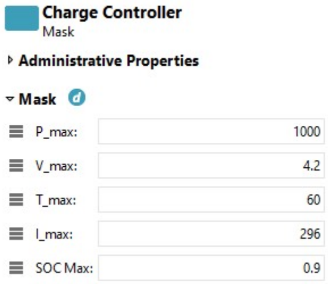
Component Design Optimization



Fast Charging





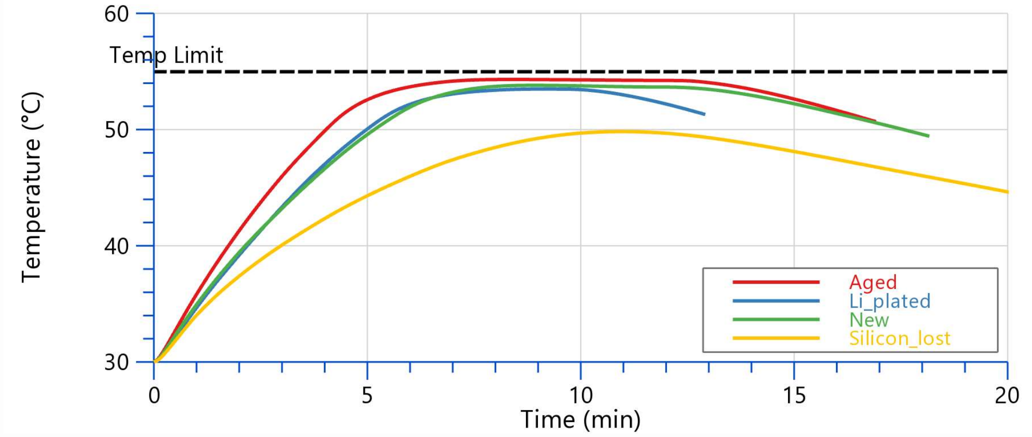


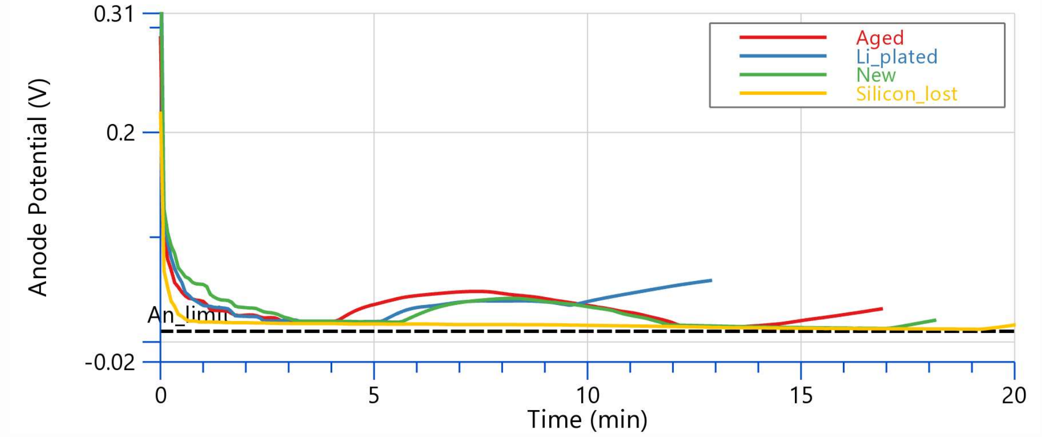
Charge Controller
Mask

Administrative Properties

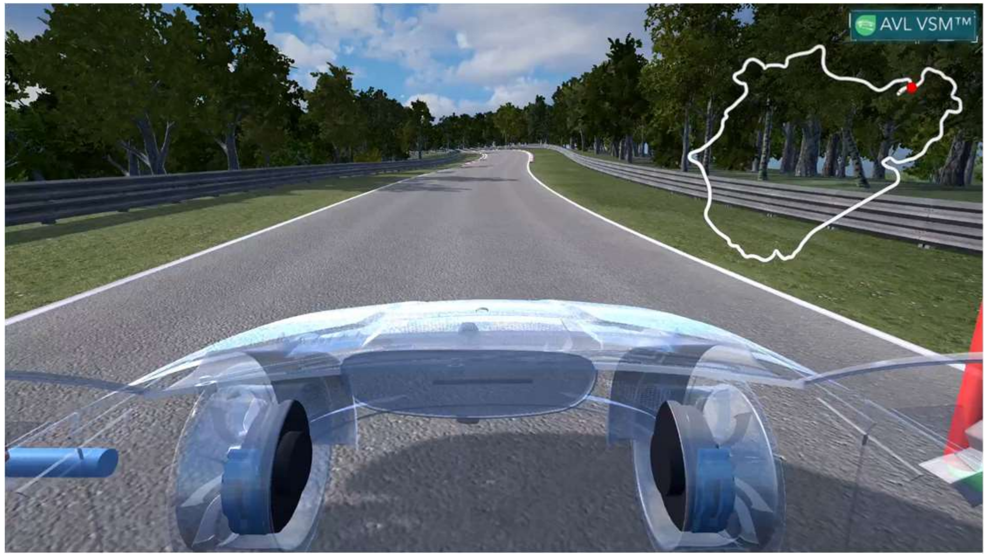
Mask

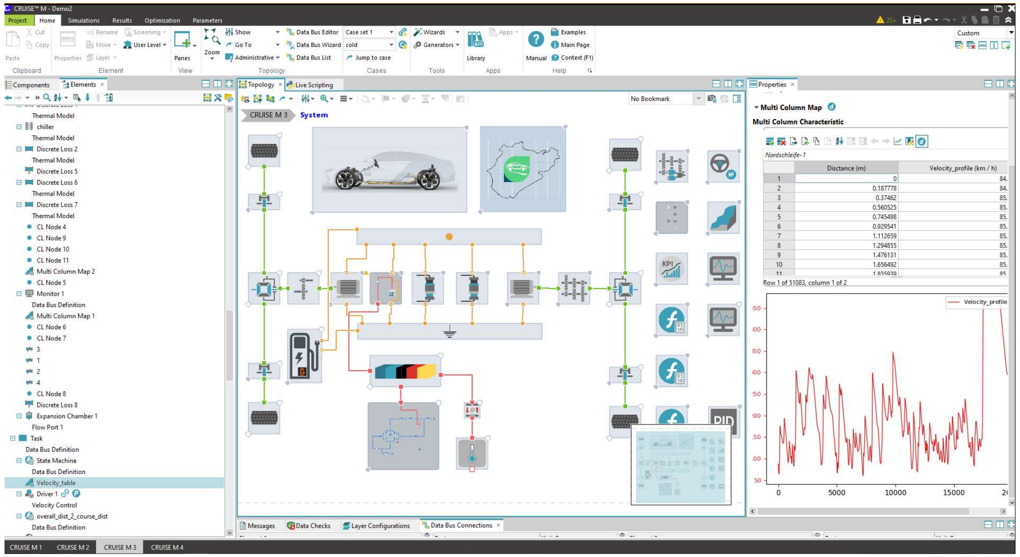
P_max: 1000
V_max: 4.2
T_max: 60
I_max: 296
SOC Max: 0.9





System Integration – AVL CRUISE™ M





Multi Column Map

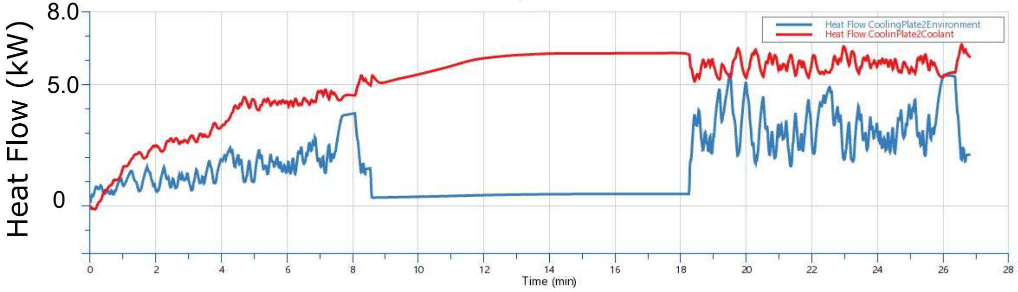
Multi Column Characteristic

Nordschleife-1

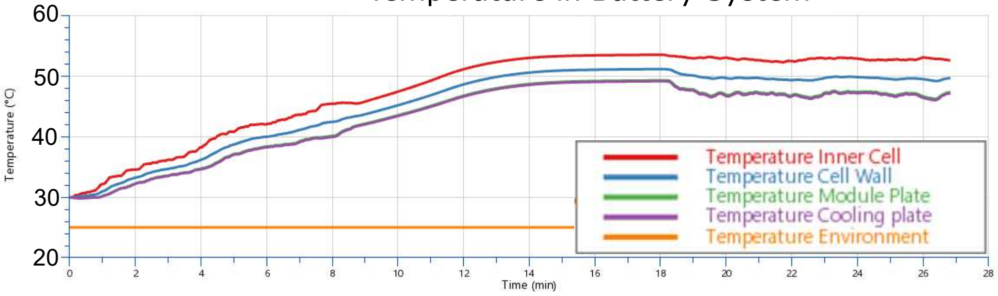
	Disctance (m)	Velocity_profile (km / h)
1	0	84.
2	0.187778	84.
3	0.37462	85.
4	0.560525	85.
5	0.745498	85.
6	0.929541	85.
7	1.112659	85.
8	1.294855	85.
9	1.476131	85.
10	1.656492	85.

Row 1 of 51083, column 1 of 2

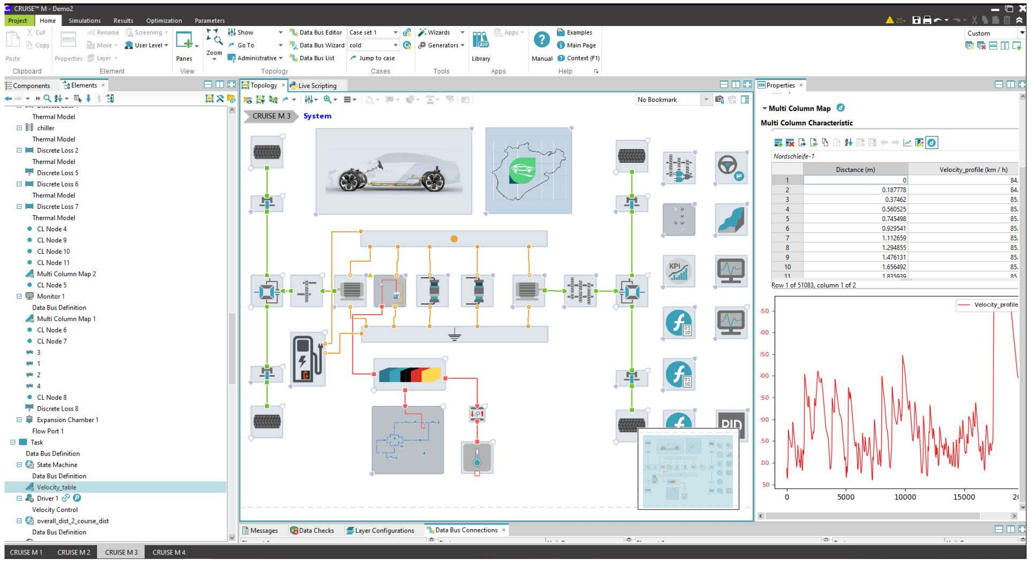
Cooling Heat Flux



Temperature in Battery System



System Integration



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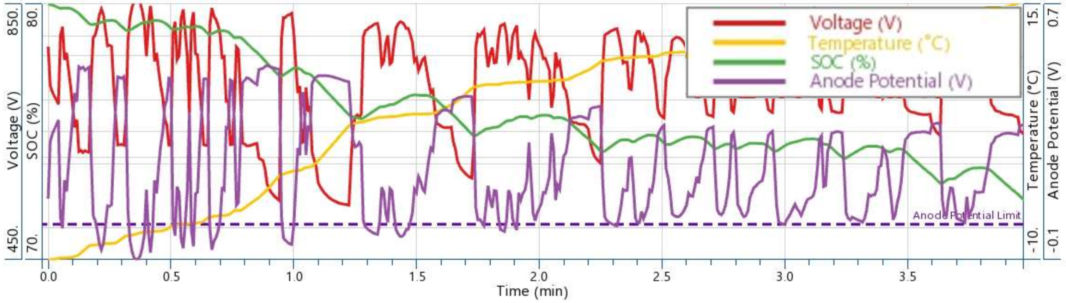
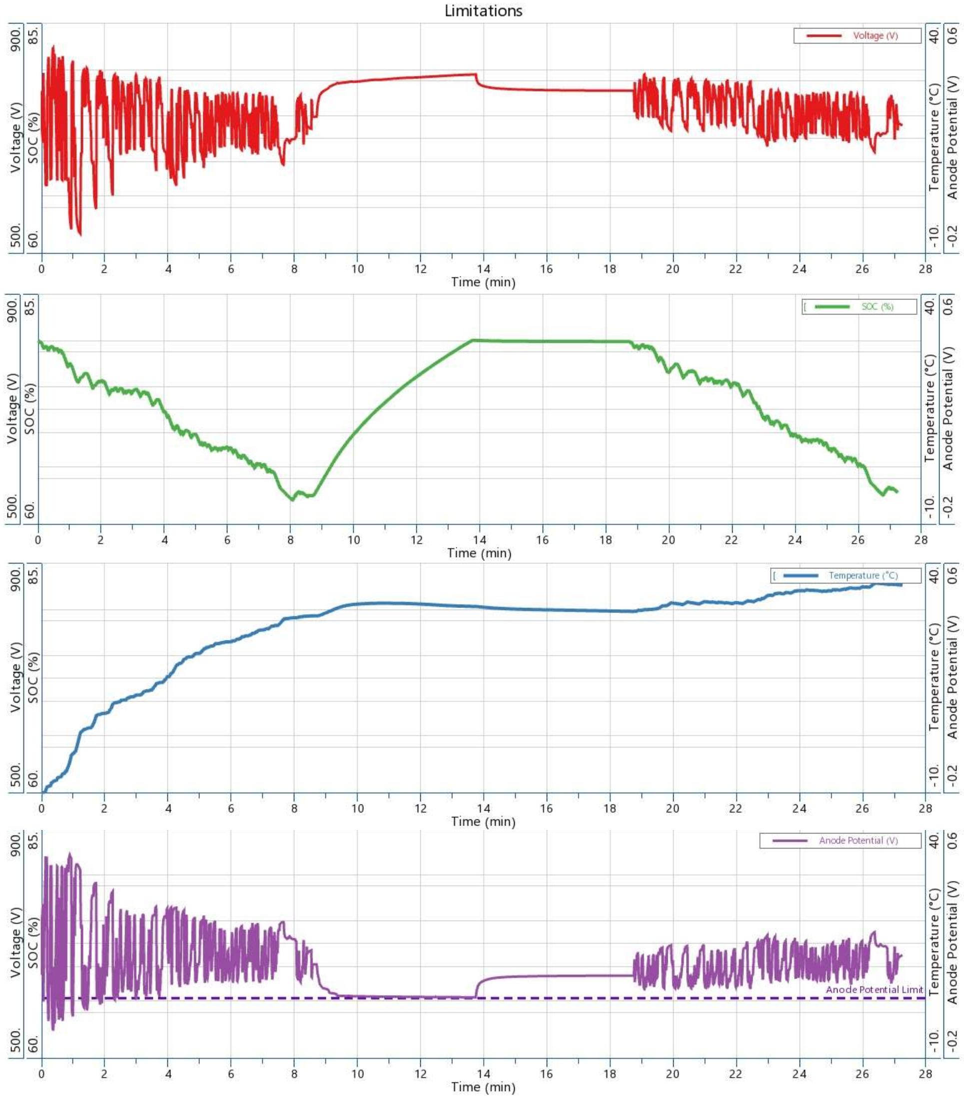
8	1.294855	85.
9	1.476131	85.
10	1.656492	85.
11	1.835939	85

Row 1 of 51083, column 1 of 2



Recuperation causes Li-plating when battery is cold



IONIQ 5

Public

IONIQ 5: Benchmark Vehicle

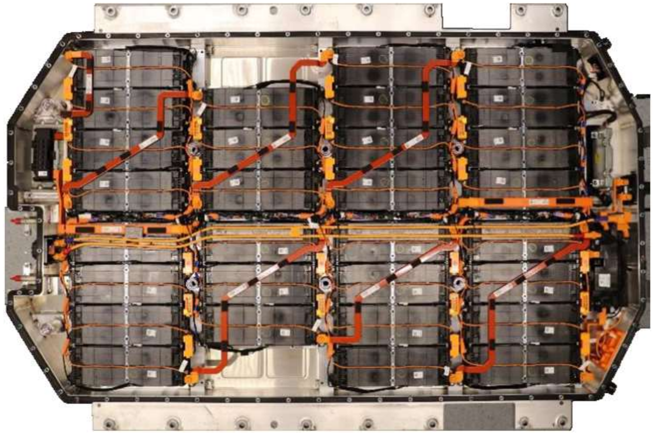
		Official[1]	**AVL[2]**
Vehicle data	Power peak (battery/e-motor front and rear)	--- / 225 kW	256 kW / 225 kW
	Power continuous (battery)	76 kW	89 kW
	Torque (combined)	605 Nm	605 Nm
	Top speed	185 kph	186 kph
	Acceleration 0-100 kph	5.2 s	5.2 s
	Range (WLTC)	460 km	436 km
	WLTC consumption	17.7 kWh/100 km	18 kWh/100 km
	Vehicle weight	2,095 kg curb weight	2,092 kg
Battery data	Energy content	72.6/75.2/73.1 kWh official/installed[4]/usable	73.1 kWh usable
	Voltage nominal	630 V	660 V
	Cell number	360	360
	Cell type	E556 pouch	E556 pouch
	Configuration	2P180S	2P180S
	Cooling	liquid	liquid
	Weight	450 kg	451 kg

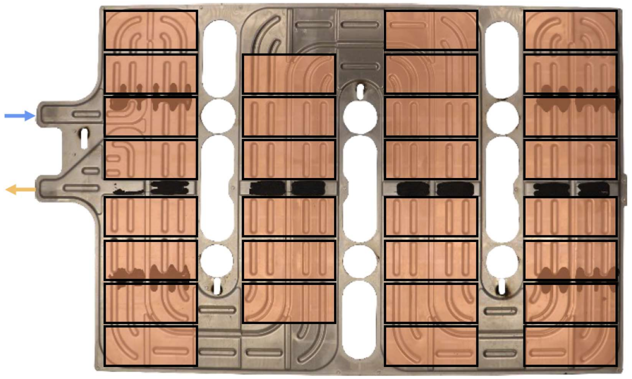
Source: AVL Benchmark Program

[1]… Sources: a) https://www.hyundai.at/
b) Vehicle Registration Paper
[2]… Measured values during benchmark *[3]… Const. max speed test* *[4]… Data at battery label*

IONIQ 5: Battey System and Module

- Battery system consists of 30 modules
- Modules are glued with thermal conductive paste to the housing
- Cooling plate is brazed to the battery housing

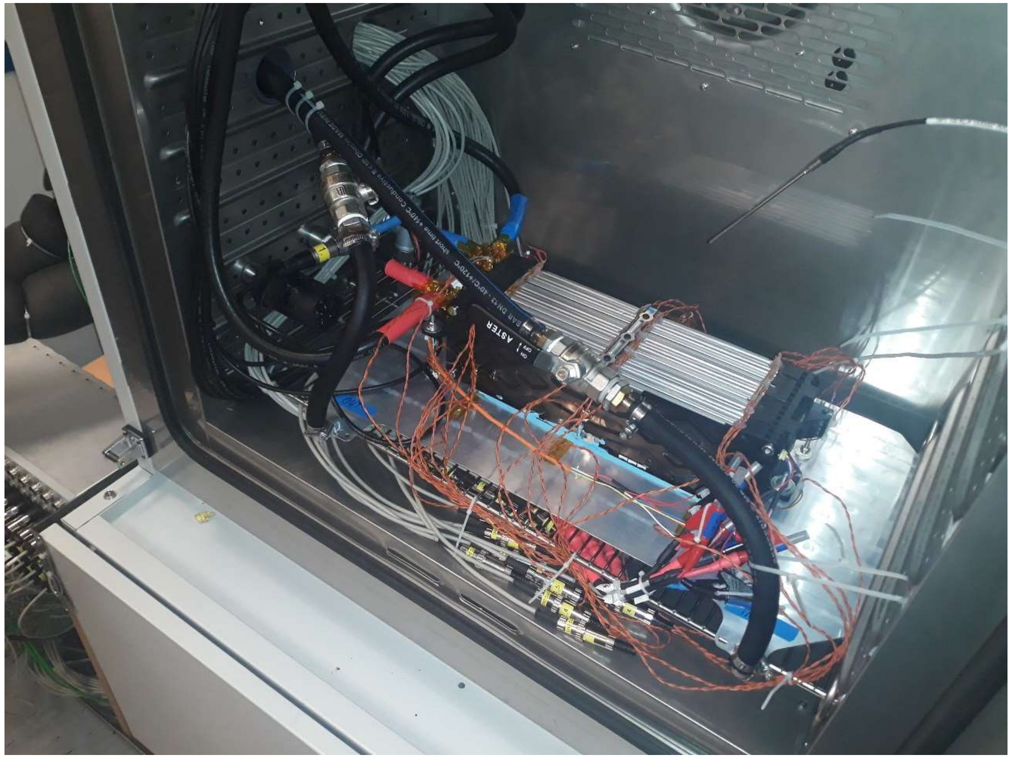




Source: AVL Benchmark Program

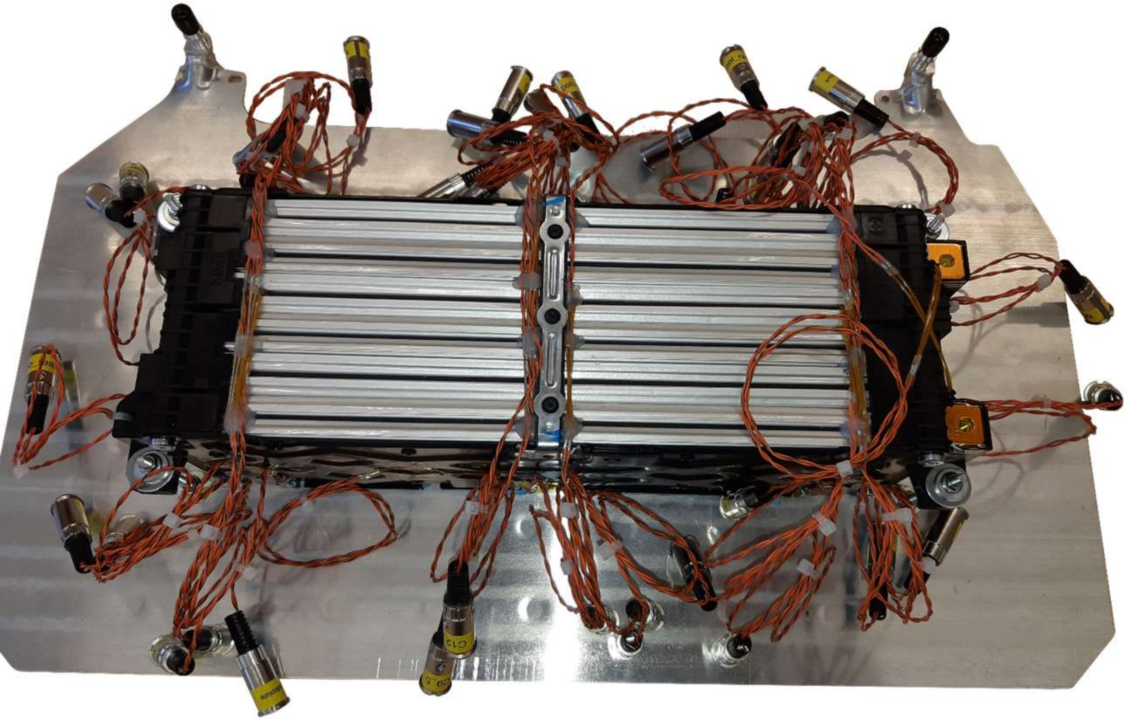
IONIQ 5: Module Measurement

	AVL Module data*
Configuration	6s2p
Number of cells	12
Nominal capacity [Ah] (C/3; 25 °C)	113,6
Nominal Voltage [V]	22,02
Max. Voltage [V]	25,2
Min. Voltage [V]	15
Energy Content [Wh]	2501,47 (Calculated)
Ri [mΩ] (1C dis.; 10 sec; 25 °C)	3,51 (w/o busbars, terminals etc.)
Dimensions [mm] (without tabs)	428 × 158 × 111
Volume [l] (without tabs)	7,506 (calculated)
Mass [g]	10870



*Module Data scaled from Benchmark cell testing Work package 8

IONIQ 5: Module Measurement



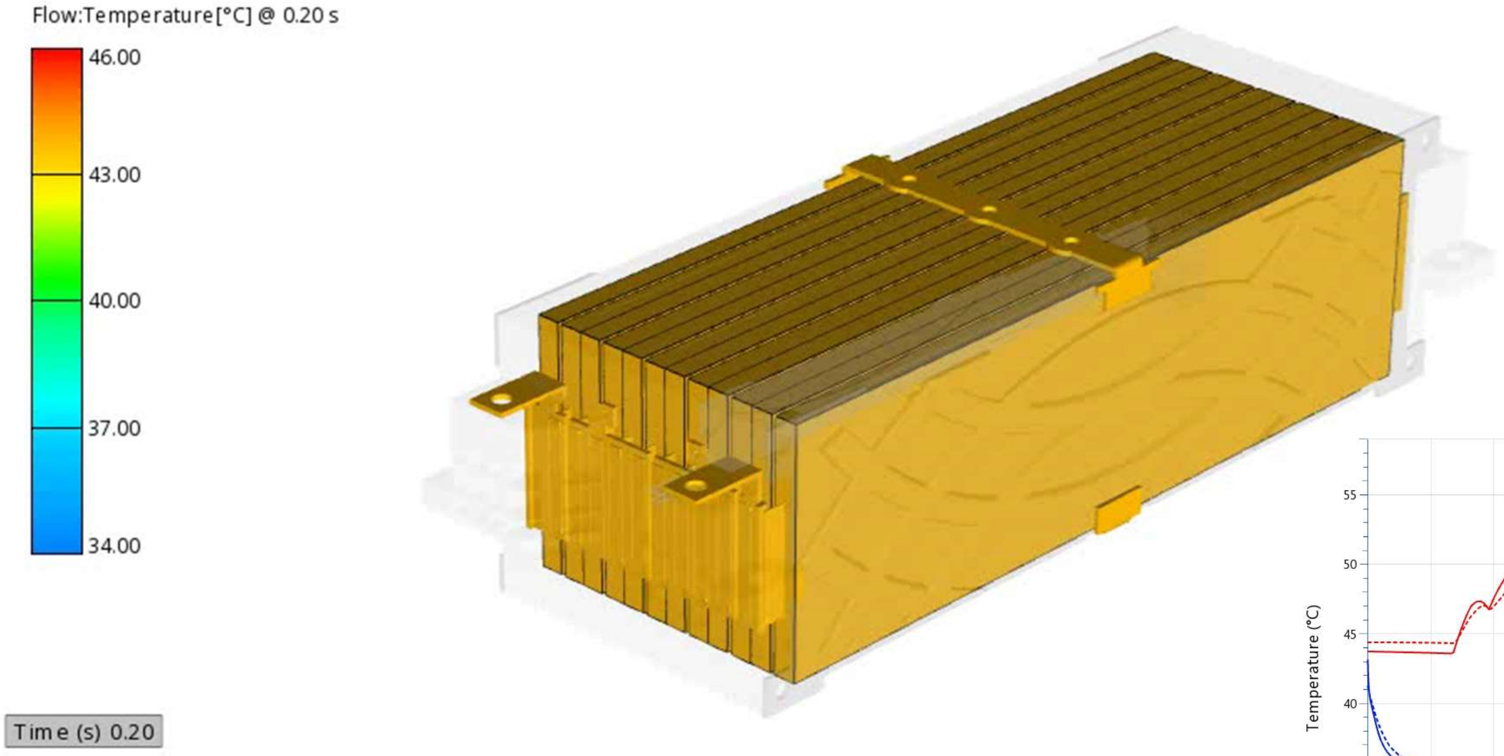
37 temperature sensors

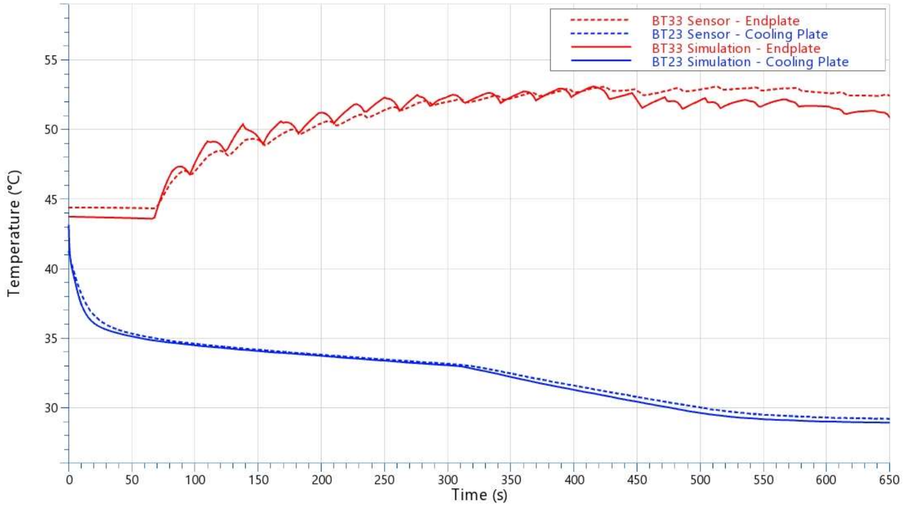
6 voltage sensors

Test program:

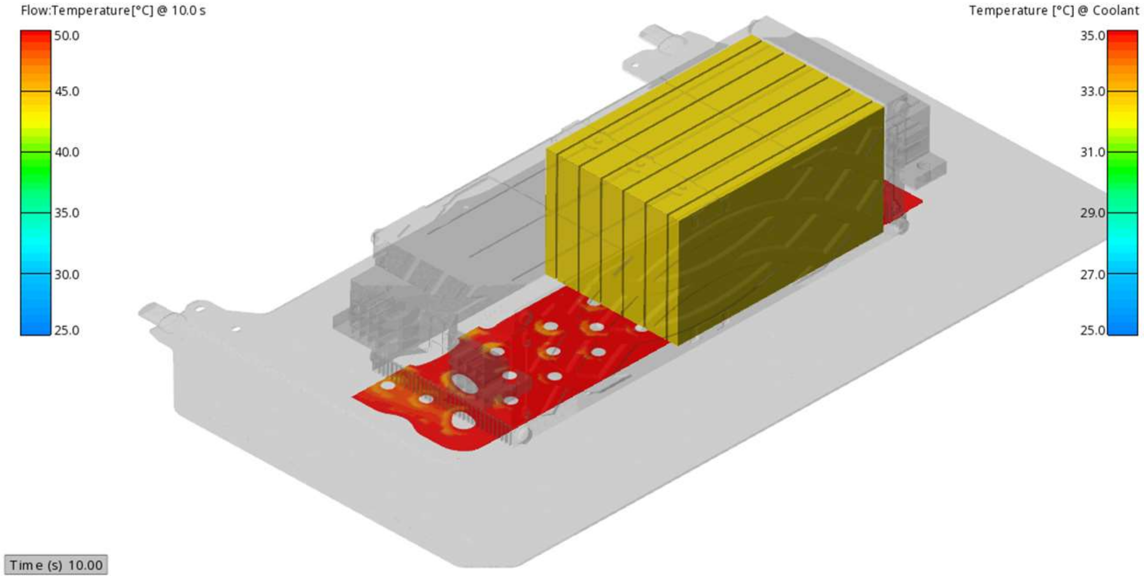
- Constant Discharge (T, C-rate variation)
- Fast Charge (T variation)
- WLTC @ 23°C
- RDE @ 9°C, 45°C
- Full Load Acceleration @ 45°C
- HPPC Test (T variation)

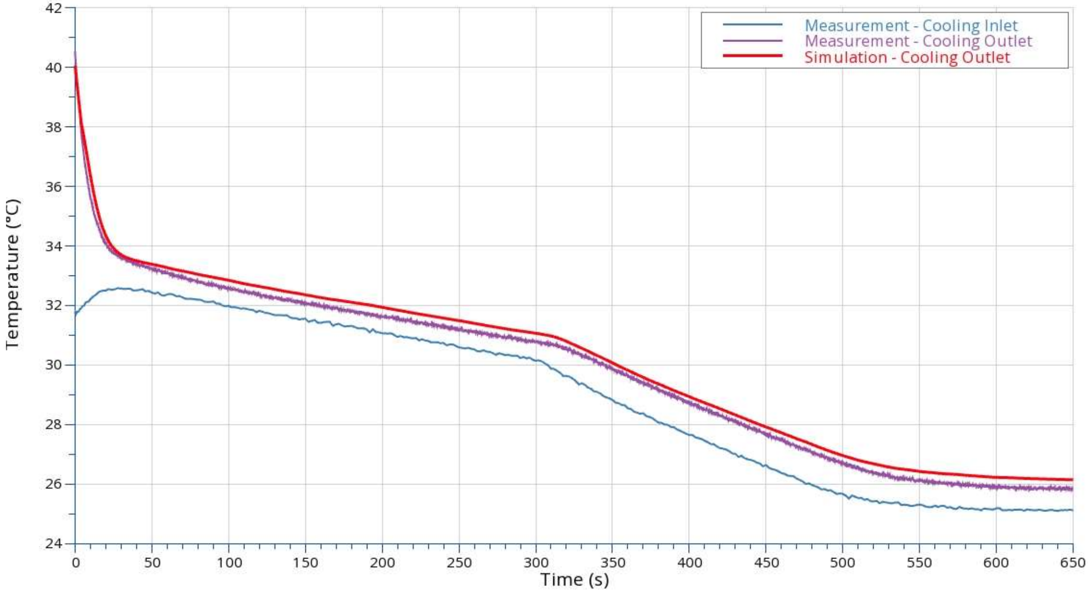
IONIQ 5: FIRE™ M Battery Module



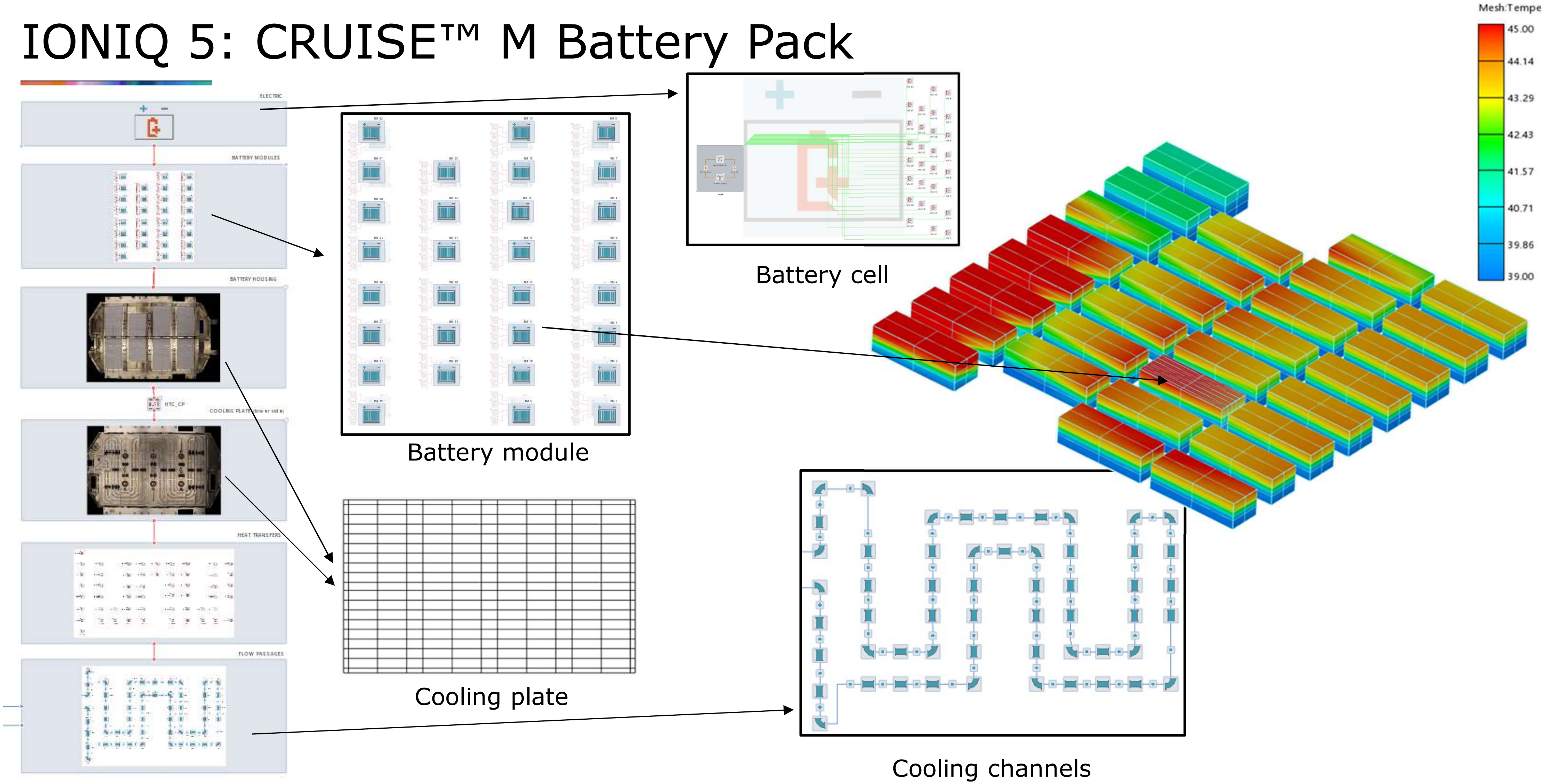


IONIQ 5: FIRE™ M Battery Module

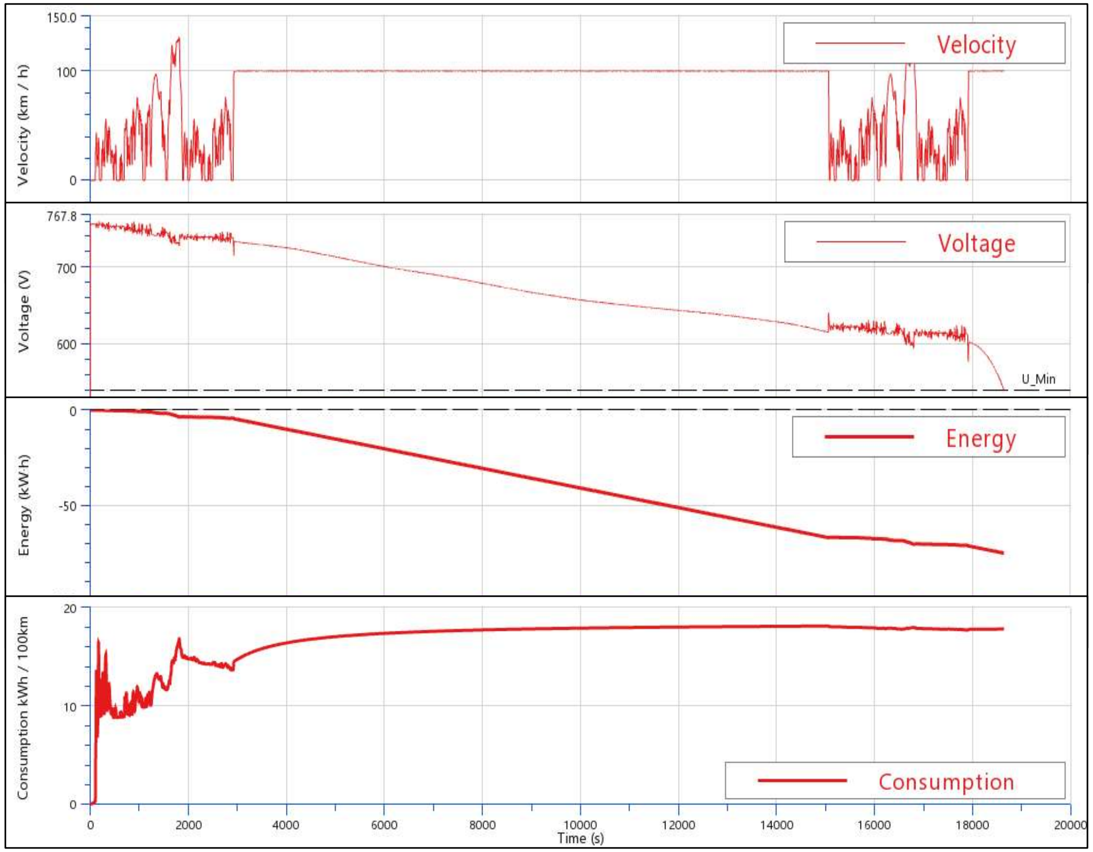




IONIQ 5: CRUISE™ M Battery Pack



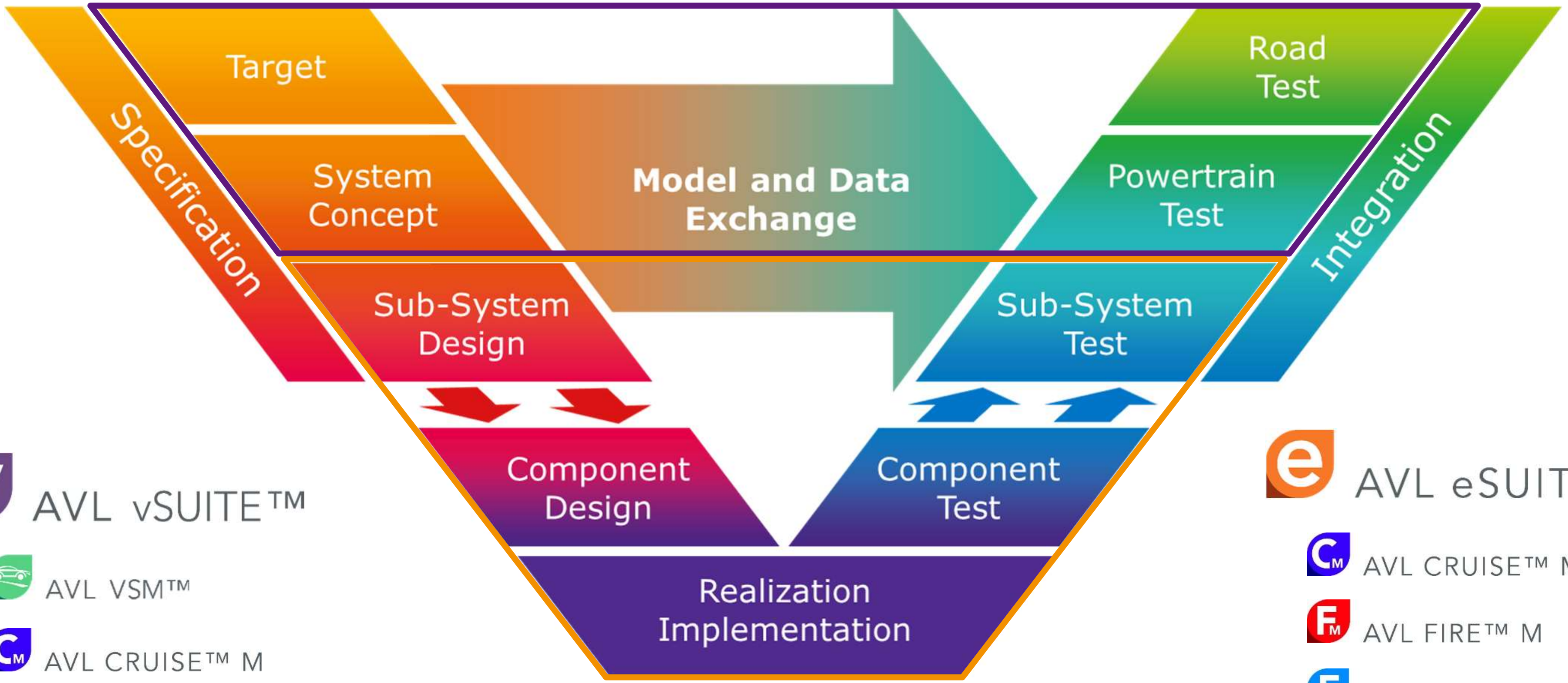
IONIQ 5: CRUISE™ M Vehicle



- Start @ 100 % SOC
- Run WLTC 1.5 times
- Run const velocity = 100 km/h until SOC <10%
- Run WLTC 1.5 times
- Run const velocity = 100 km/h until Voltage < U_{min} = 540 V (3V Cell)

Results	
Distance	420.17 km
Energy	74.87 kWh
Energy vehicle measurement	73.10 kWh usable
Consumption vehicle **simulation**	**17.82 kWh/100 km**
Consumption vehicle **measurement**	**18 kWh/100 km**

AVL Battery Virtual Twin – From Concept to Integration



AVL vSUITE™

- AVL VSM™
- AVL CRUISE™ M

AVL eSUITE™

- AVL CRUISE™ M
- AVL FIRE™ M
- AVL EXCITE™

Today‘s Presenter

Juergen Schneider

Solution Manager – Battery
AVL List GmbH, Graz

Battery Modelling

Mark Holdstock

Contents

Modelling in Context

Modelling in Context
Reducing validation time, cost, risk

Development Validation

Validation Effort Reduction

Test **Duration** Reduction

Test **Quantity** Reduction

Test **Costs** Reduction

Simulation for Test Specification

Do the test first time right!

- Simulation of test setup to ensure representative environment (e.g. shaker table),
- Selection of most critical load cases,
- Placement of sensors.

Load Matrix for Test Specification

Combine physics & statistics

- Usage space analysis,
- Load Matrix damage models for more failure modes and location,
- Include also component tests and vehicle durability test.

Simulation for Sub-System Test Definition.

Test on simplest parts as possible

- Determine representative test setup via simulation,
- Verification of system behavior at component level,
- Reduced cost of DUT and test execution.

Simulation for Test **Substitution**

Virtual A-sample

- Virtual verification in A-sample,
- Production process variants,
- Derivative development.

Data Management for Test Control

Daily test result observation

- Test results observation from internal & external test facilities via web interface,
- Trend analysis.

Modelling in Context
Synergies between physical and digital testing/simulation

Development Validation

Simulation and Testing Synergy

Simulation

- Identification of critical load case,
- Definition of test bed set-up,
- Definition of sensor type & position,
- Approval for test.

Test

- Test specification after simulation input,
- Hardware validation,
- Release process.

Correlation

- Adjustment of models,
- Model transfer,
- Model integration to vehicle development.

Simulation

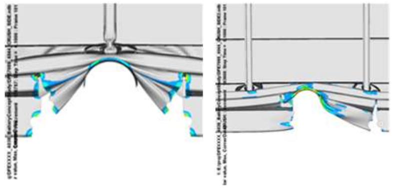
- Extended simulation of load cases with correlated models after test,
- Verification of load cases.

Simulation for efficient test execution:

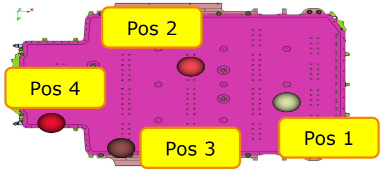
- Enables that tests will be passed
- Enables that test is done first time right
- Enables that test is meaningful

Examples

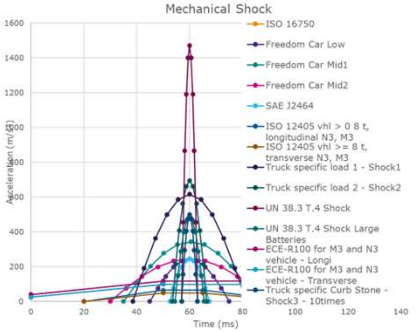
Crush Positioning



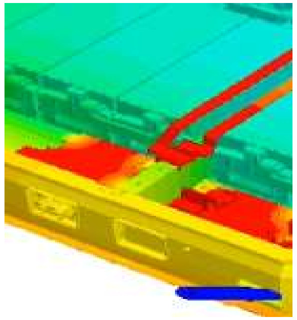
Bottom Intrusion Positioning



Various load profiles Which is most severe?



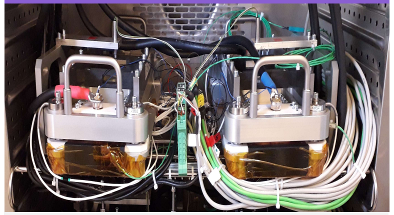
Sensor Position at local hot-spot



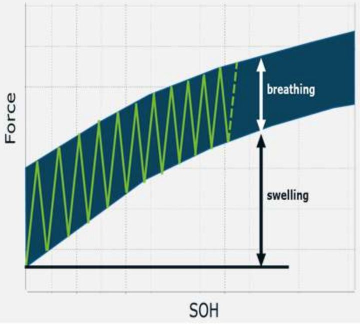
Example 1:
Swelling compensation for durable and robust design

Evaluation Method

Cell Testing

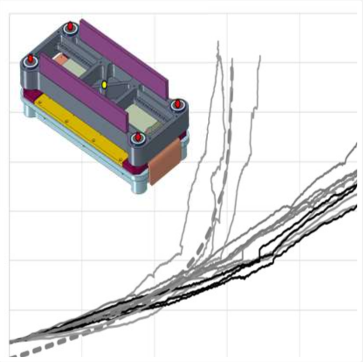


- Standard test program:
- 12 test configurations,
- 40000h testing time,
- 12 cells tested in parallel,
- 6-9 months duration.



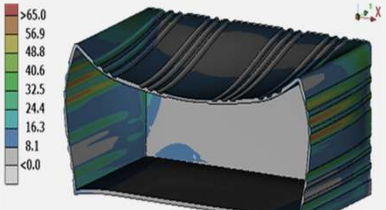
FE Model Parameterisation

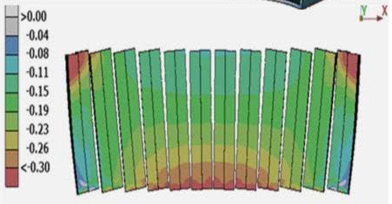
- Setup of material card:
  - Stiffness,
  - Breathing,
  - Swelling.
- Validation of prediction model:
  - Simulation according to test setup,
  - Calibration.



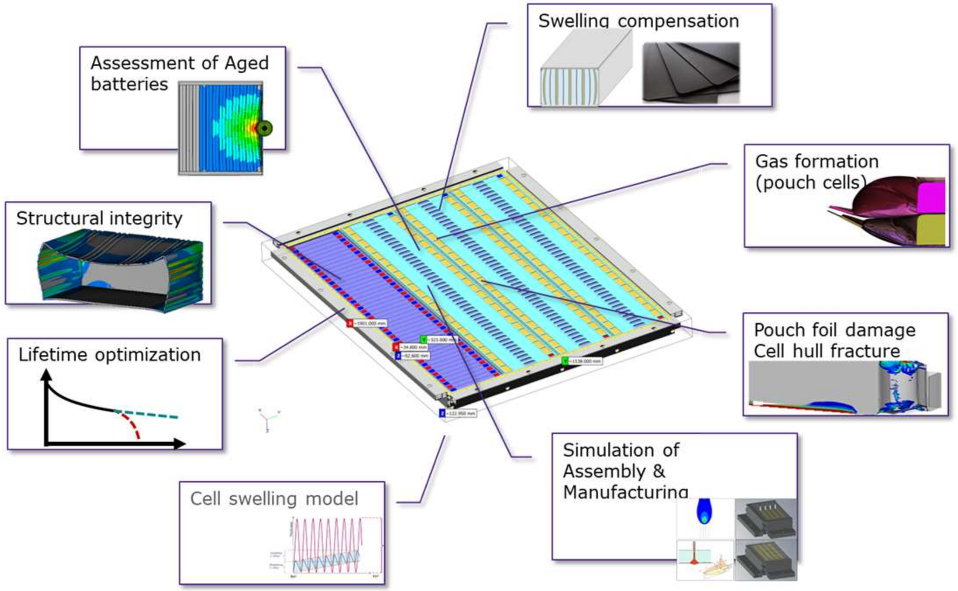
Module / Pack Simulation

- Prediction of module strength in dependence of SoH,
- Optimization of module design regarding swelling,
- Considering EOL conditions in crush & crash simulation,





Engineering



Swelling compensation

Assessment of Aged batteries

Gas formation (pouch cells)

Structural integrity

Pouch foil damage
Cell hull fracture

Lifetime optimization

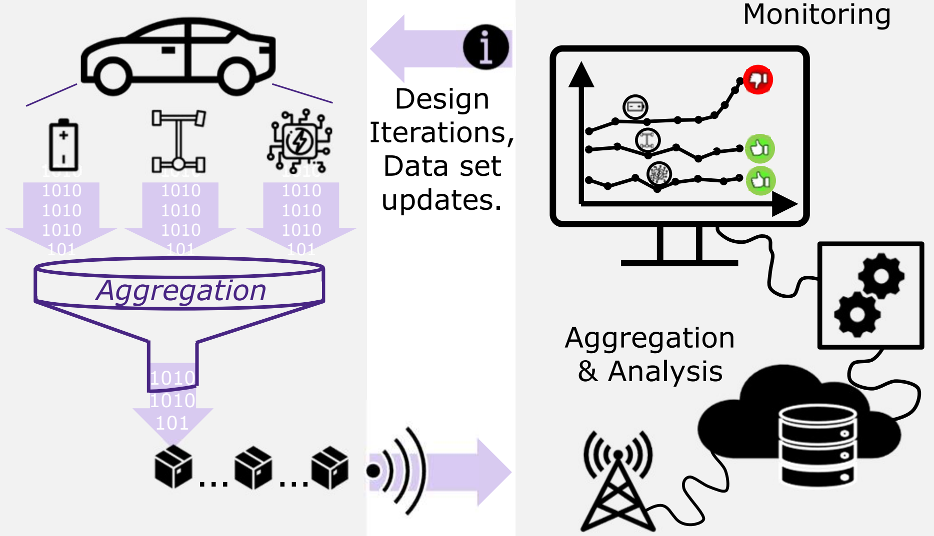
Simulation of Assembly & Manufacturing

Cell swelling model

Example 2:

Battery Analytics

Overview



On-board

Cloud

Evaluation & Monitoring

Design Iterations, Data set updates.

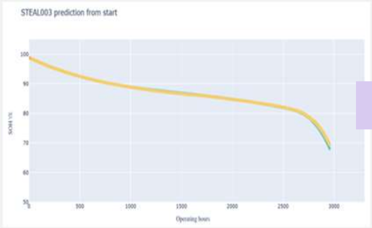
Aggregation & Analysis

AVL Know How:
- Battery design,
- BMS development,
- Vehicle Integration.

AVL Know How:
- Battery modelling,
- Data analytics,
- Machine learning,
- Cloud deployment.

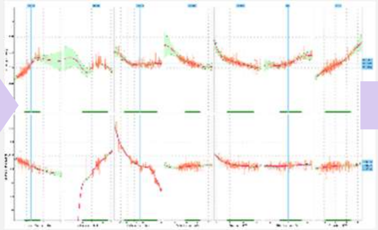
Lifetime Modelling & Prediction

SoC & SoH Estimation



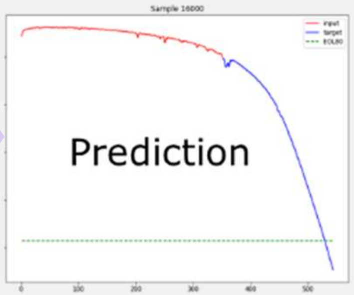
- Estimation of Battery energy consumption (~SoC) and health (SoH)
- Based on capacity decay and inner resistance increase.
- Using physics-based, ‘physics-informed’, semi-empirical and statistical modelling techniques.

Pattern Identification



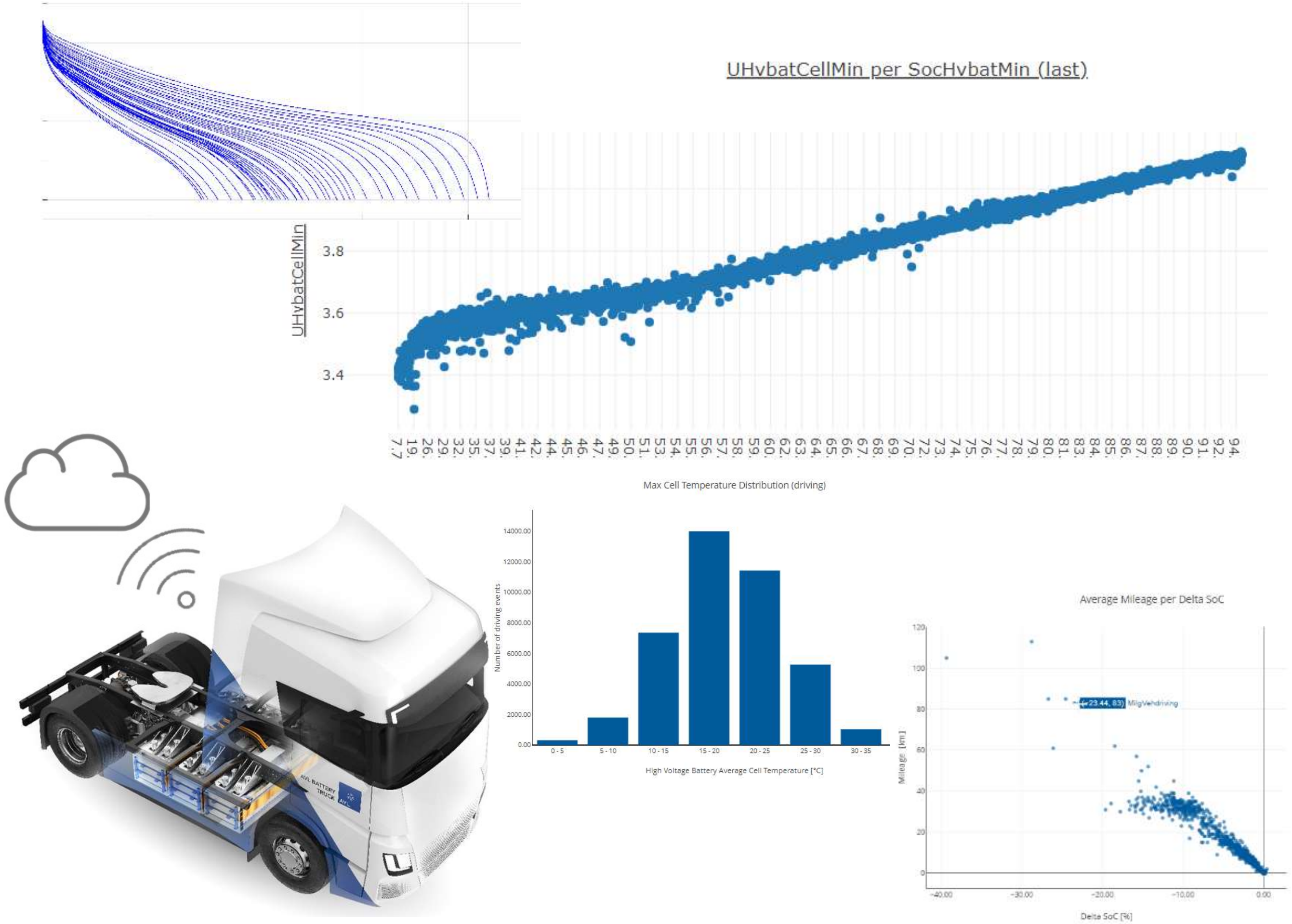
- Link SoC/SoH to influencing factors like driving and ambient conditions
- Based on the complete fleet data.
- Enables prediction in the future & fleet operation optimization (adaptive controls).

Lifetime Prediction



- Machine learning approach to predict the future behavior of the SoC/SoH
- Based on historic driving, ambient conditions, street and traffic information.

Example 2:
Battery Analytics: Cloud BMS Monitoring & Warranty Reduction



Project Description

Customer Benefits

- Improve SoH estimation precision,
- Reduce warranty costs,
- Reduce customer down-time,
- Extend life-time and enhance residual value.

Challenges

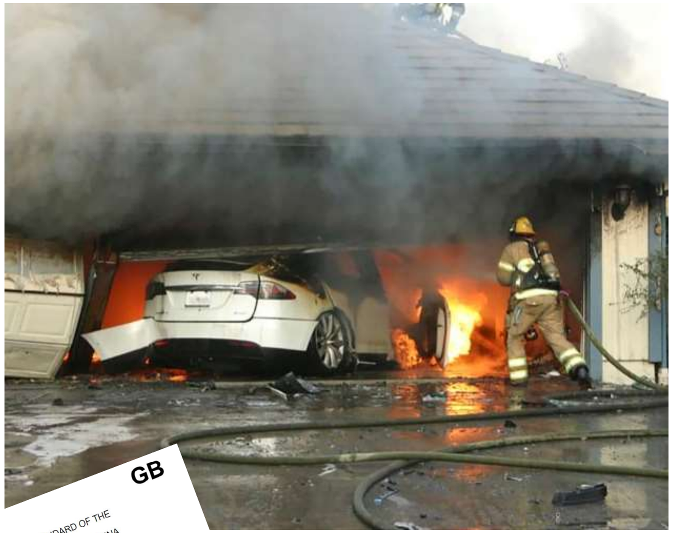
- Connect On-Board BMS with back-end cloud algorithms,
- Working with huge amount of data from the field,
- Bring machine learning models into production.

AVL Tasks & Deliverables

- Combine domain and data science expertise for a data-driven SoH modelling,
- Identify SoH influencing factors and predict remaining useful life for each vehicle,
- Develop data analytics methods and processes ,
- Implement machine learning models and deploy to production environment.

Thermal Propagation

Thermal Propagation



GB

NATIONAL STANDARD OF THE
PEOPLE'S REPUBLIC OF CHINA

ICS 43.080
T 47

GB 38031-2020
Replacing GB/T 31485-2015, GB/T 31467.3-2015

Electric Vehicles Traction Battery Safety requirements
电动汽车用动力蓄电池安全要求

>5min
…from detection
to propagation

- Current legal requirement (GB 38031-2020)

>15 to 30min

- Time demand for emergency arrival or escape time for injured,
- Minimum customer requirement.

No Propagation

- Today's customer wish; future demand,
- Ensures safety even for infrastructure and parking surrounding.

No Propagation:
The only way to ensure safety in every circumstance

No Propagation means:

No flames out of battery without any time limit

No Propagation:
The only way to ensure safety in every circumstance

No Propagation requires:

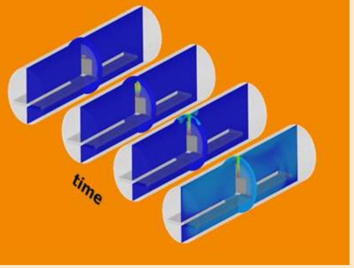
- Correct Cell Chemistry/ Package
- No Gas Ignition
- No/slow Cell2Cell propagation
- Robust Design No Melting/Arcing
- Robust Design Cover & Sealing

No Propagation Modelling & Design

No Propagation requires:

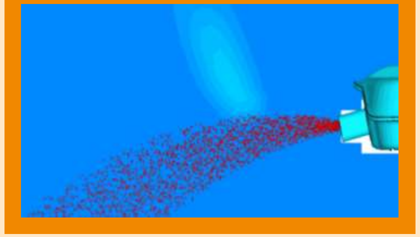
Correct Cell Chemistry/Package

- Cell tests and benchmarking,
- Cell selection studies,
- Electrothermal & electrochemical modelling.



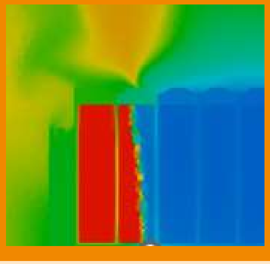
No Gas Ignition

- Gas guidance,
- Gas cool-down within venting path,
- Heat path to environment.



No/slow Cell2Cell Propagation

- Proper energy balance,
- Mix of insulating cells and distributing heat to prevent / delay propagation

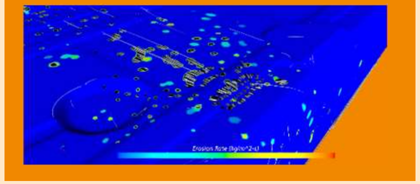


Robust Design No Melting/Arcing

- Separation of HV and venting path
- Distributing heat and releasing energy

Robust Design Cover & Sealing

- Distributing heat and releasing energy,
- Abrasive and conductive ejected particles.



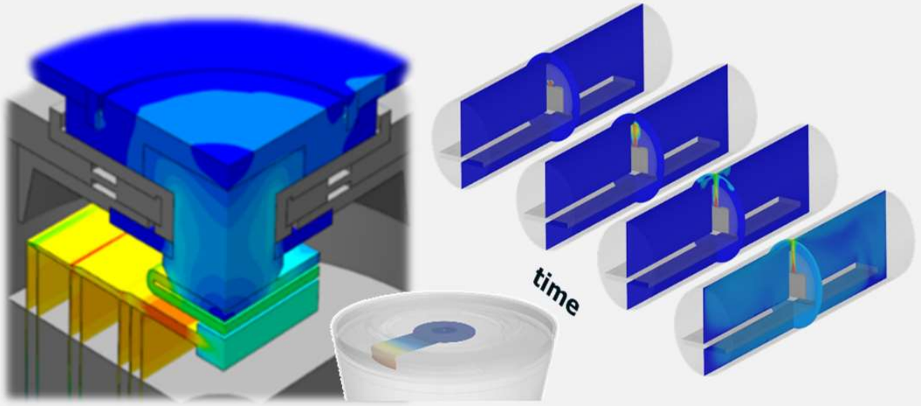
AVL conducts & implements: (listed under each requirement above)

No Propagation Modelling & Design

Correct Cell Chemistry/Package

Heat / Current Density, Gas Evolution Modelling

- Gas release,
- Temperature dependent heat release,
- Gas composition after venting event,
- Cell expansion,
- Particle flow,
- Model validation.

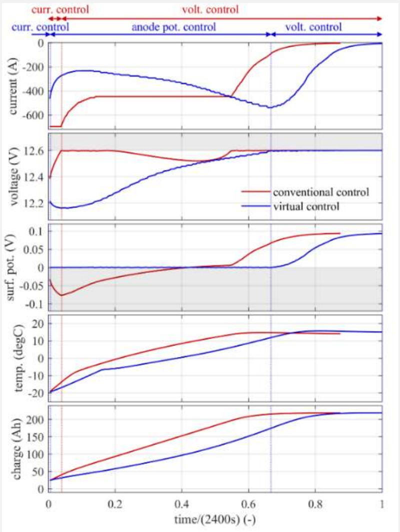


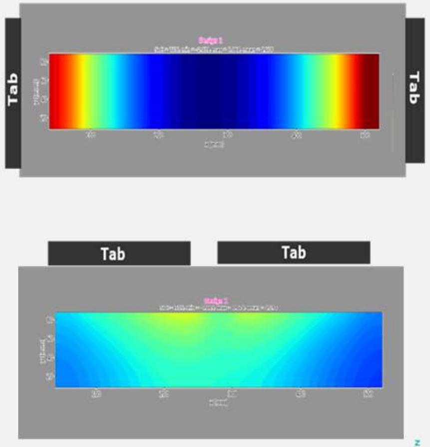
Cell Characterisation Testing

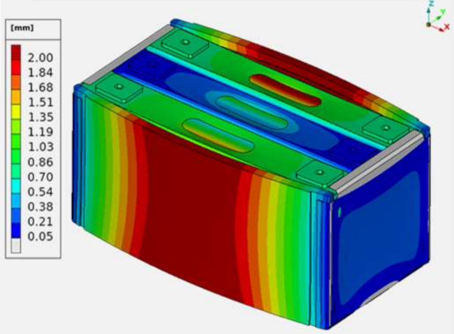
Standard test program:
- 3-4 tests
- Thermal triggered event,

Measured quantities:
- Heat release,
- Gas temperature & pressure,
- Gas volume & composition.

Design & Fast Charge Optimisation





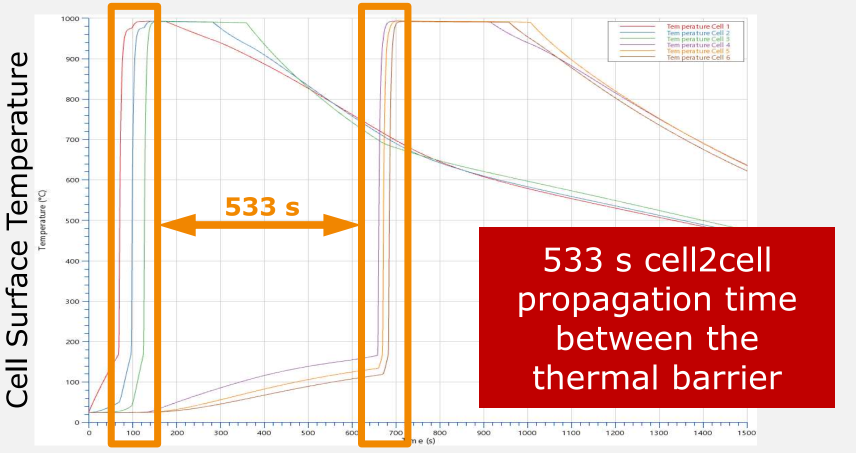


- Fast charge optimization (more later…)
- Cell design optimisation – e.g. current density
- Swelling

No Propagation Modelling & Design

No/slow Cell2Cell Propagation

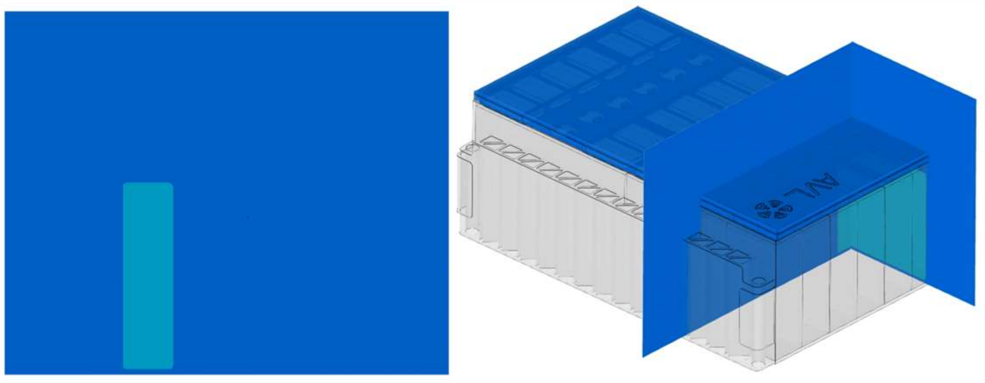
Cell2Cell Propagation **without cooling**



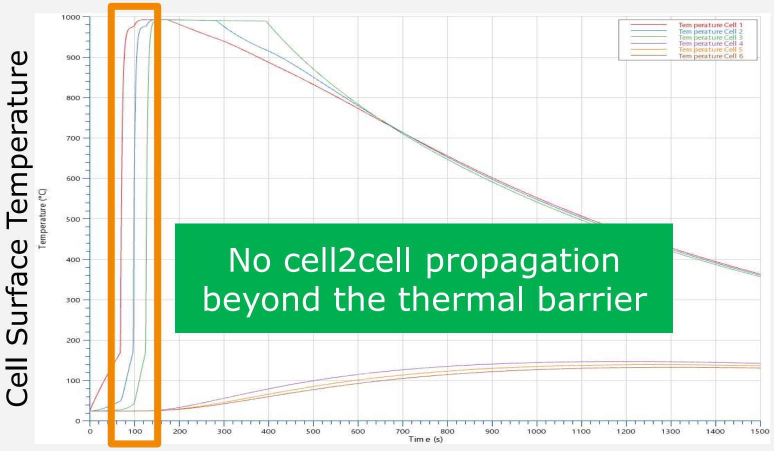
533 s cell2cell propagation time between the thermal barrier

Delay Cell2Cell Propagation

- Cell2cell propagation time must be delayed so that energy release can be handled by the housing.

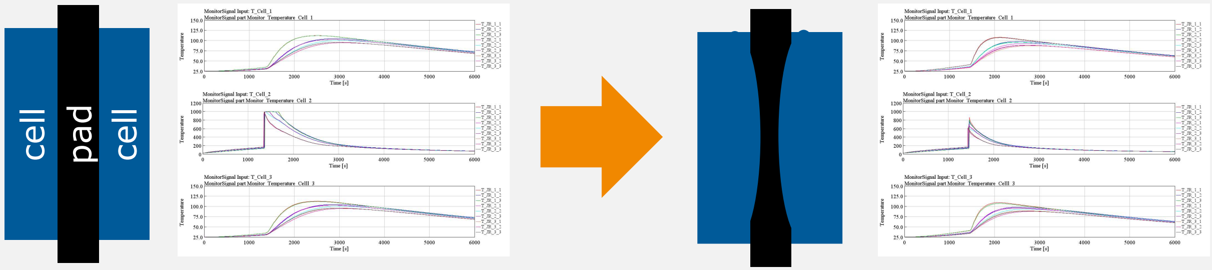


Cell2Cell Propagation **with cooling**



No cell2cell propagation beyond the thermal barrier

BoL vs EoL

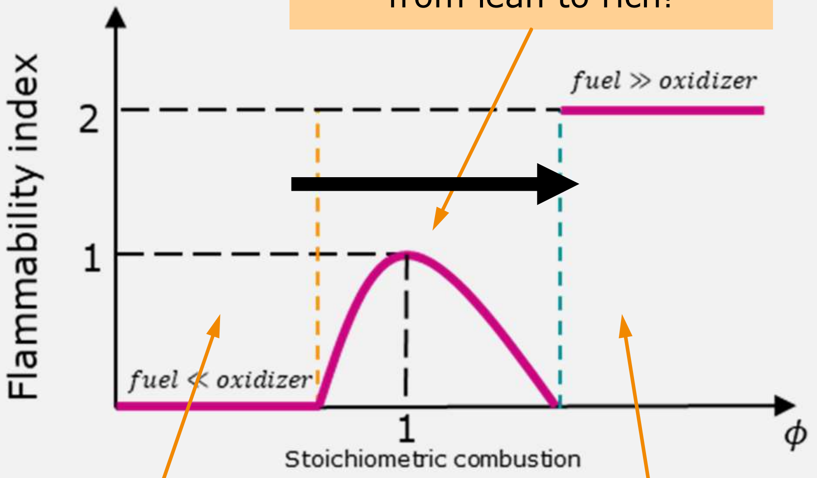


No Propagation Modelling & Design

No Gas Ignition

Gas ignition dependent on O_2 availability

1: Ignitable by spark
2: Auto-ignitable

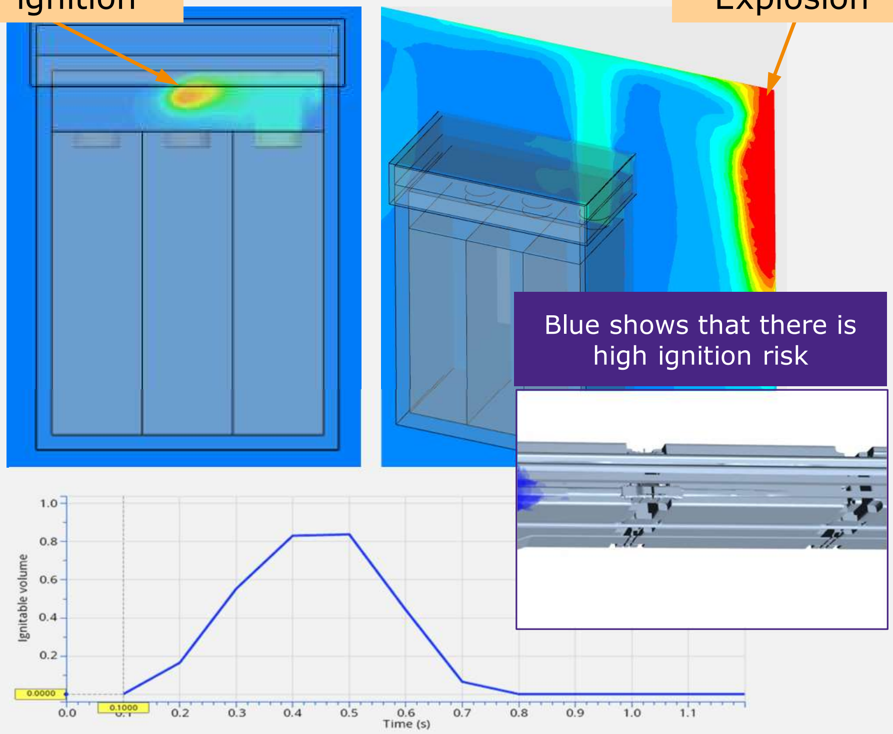


During venting: transition from lean to rich!

Before venting: 100% air, 0% fuel

After venting: mixture too rich, oxygen is replaced or deflagrated

Transient prediction of ignition risk



Pre-ignition

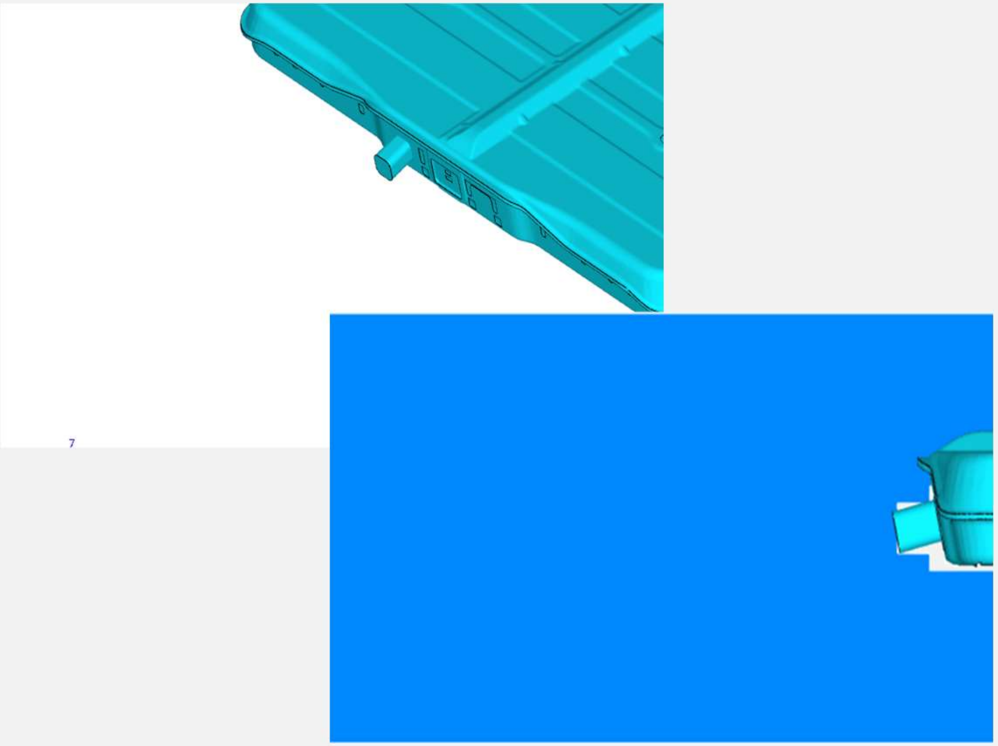
Explosion

Blue shows that there is high ignition risk

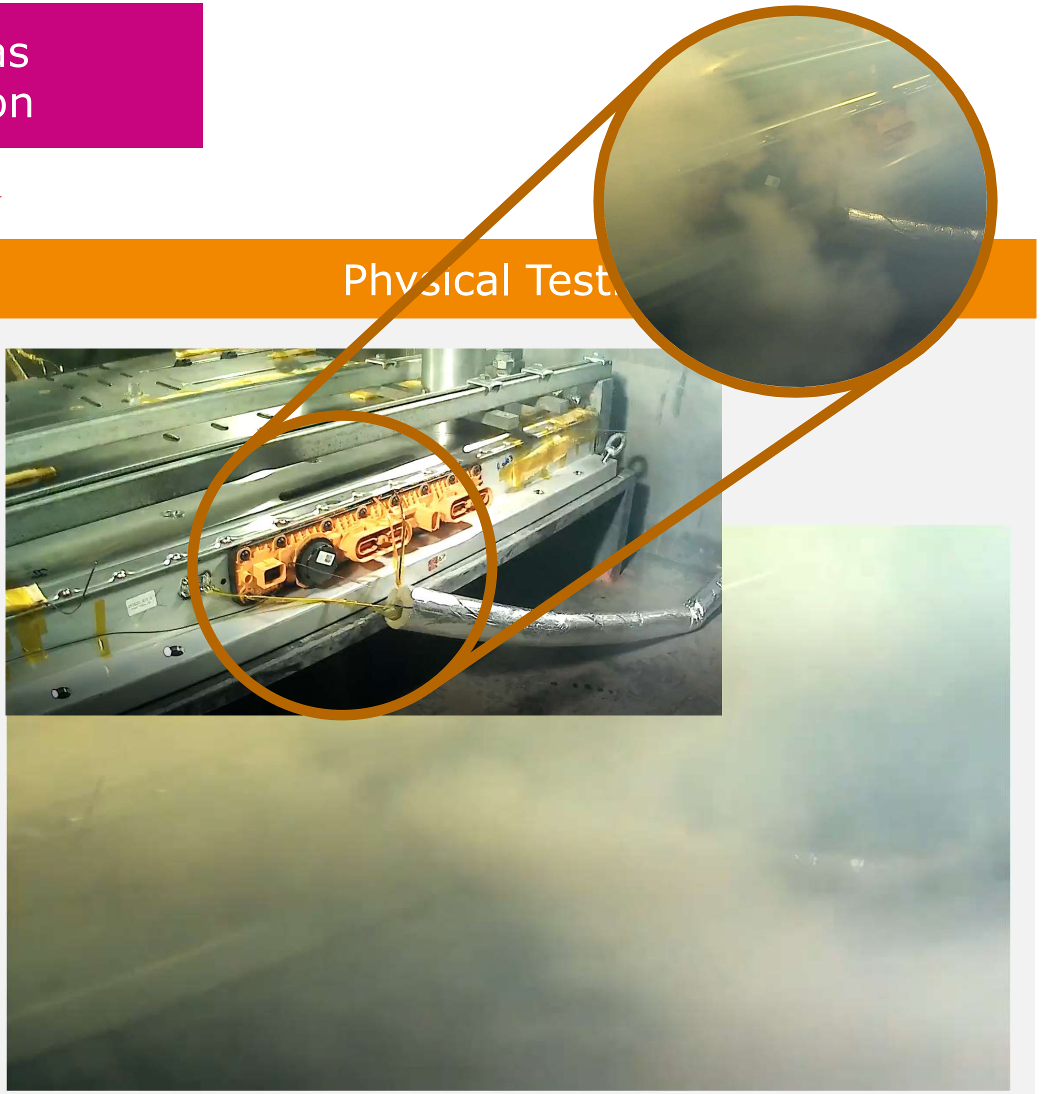
No Propagation Modelling & Design

No Gas Ignition

Simulation



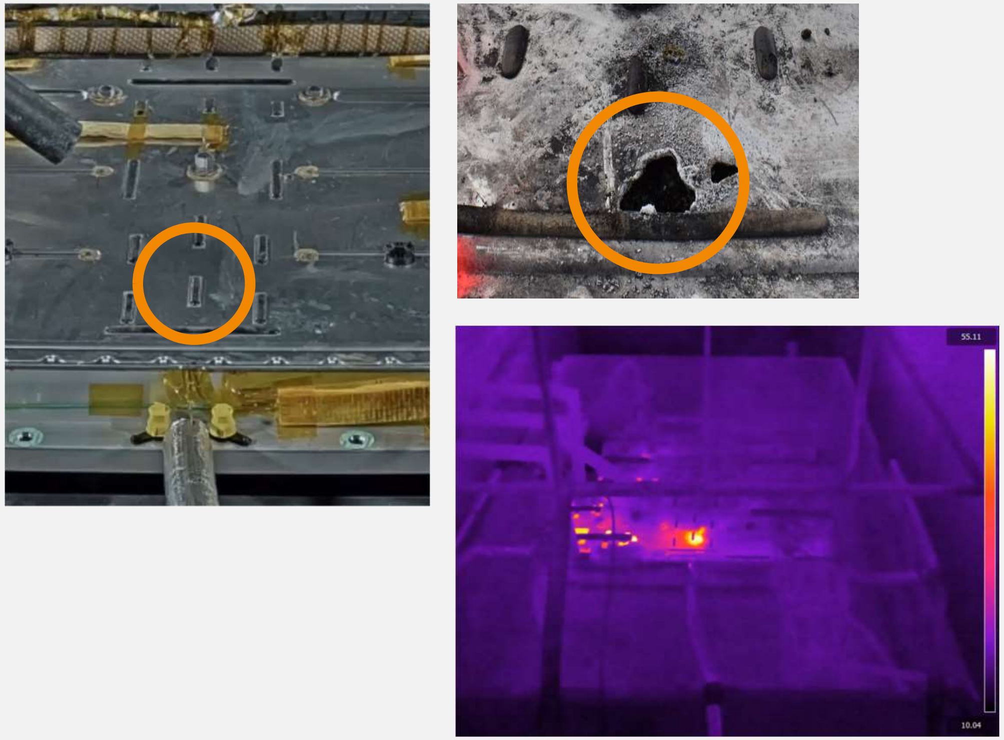
Physical Test



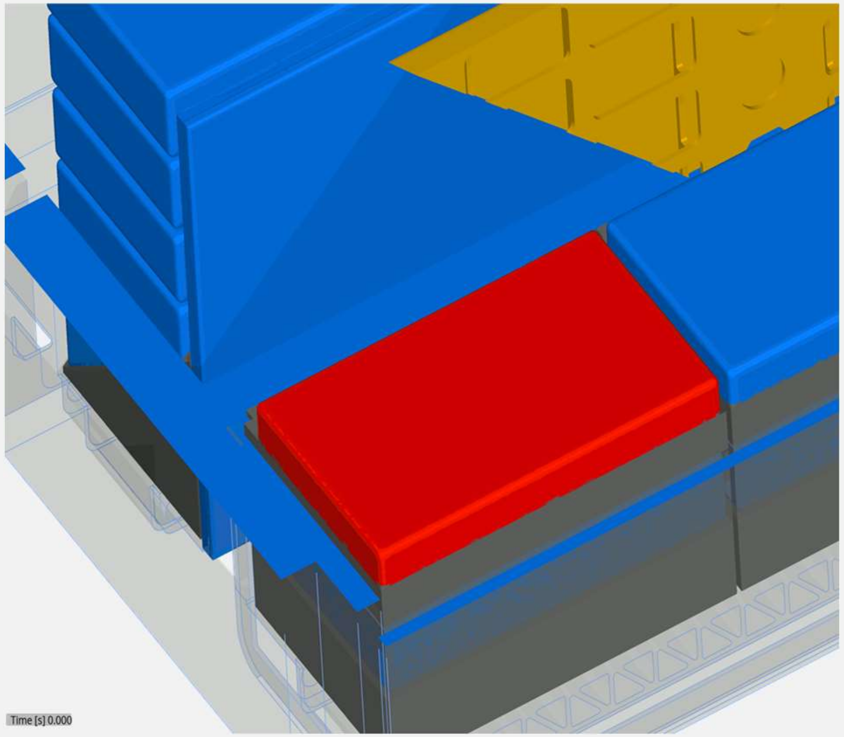
No Propagation Modelling & Design

Robust Design
No Melting/Arcing

Physical Testing



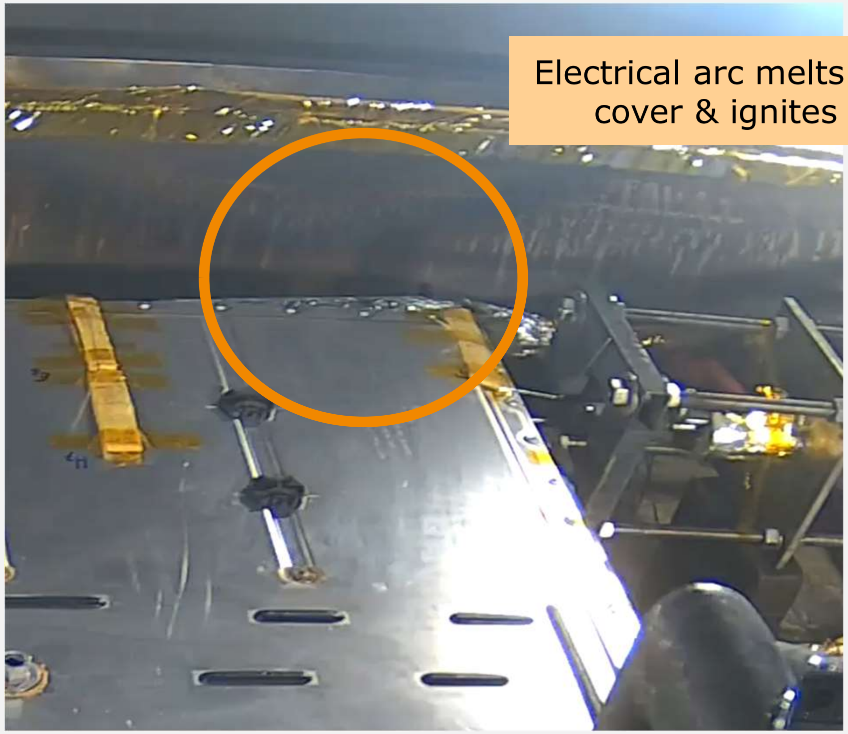
Simulation



No Propagation Modelling & Design

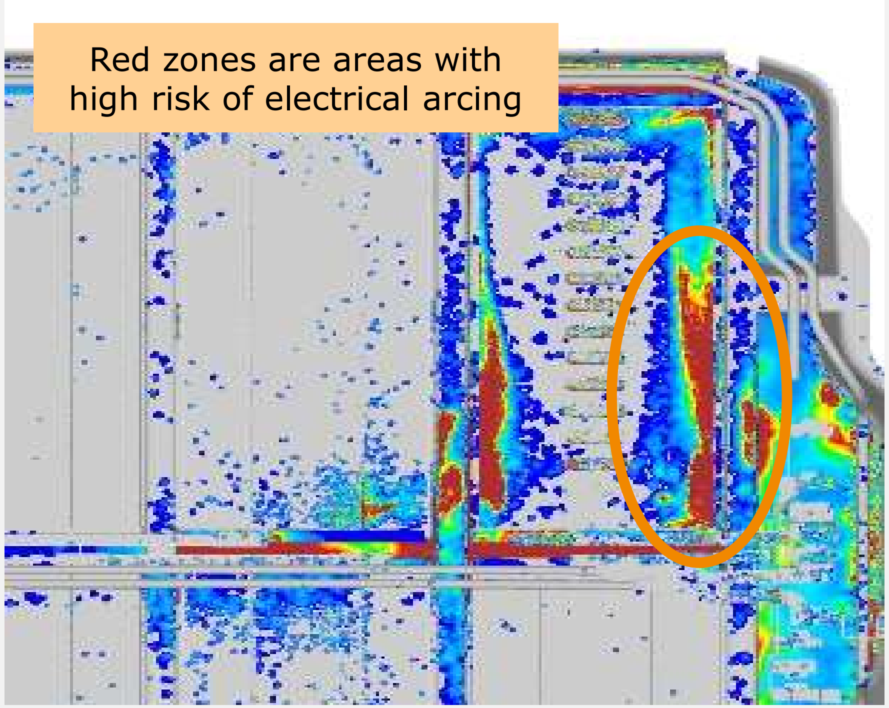
Robust Design
No Melting/Arcing

Physical Testing



Electrical arc melts hole in cover & ignites gas

Simulation

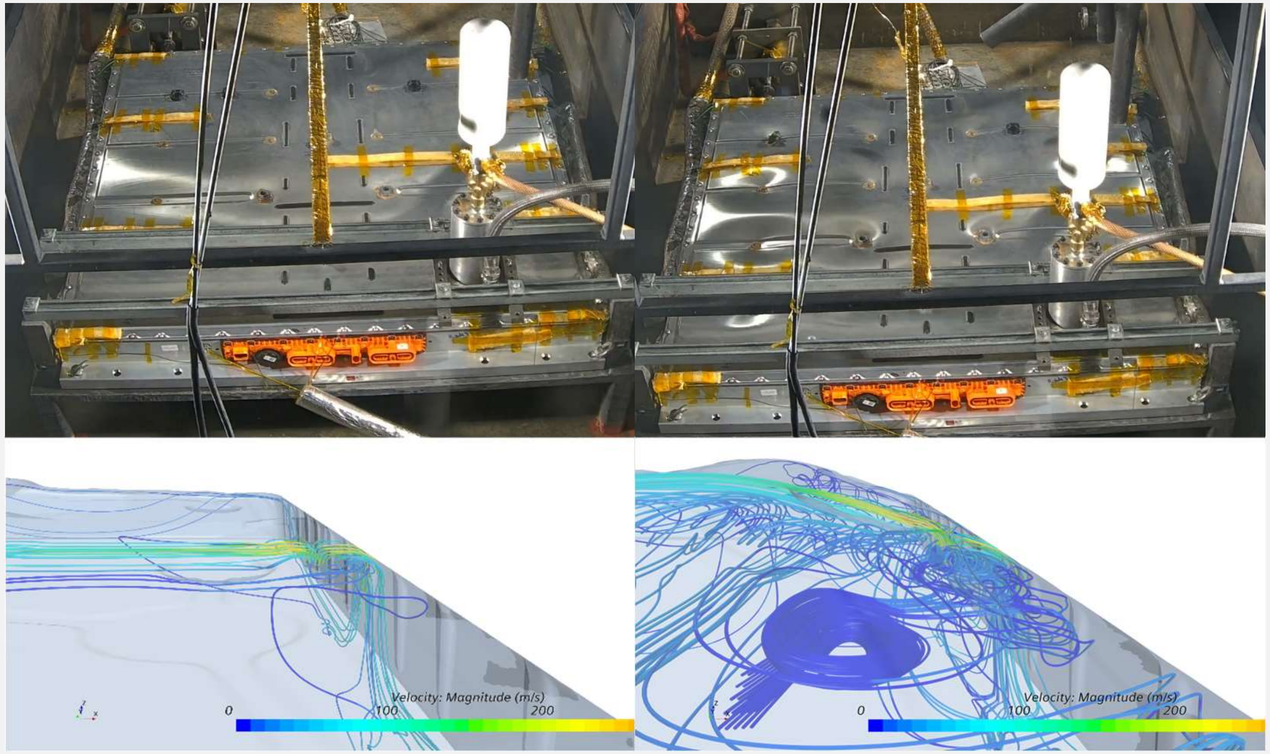


Red zones are areas with high risk of electrical arcing

No Propagation Modelling & Design

Robust Design Cover & Sealing

Cover Deformation Following Gas Release From Cell



Sealing Leak

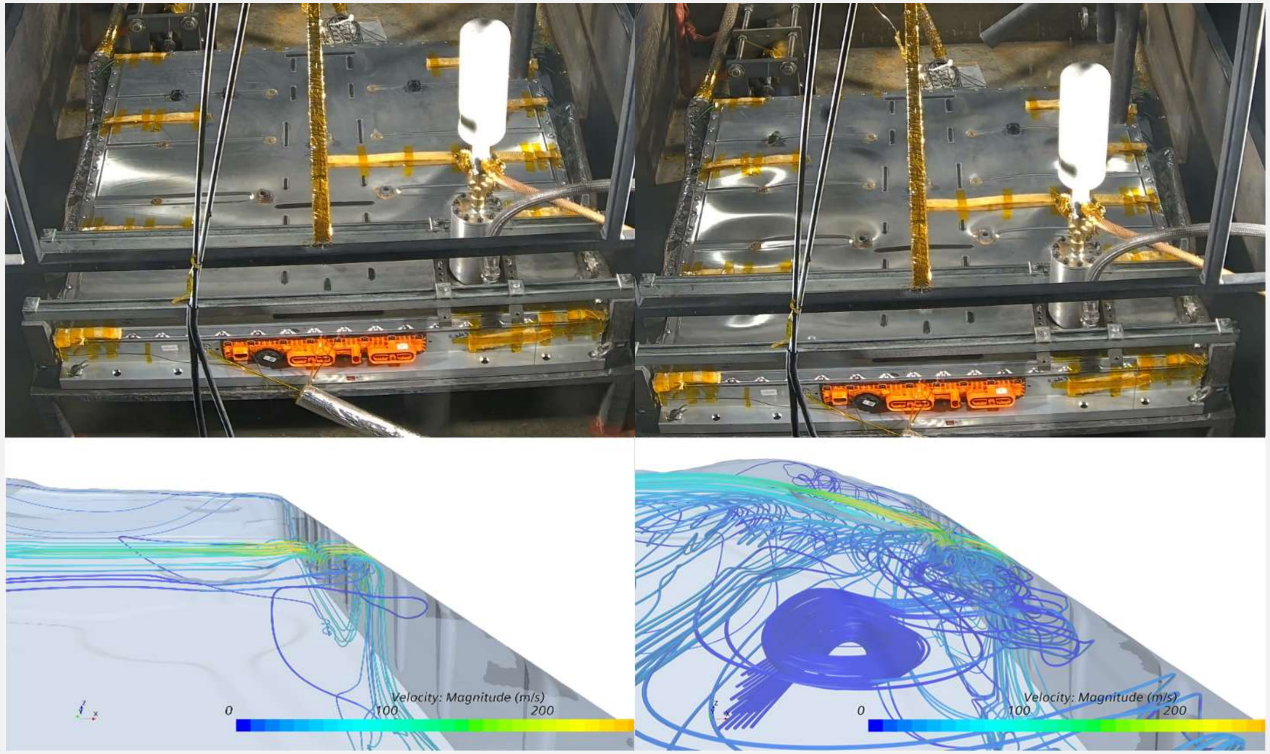
- Leakage in sealing line releases gas which ignites

No Propagation Modelling & Design

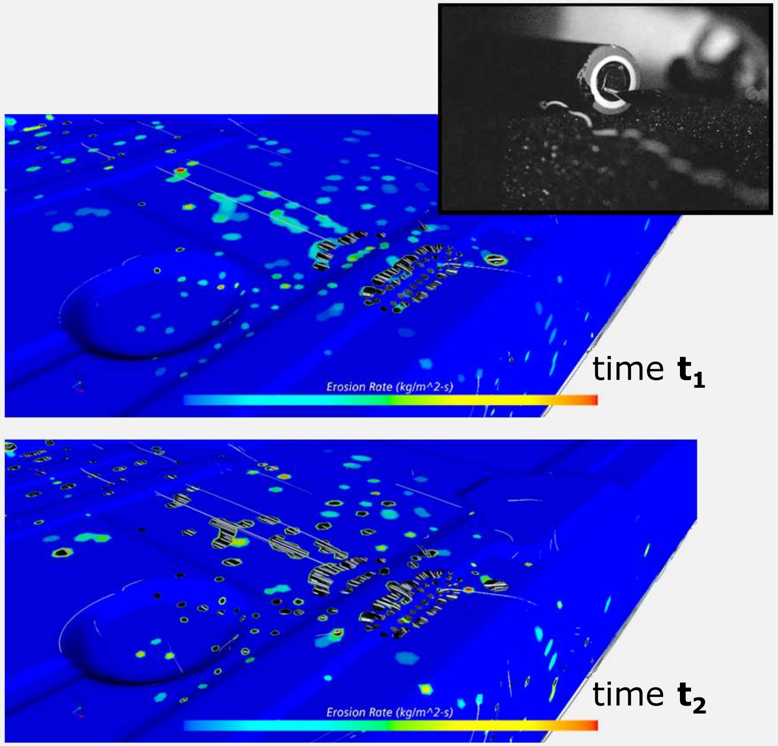
Robust Design Cover & Sealing

Ejecta

Cover Deformation Following Gas Release From Cell



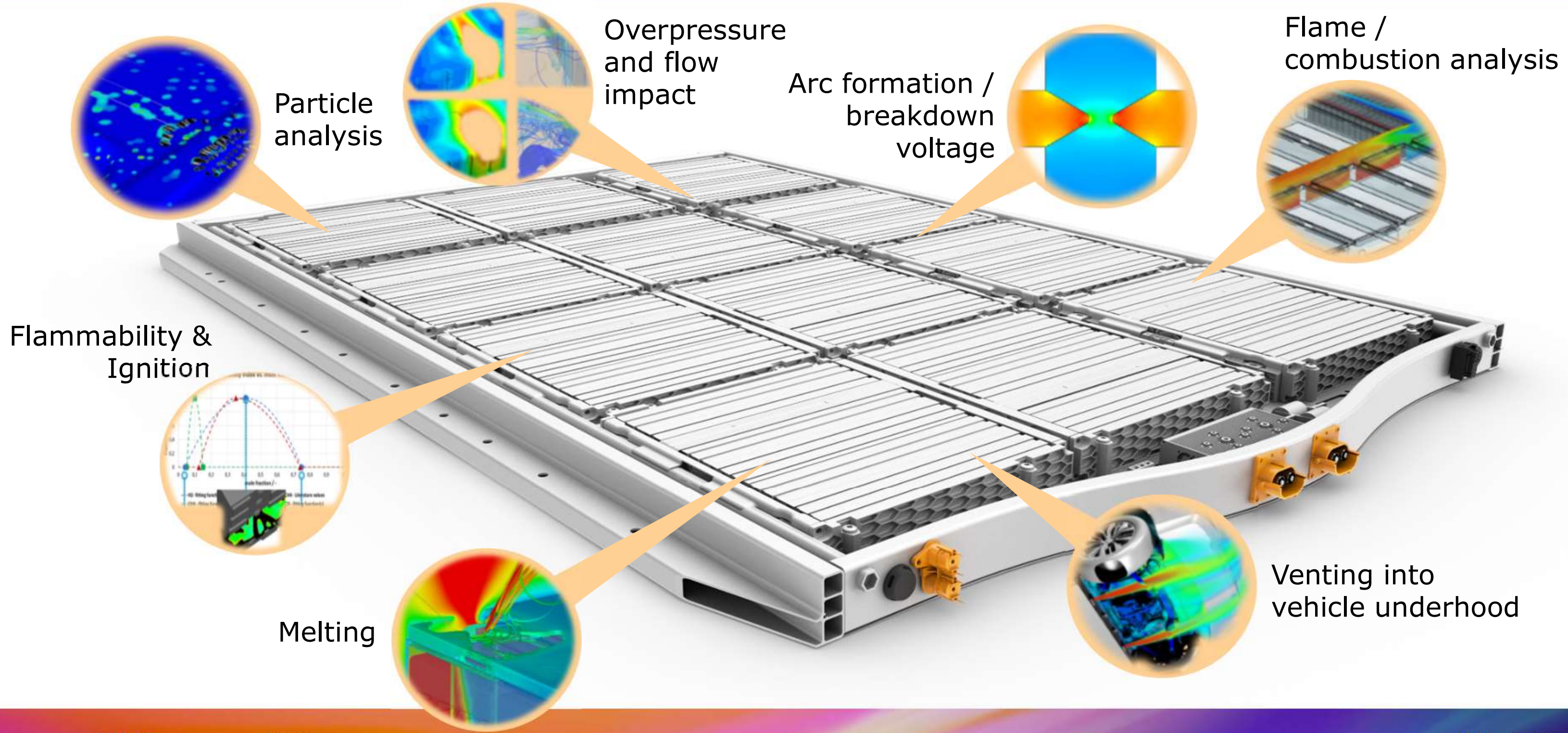
Abrasive & Conductive Particles



No Propagation
Conclusion & Take Away

No Propagation requires:

Correct Cell Chemistry/Package	No Gas Ignition	No/slow Cell2Cell Propagation	Robust Design No Melting/Arcing	Robust Design Cover & Sealing



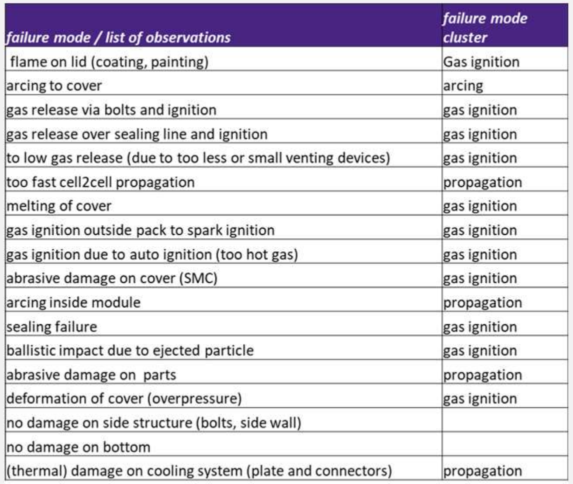
- Coupling of test analysis with simulation results is the key for gaining deep understating and knowhow,
- Full virtual development must include thermal system, cell chemistry and thermal propagation.
- AVL method applied in SOP developments, concept studies, & trouble shootings.
- New and future cell chemistry will have major impact on cooling, breathing/swelling and Thermal Safety behaviour.

Multiple rout causes and failure modes lead to Thermal Propagation

Systematic approach to cover all aspects of thermal propagation

Inductive - lesson learned

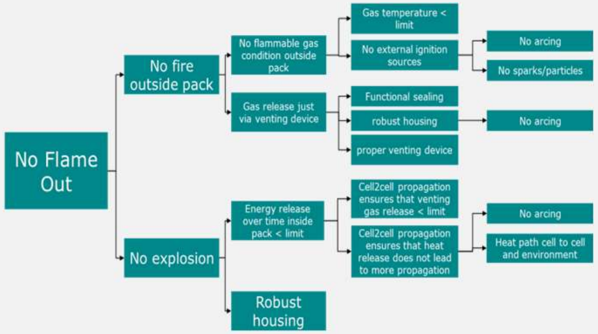
Collection and benchmark of various observed failure modes



failure mode / list of observations	*failure mode cluster*
flame on lid (coating, painting)	Gas ignition
arcing to cover	arcing
gas release via bolts and ignition	gas ignition
gas release over sealing line and ignition	gas ignition
to low gas release (due to too less or small venting devices)	gas ignition
too fast cell2cell propagation	propagation
melting of cover	gas ignition
gas ignition outside pack to spark ignition	gas ignition
gas ignition due to auto ignition (too hot gas)	gas ignition
abrasive damage on cover (SMC)	gas ignition
arcing inside module	propagation
sealing failure	gas ignition
ballistic impact due to ejected particle	gas ignition
abrasive damage on parts	propagation
deformation of cover (overpressure)	gas ignition
no damage on side structure (bolts, side wall)	
no damage on bottom	
(thermal) damage on cooling system (plate and connectors)	propagation

Deductive - derivation of failure chains

Systematic forensic approach to identify rout causes and failure chains



No Flame Out

No fire outside pack

No flammable gas condition outside pack

Gas temperature < limit

No external ignition sources

No arcing

No sparks/particles

Gas release just via venting device

Functional sealing

robust housing

No arcing

proper venting device

No explosion

Energy release over time inside pack < limit

Cell2cell propagation ensures that venting gas release < limit

Cell2cell propagation ensures that heat release does not lead to more propagation

No arcing

Heat path cell to cell and environment

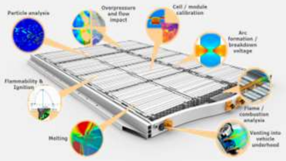
Robust housing

Multi-physical side phenomena

Beside cell thermal runaway behavior, complex system interactions and multi-physical side phenomena are main drivers of thermal propagation

Interaction of

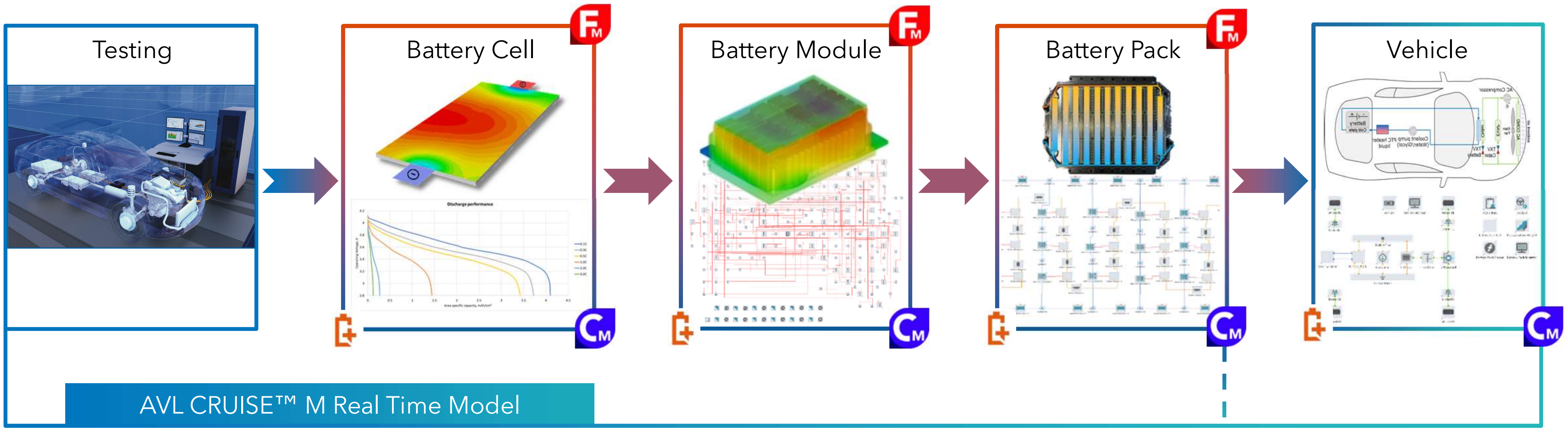
- heat transfer
- material melting
- HV
- LV
- venting gas flow
- Gas ignition
- abrasive damage
- test specification
- vehicle interfaces
- Etc.



CRUISE™ M System
Simulation Battery Modelling

Public

From Cell to Pack



Testing

Battery Cell

Battery Module

Battery Pack

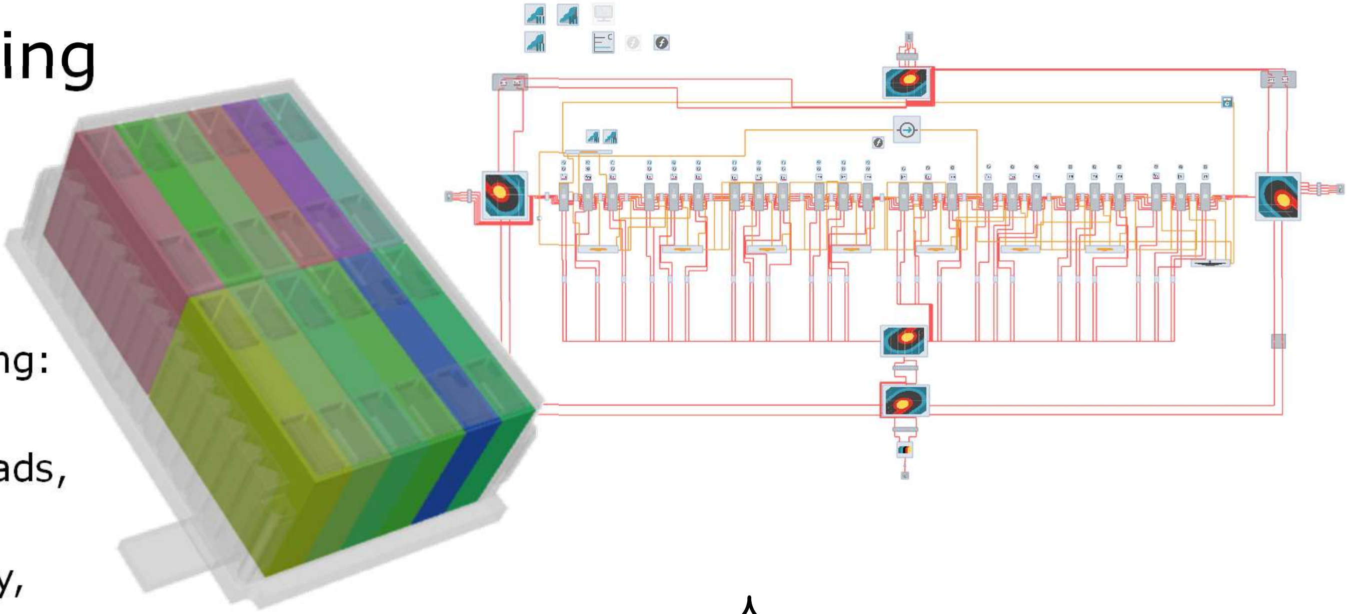
Vehicle

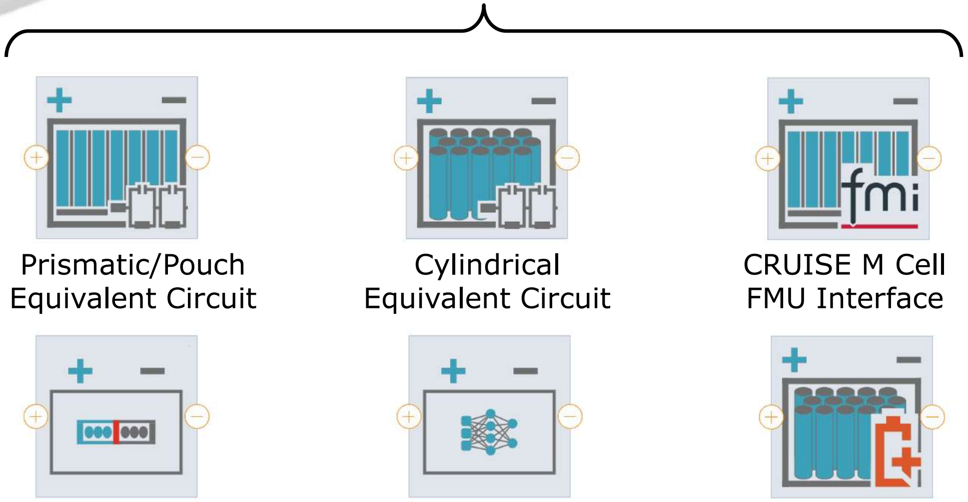
AVL CRUISE™ M Real Time Model

AVL Virtual Battery Development

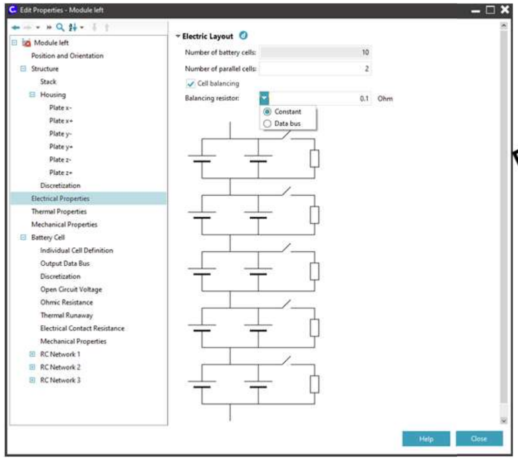
CRUISE™ M Cell Modelling Battery Module

- Dedicated to detailed simulation of overall battery stacks/modules including:
  - multiple batteries stack, housing, cooling plates and compression pads,
- Each battery cell can be defined individually and is evaluated separately,
- Detailed modeling of battery thermal management, electrical and mechanical properties - fully automated coupling.
- Development of strategy for cell balancing,
- Cooling plate materials benchmark and coolant performance evaluation,
- Cooling strategies development,
- Sizing of cooling pump.





Battery Module Structure & Flexibility



Electric Layout

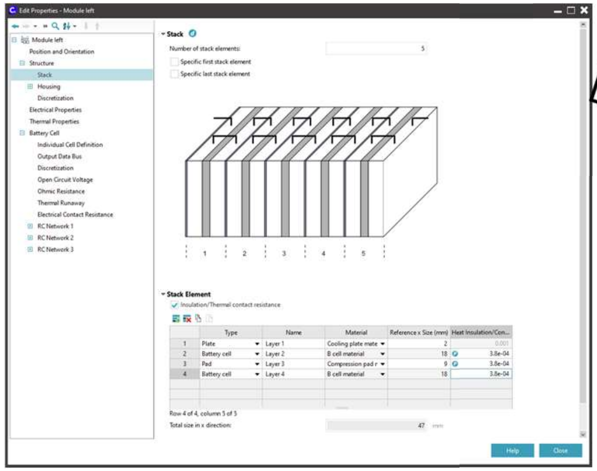
Number of battery cells: 10

Number of parallel cells: 2

☑ Cell balancing

Balancing resistor: 0.1 Ohm

● Constant
○ Data bus



Stack

Number of stack elements: 5

☐ Specific first stack element

☐ Specific last stack element

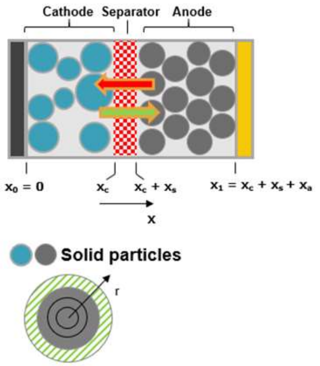
Stack Element

☑ Insulation/Thermal contact resistance

	Type	Name	Material	Reference x Size (mm)	Heat Insulation/Con...
1	Plate	Layer 1	Cooling plate mate	2	0.001
2	Battery cell	Layer 2	B cell material	18	3.8e-04
3	Pad	Layer 3	Compression pad r	9	3.8e-04
4	Battery cell	Layer 4	B cell material	18	3.8e-04

Row 4 of 4, column 5 of 5

Total size in x direction: 47 mm



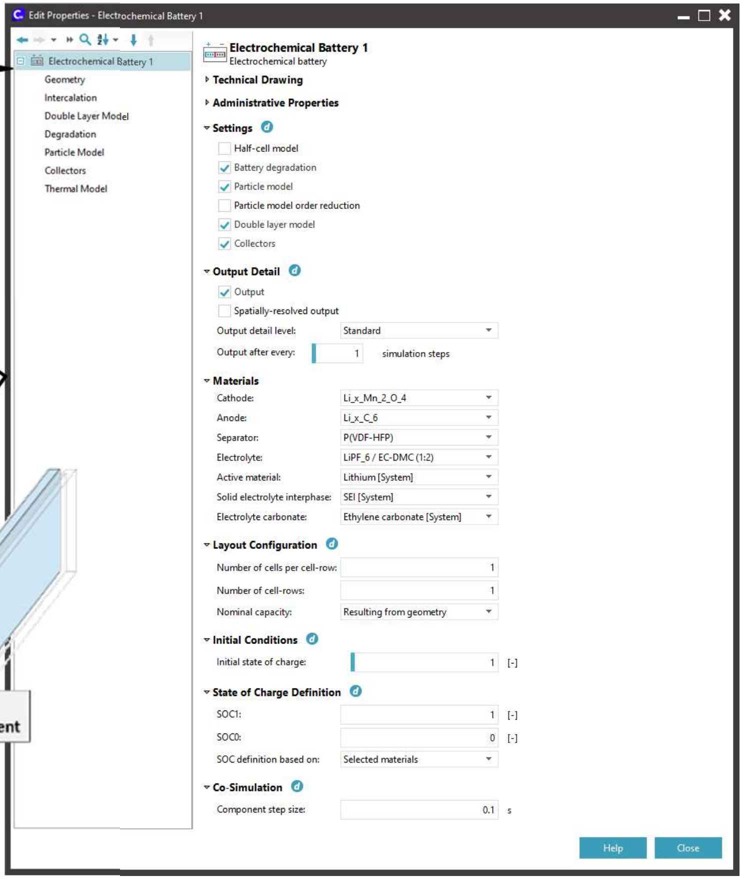
Materials

Solids:

- Active material e.g. (Li) 🟩 charge 🟥 discharge
- ● Metal oxide electrode e.g. (Li_xMO_2)
- ● Graphite electrode e.g. (Li_xC_n)
- ▨ Permeable membrane e.g. P(VDF-HFP)
- ▨ Optional: Solid electrolyte interphase layer SEI

Liquids:

- ☐ Electrolyte e.g. (LiPF_6 / EC-DMC (1:2))
- ▨ Optional: Electrolyte carbonate e.g. ($C_3H_4O_3$)



Electrochemical Battery 1
Electrochemical battery

Settings

☐ Half-cell model
☑ Battery degradation
☑ Particle model
☐ Particle model order reduction
☑ Double layer model
☑ Collectors

Output Detail

☑ Output
☐ Spatially-resolved output

Output detail level: Standard

Output after every: 1 simulation steps

Materials

Cathode: Li_x_Mn_2_O_4

Anode: Li_x_C_6

Separator: P(VDF-HFP)

Electrolyte: LiPF_6 / EC-DMC (1:2)

Active material: Lithium [System]

Solid electrolyte interphase: SEI [System]

Electrolyte carbonate: Ethylene carbonate [System]

Layout Configuration

Number of cells per cell-row: 1

Number of cell-rows: 1

Nominal capacity: Resulting from geometry

Initial Conditions

Initial state of charge: 1 [-]

State of Charge Definition

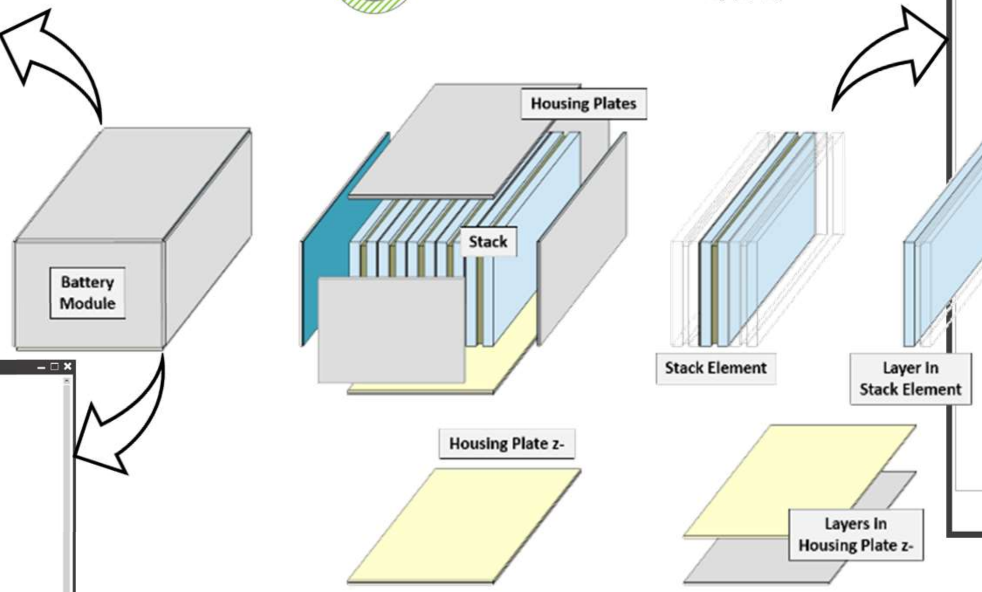
SOC1: 1 [-]

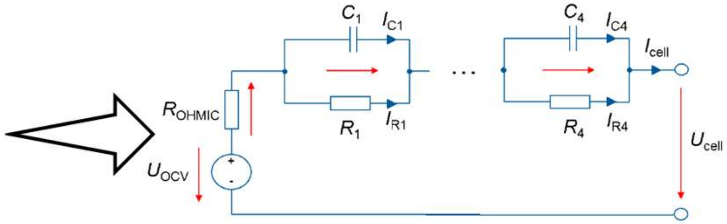
SOC0: 0 [-]

SOC definition based on: Selected materials

Co-Simulation

Component step size: 0.1 s



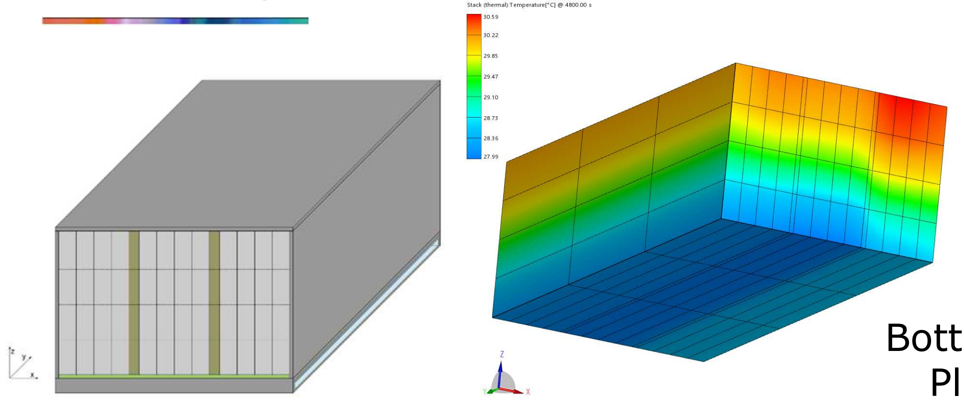


CC/CV Cycle Controller

DC-DC Converter

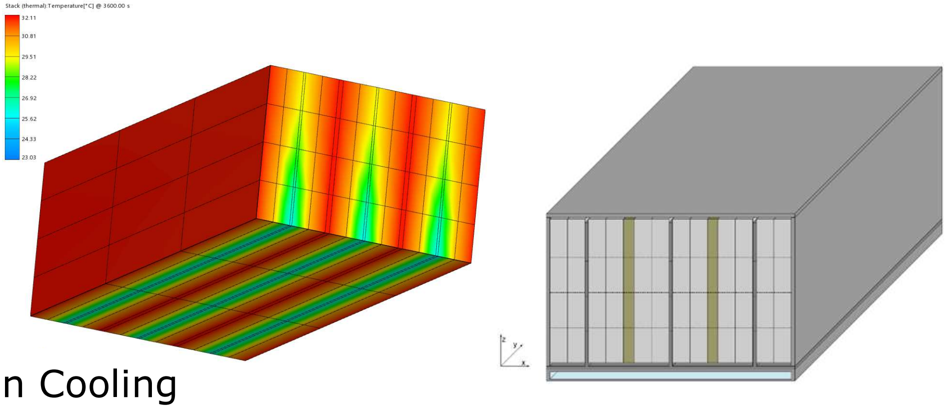
BMS Limits

Battery Module Cooling Examples

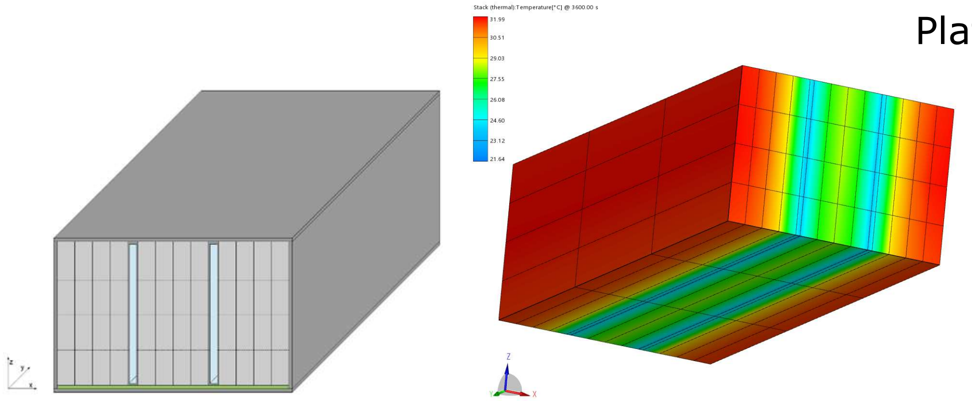


Bottom Plate

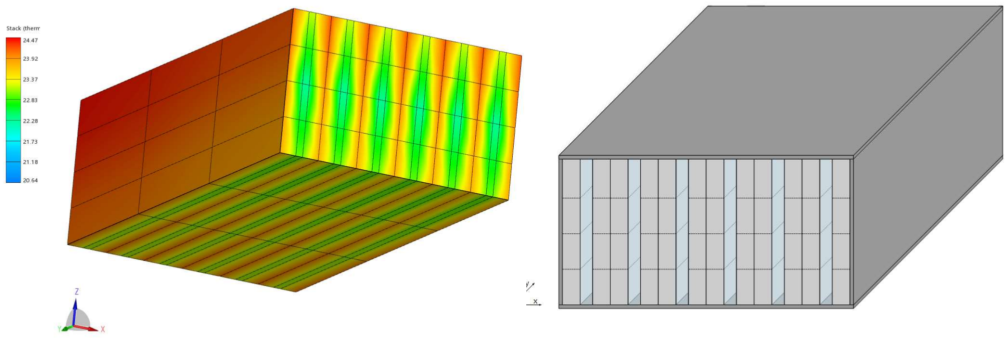
Fin Cooling



Cooling Plates



Immersion Cooling



CRUISE™ M System Simulation
Battery Modelling:
Cell Property Optimization

Find Optimum Combination of Cell Properties

Target / KPIs

Maximize:

Cell Capacity [As]

Charge Capability* [V]

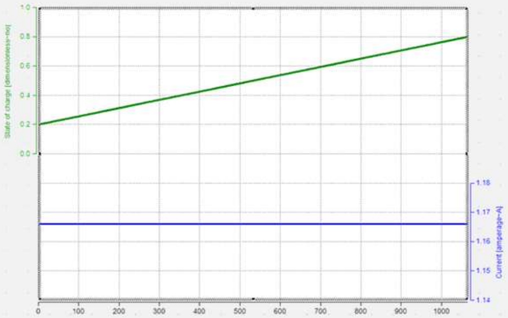
Minimize:

Charging Losses [Ws]

* Charge Capability = Final Anode Potential: Desired > 0 to avoid Lithium Plating

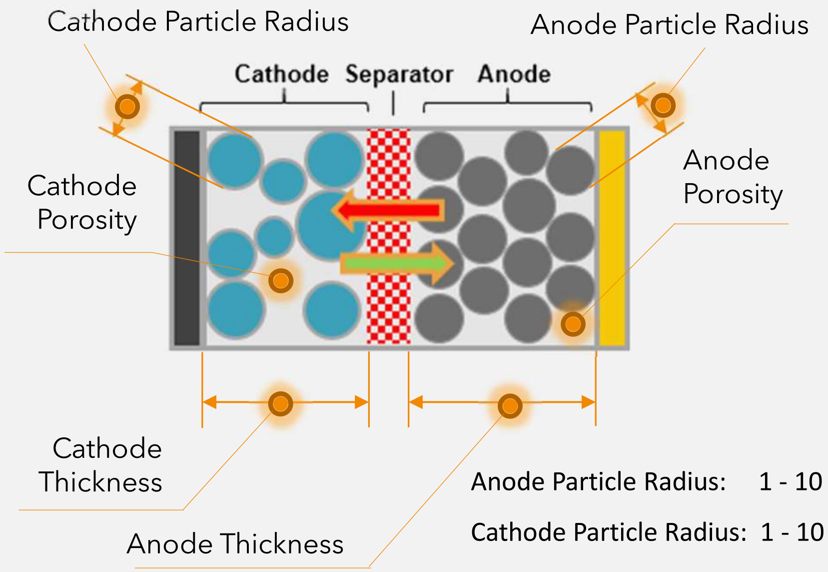
Use Case

- Charge from 20% to 80% SOC
- Constant Current



* Temperature/current kept constant in this example – can also be varied.

Modelling Approach



Anode Particle Radius: 1 - 10 µm

Cathode Particle Radius: 1 - 10 µm

Porosity Cathode: 0.15 - 0.5 Ratio

Porosity Anode: 0.15 - 0.5 Ratio

Cathode thickness: 50 to 100 µm

Anode thickness: 60 to 120 µm

Find Optimum Combination of Cell Properties

Target / KPIs

Maximize:

Cell Capacity [As]

Charge Capability* [V]

Minimize:

Charging Losses [Ws]

* Charge Capability = Final Anode Potential: Desired > 0 to avoid Lithium Plating

Use Case

- Charge from 20% to 80% SOC
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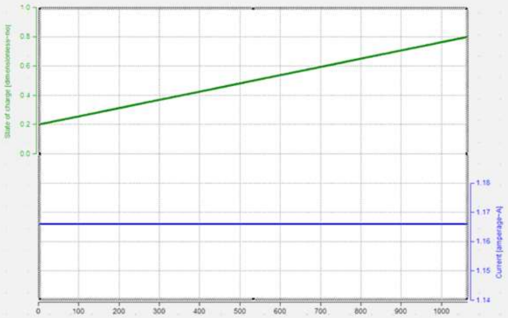
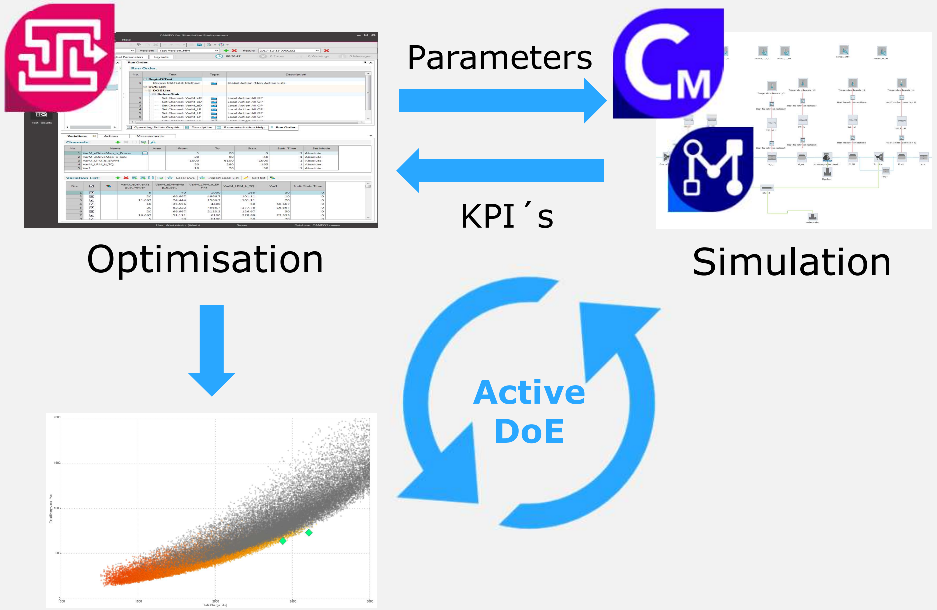


* Temperature/current kept constant in this example – can also be varied.

Modelling Approach



Parameters

KPI´s

Optimisation

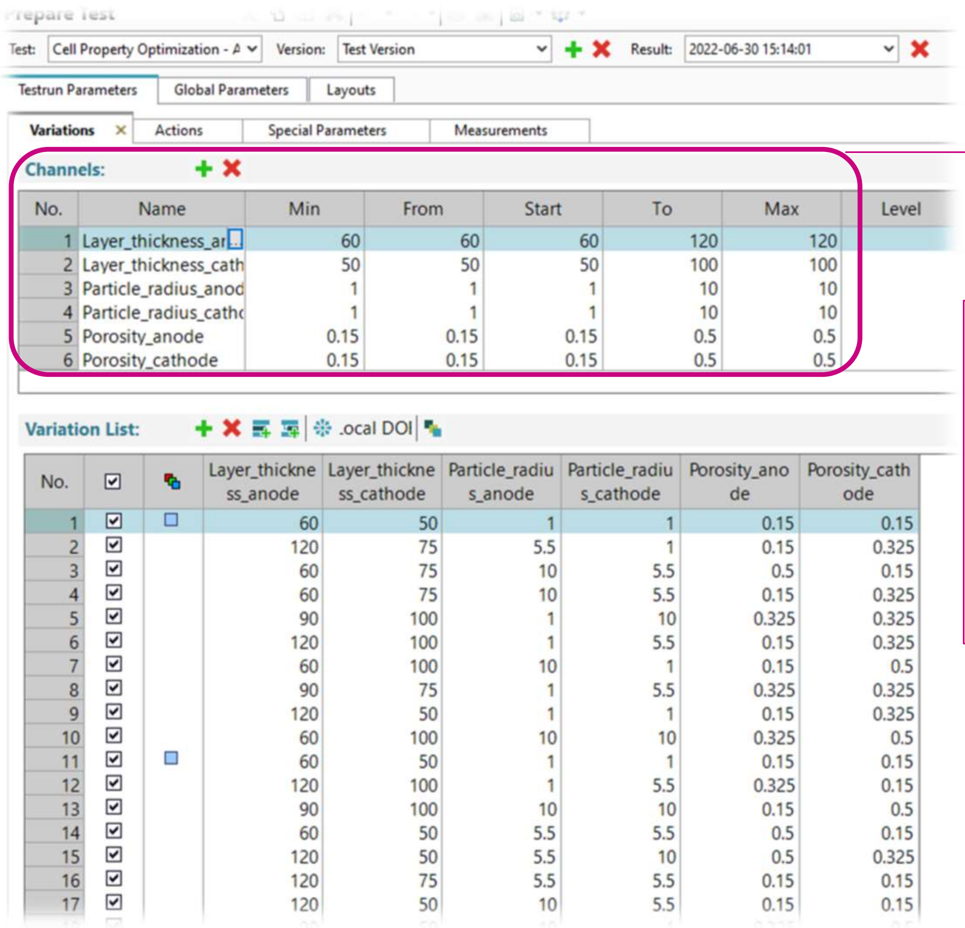
Simulation

Active DoE

Result

Active DoE Test Preparation

- **Parameters & Ranges Definition**



Test: Cell Property Optimization - A
Version: Test Version
Result: 2022-06-30 15:14:01

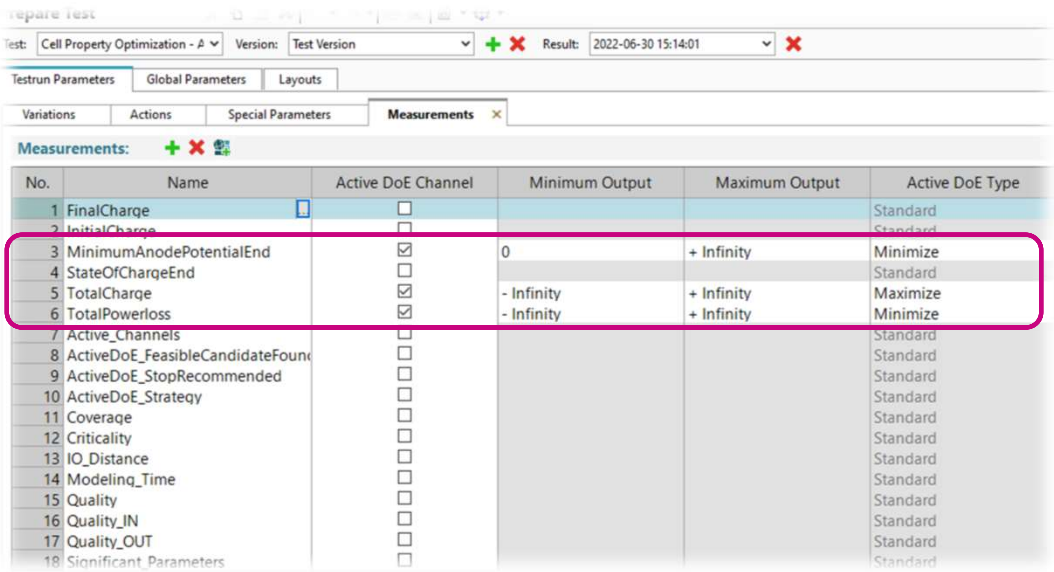
Channels:

No.	Name	Min	From	Start	To	Max	Level
1	Layer_thickness_ar	60	60	60	120	120	
2	Layer_thickness_cath	50	50	50	100	100	
3	Particle_radius_anod	1	1	1	10	10	
4	Particle_radius_cathc	1	1	1	10	10	
5	Porosity_anode	0.15	0.15	0.15	0.5	0.5	
6	Porosity_cathode	0.15	0.15	0.15	0.5	0.5	

Variation List:

No.	☑		Layer_thickness_anode	Layer_thickness_cathode	Particle_radius_anode	Particle_radius_cathode	Porosity_anode	Porosity_cathode
1	☑	☐	60	50	1	1	0.15	0.15
2	☑		120	75	5.5	1	0.15	0.325
3	☑		60	75	10	5.5	0.5	0.15
4	☑		60	75	10	5.5	0.15	0.325
5	☑		90	100	1	10	0.325	0.325
6	☑		120	100	1	5.5	0.15	0.325
7	☑		60	100	10	1	0.15	0.5
8	☑		90	75	1	5.5	0.325	0.325
9	☑		120	50	1	1	0.15	0.325
10	☑		60	100	10	10	0.325	0.5
11	☑	☐	60	50	1	1	0.15	0.15
12	☑		120	100	1	5.5	0.325	0.15
13	☑		90	100	10	10	0.15	0.5
14	☑		60	50	5.5	5.5	0.5	0.15
15	☑		120	50	5.5	10	0.5	0.325
16	☑		120	75	5.5	5.5	0.15	0.15
17	☑		120	50	10	5.5	0.15	0.15

- **Active DoE Focus and Limits Definition**

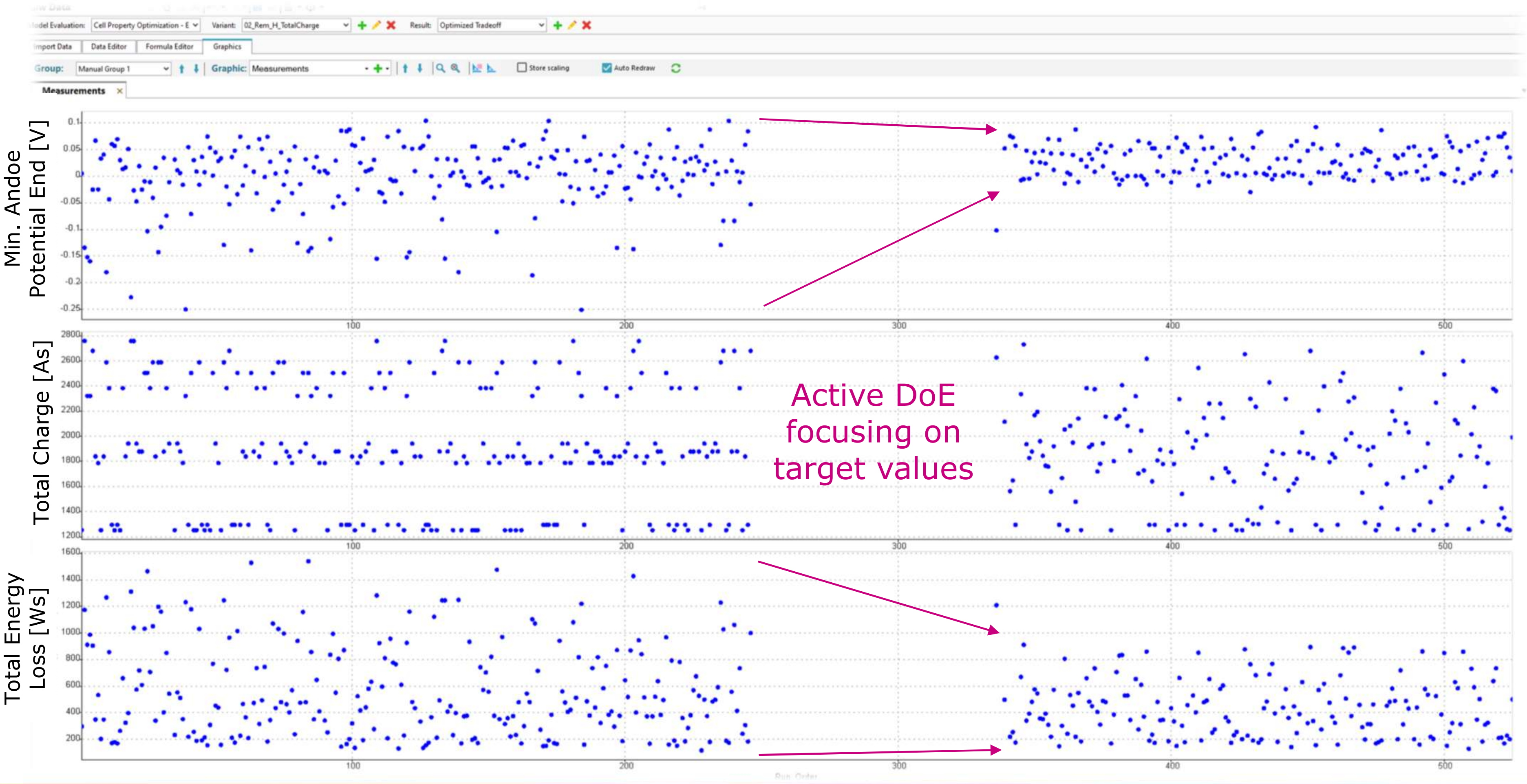


Test: Cell Property Optimization - A
Version: Test Version
Result: 2022-06-30 15:14:01

Measurements:

No.	Name	Active DoE Channel	Minimum Output	Maximum Output	Active DoE Type
1	FinalCharge	☐			Standard
2	InitialCharge	☐			Standard
3	MinimumAnodePotentialEnd	☑	0	+ Infinity	Minimize
4	StateOfChargeEnd	☐			Standard
5	TotalCharge	☑	- Infinity	+ Infinity	Maximize
6	TotalPowerloss	☑	- Infinity	+ Infinity	Minimize
7	Active_Channels	☐			Standard
8	ActiveDoE_FeasibleCandidateFound	☐			Standard
9	ActiveDoE_StopRecommended	☐			Standard
10	ActiveDoE_Strategy	☐			Standard
11	Coverage	☐			Standard
12	Criticality	☐			Standard
13	IO_Distance	☐			Standard
14	Modeling_Time	☐			Standard
15	Quality	☐			Standard
16	Quality_IN	☐			Standard
17	Quality_OUT	☐			Standard
18	Significant_Parameters	☐			Standard

Active DoE Measured Data



odel Evaluation: Cell Property Optimization - E

Variant: 02_Rem_H_TotalCharge

Result: Optimized Tradeoff

Group: Manual Group 1

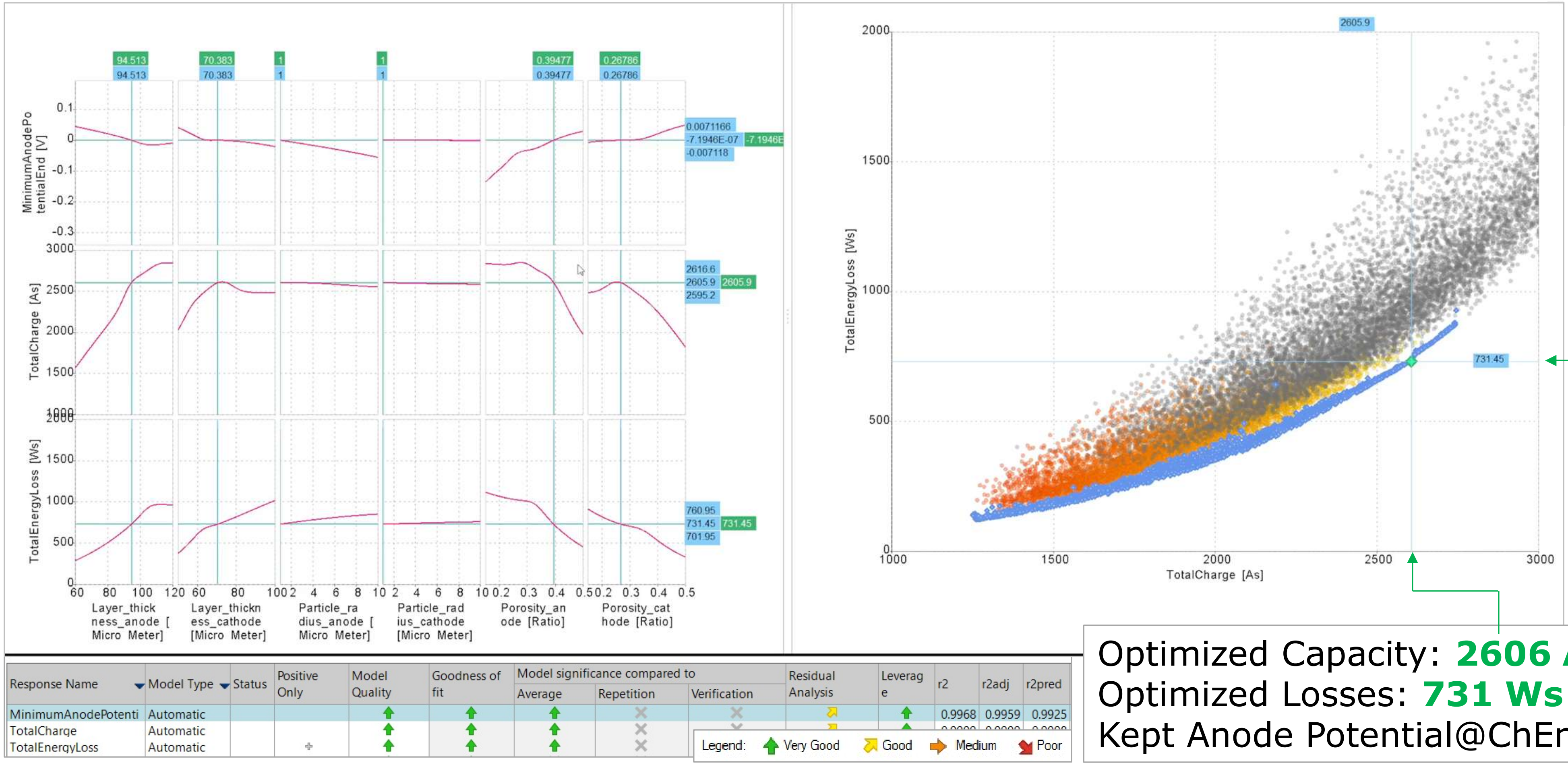
Graphic: Measurements

☐ Store scaling

☑ Auto Redraw

Active DoE focusing on target values

Step 1
Interactive Model and Trade-off Optimization Result



Response Name	Model Type	Status	Positive Only	Model Quality	Goodness of fit	Model significance compared to Average	Repetition	Verification	Residual Analysis	Leverage	r2	r2adj	r2pred
MinimumAnodePotenti	Automatic			⬆	⬆	⬆	✗	✗	↗	⬆	0.9968	0.9959	0.9925
TotalCharge	Automatic			⬆	⬆	⬆	✗	✗	↗	⬆	[illegible]	[illegible]	[illegible]
TotalEnergyLoss	Automatic		✥	⬆	⬆	⬆	✗						

Legend: ⬆ Very Good ↗ Good ➡ Medium ↘ Poor

Optimized Capacity: **2606 As**
Optimized Losses: **731 Ws**
Kept Anode Potential@ChEnd: **0 V**

Step 2
Take Tolerances into account

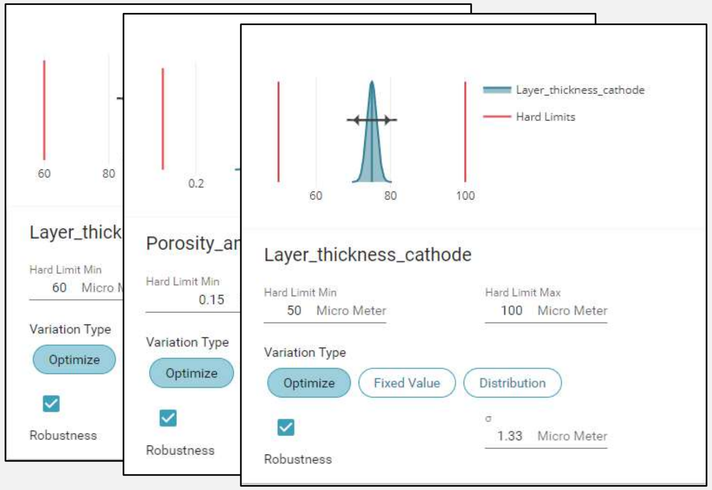
Step 1: Result

- Cell optimized with
  - Capacity: 2600 As,
  - Charging Losses: 731 Ws
  - Anode Potential > 0V.
- However, production variations will have significant impact on the cell properties.
- The cell cannot be produced reasonably without considering these tolerances: this requires robust optimization.

Step 2: Robust Optimisation

Production Considerations:

- Capacity limit defined to 2300 As
- Losses limit defined to 750 Ws
- Nominal Charge Capability > 0V
- Defined Production Tolerances:



Layer_thick

Hard Limit Min
60 Micro M

Variation Type
Optimize

☑ Robustness

Porosity_an

Hard Limit Min
0.15

Variation Type
Optimize

☑ Robustness

Layer_thickness_cathode

Hard Limit Min: 50 Micro Meter
Hard Limit Max: 100 Micro Meter

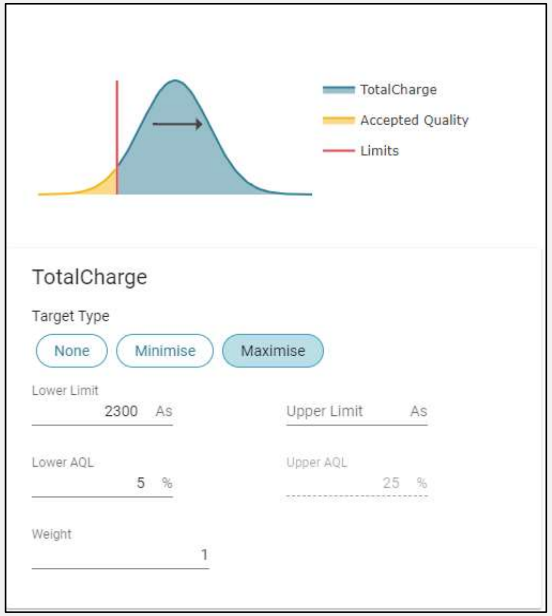
Variation Type: Optimize | Fixed Value | Distribution

☑ Robustness

σ: 1.33 Micro Meter

New Target:

- Scrap production < 5%



TotalCharge

Target Type: None | Minimise | Maximise

Lower Limit: 2300 As
Upper Limit As

Lower AQL: 5 %
Upper AQL: 25 %

Weight: 1

Step 2
Take Tolerances into account

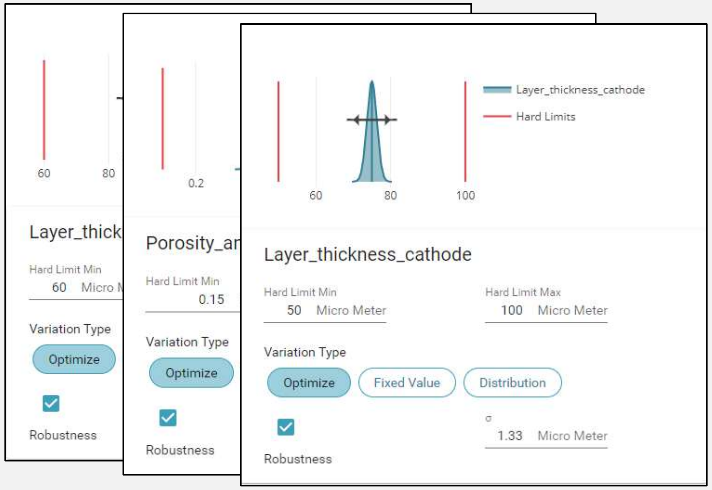
Step 1: Result

- Cell optimized with
  - Capacity: 2600 As,
  - Charging Losses: 731 Ws
  - Anode Potential > 0V.
- However, production variations will have significant impact on the cell properties.
- The cell cannot be produced reasonably without considering these tolerances: this requires robust optimization.

Step 2: Robust Optimisation

Production Considerations:

- Capacity limit defined to 2300 As
- Losses limit defined to 750 Ws
- Nominal Charge Capability > 0V
- Defined Production Tolerances:



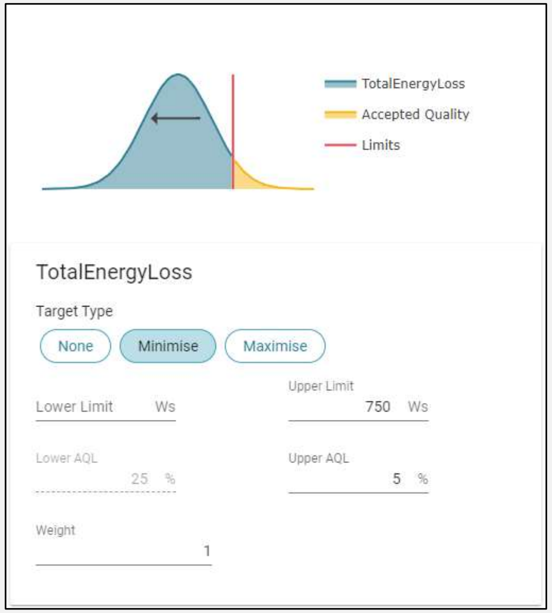
Layer_thick
Hard Limit Min: 60 Micro M
Variation Type: Optimize
☑ Robustness

Porosity_an
Hard Limit Min: 0.15
Variation Type: Optimize
☑ Robustness

Layer_thickness_cathode
Hard Limit Min: 50 Micro Meter
Hard Limit Max: 100 Micro Meter
Variation Type: Optimize
☑ Robustness
σ: 1.33 Micro Meter

New Target:

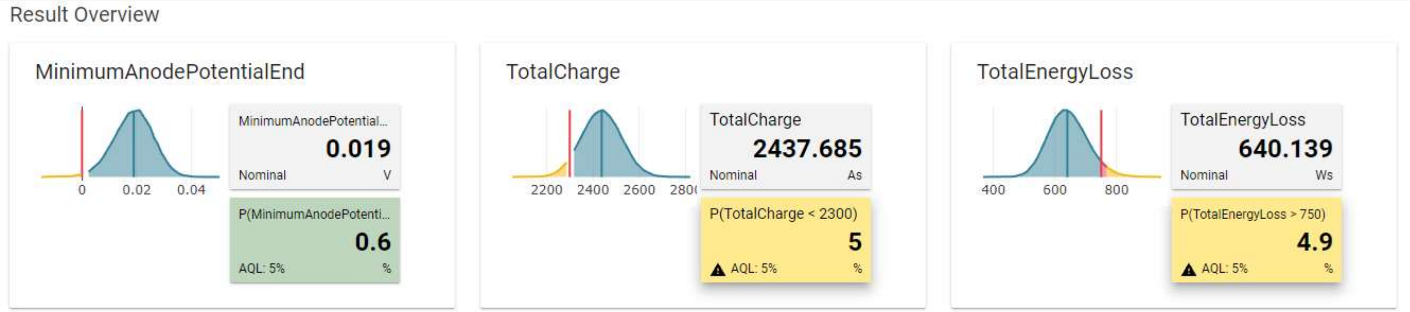
- Scrap production < 5%



TotalEnergyLoss
Target Type: Minimise
Lower Limit: Ws
Upper Limit: 750 Ws
Lower AQL: 25 %
Upper AQL: 5 %
Weight: 1

Robust Optimization Result

Robust Optimisation Result


Result Overview

MinimumAnodePotentialEnd

MinimumAnodePotential...
0.019
Nominal V

P(MinimumAnodePotenti...
0.6
AQL: 5% %

TotalCharge

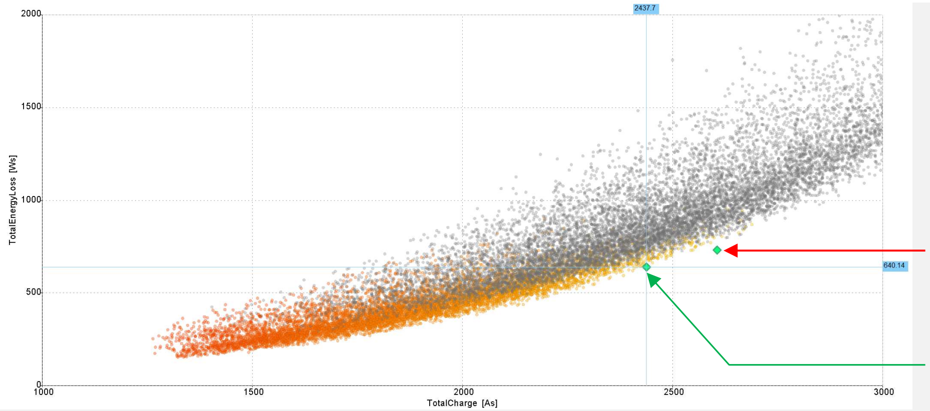
TotalCharge
2437.685
Nominal As

P(TotalCharge < 2300)
5
⚠ AQL: 5% %

TotalEnergyLoss

TotalEnergyLoss
640.139
Nominal Ws

P(TotalEnergyLoss > 750)
4.9
⚠ AQL: 5% %

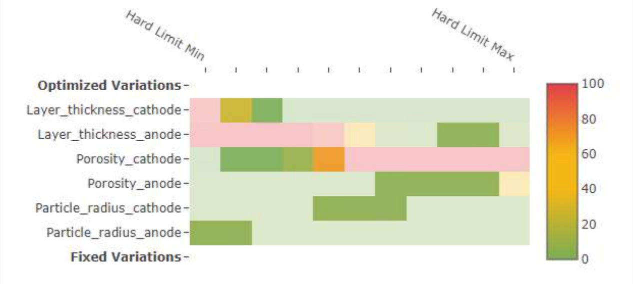


Cell with average 2437 As Capacity and 640 Ws Losses can be produced with given Tolerances and 5% accepted scrap production.

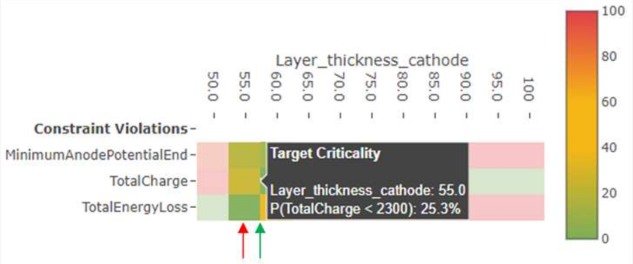
Original Trade-Off Optimized Result

Production Robust Optimized Result

Tolerance Analysis



Layer Thickness Cathode is the most critical parameter - if the average of this parameter changes from 58 to 55 µm the scrap production rate deteriorates from 5% to 25%


Target Criticality
Layer_thickness_cathode: 55.0
P(TotalCharge < 2300): 25.3%

Thank-You For Listening.

Any Questions?

With thanks to:
Thomas Ebner, Bernhard Brunnsteiner, Matthias Pichler.

Sustainable Li Ion Battery Pack Design

AVL Battery Technology Day

About Me

Dr Saikat Ghosh

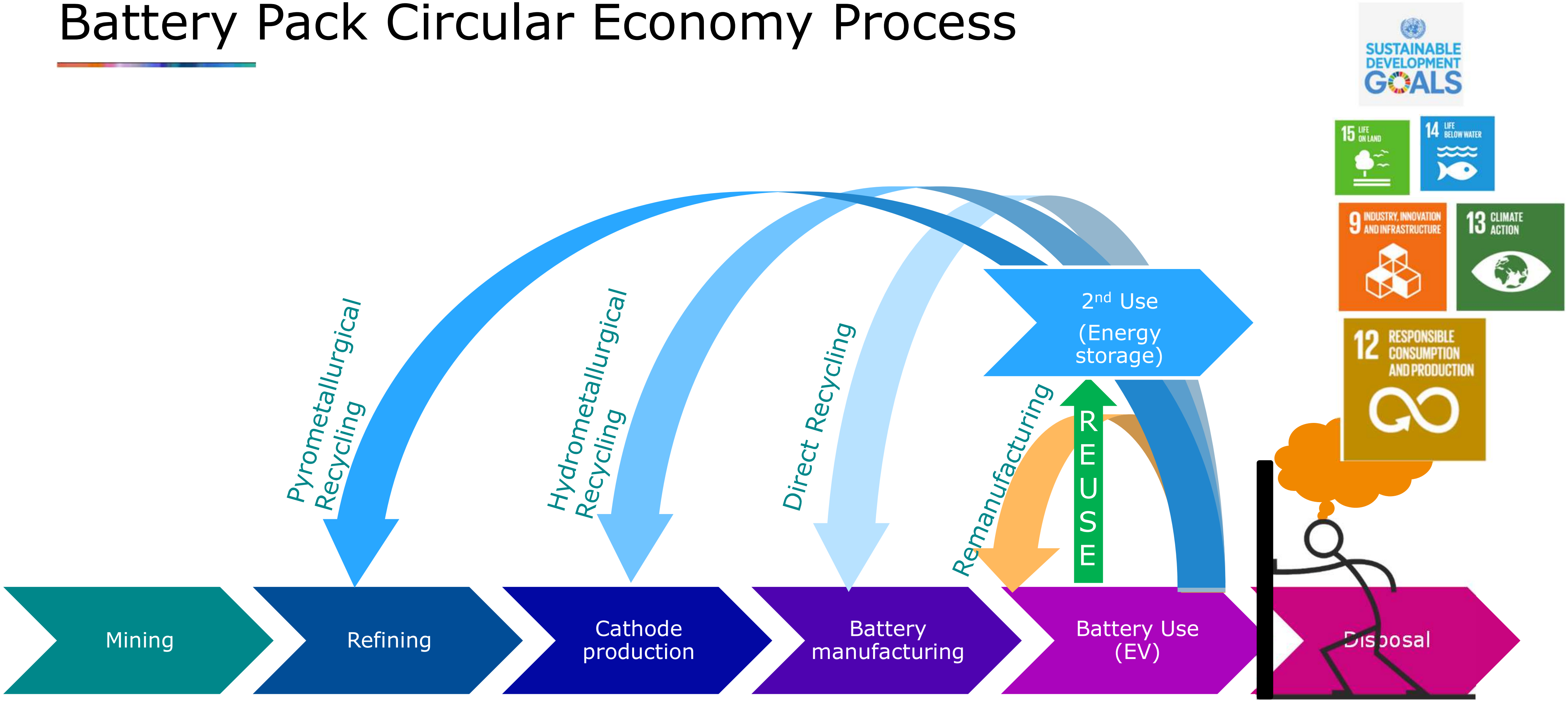
Lead Engineer : Battery Systems

System Integration, Design Department

AVL Powertrain UK Ltd

saikat.ghosh@avl.com

Battery Pack Circular Economy Process



Pyrometallurgical Recycling

Hydrometallurgical Recycling

Direct Recycling

Remanufacturing

REUSE

2nd Use (Energy storage)

Mining

Refining

Cathode production

Battery manufacturing

Battery Use (EV)

Disposal

Life Cycle of an EV Lithium-Ion Battery

Agenda

1 **EU Proposal for Sustainable Batteries Regulation**

Overview sustainability requirements for EV batteries

2 **Battery Recycling Market Study**

Overview of the battery recycling process

3 **Design of Battery Packs for Reuse, Remanufacture and Recycling**

Innovate UK Funded R&D project delivered by AVL PTE UK 2020-2021

4 **Second Life Batteries 4 Storage**

Assessment of vehicle battery pack for stationary energy storage application

Overview Sustainability Requirements for Electric Vehicle Batteries

EU Proposal Sustainable Batteries Regulation

Public

EU Sustainable Batteries

Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL concerning batteries and waste batteries, repealing Directive 2006/66/EC and amending Regulation (EU) No 2019/1020, 10 December 2020

Status: Awaiting Parliament's position in 1st reading with minor changes

Chapter I - General provisions

Subject matter and scope - Article 1

1. This Regulation establishes **requirements on sustainability, safety, labelling and information** to allow the placing on the market or putting into service of batteries, as well as **requirements for the collection, treatment and recycling** of waste batteries.

2. This Regulation shall apply to **all batteries**, namely portable batteries, automotive batteries, electric vehicle batteries and industrial batteries, regardless of their shape, volume, weight, design, material composition, use or purpose. It shall also apply to batteries incorporated in or added to other products.

3. This Regulation shall not apply to batteries in:

(a) equipment connected with the protection of Member States' essential security interests, arms, munitions and war material, with the exclusion of products that are not intended for specifically military purposes; and

(b) equipment designed to be sent into space.

Regulation Scope

- **Sustainability and safety:** rules for carbon footprint, minimum recycled content, performance and durability criteria, safety parameters
- **Labeling and information:** storing of information on sustainability and data on state of health and expected lifetime
- **End-of-life management:** extended producer responsibility, collection targets and obligations, targets for recycling efficiencies and levels of recovered materials
- **Obligations of economic operators:** linked to product requirements and due diligence schemes
- **Electronic exchange of information**

Minimum share of cobalt, lead, lithium or nickel recovered from waste present in active materials in each battery model and batch per manufacturing plant for industrial batteries, electric vehicle batteries and automotive batteries with internal storage and a capacity above 2 kWh

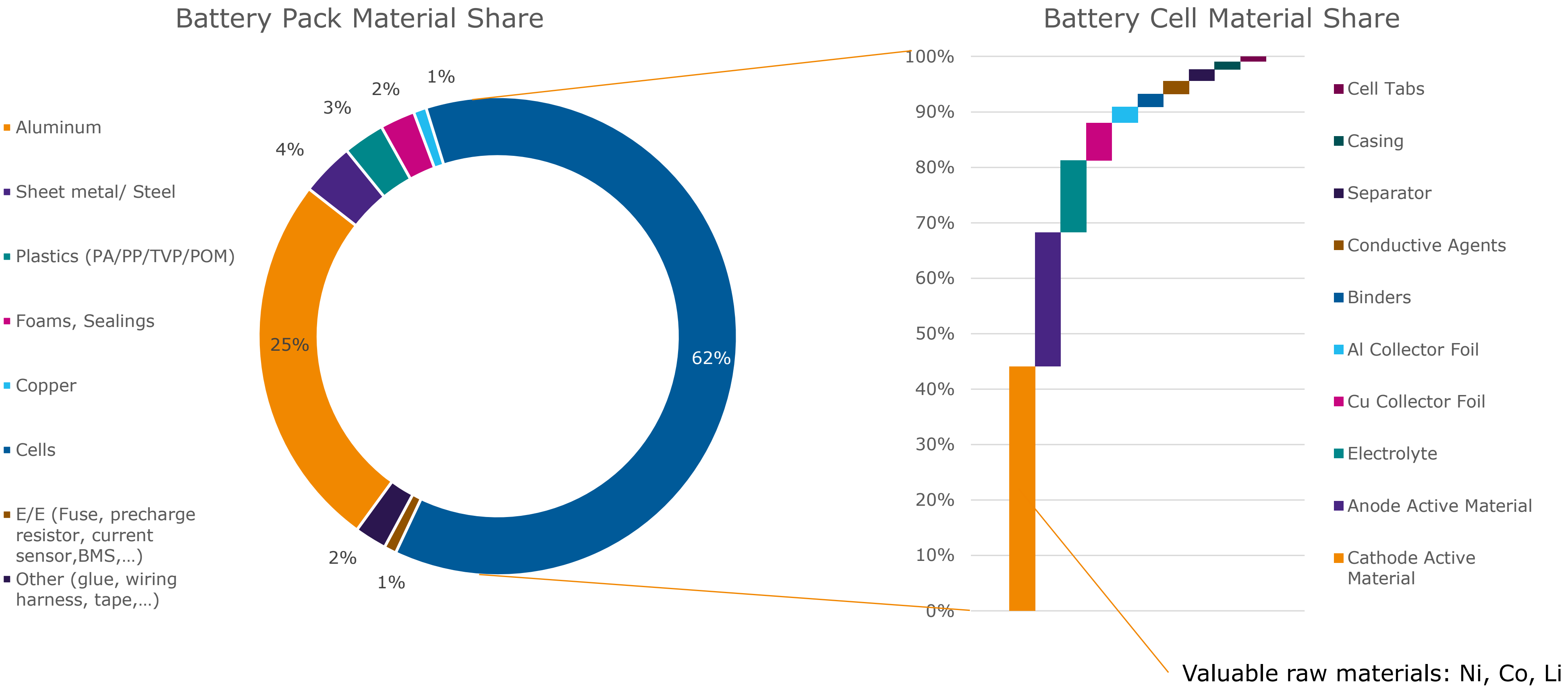
From 1 January 2030	From 1 January 2035
12% cobalt	20% cobalt
85% lead	85 % lead
4% lithium	10% lithium
4% nickel	12% nickel

Source: What's New in the EU Draft Batteries and Waste Batteries Regulation?, compliance & risks, March 2021

Battery Recycling Market Study

Public

Weight Distribution on Battery Pack and Cell Level



There are several ways to process the black mass in order to extract valuable material

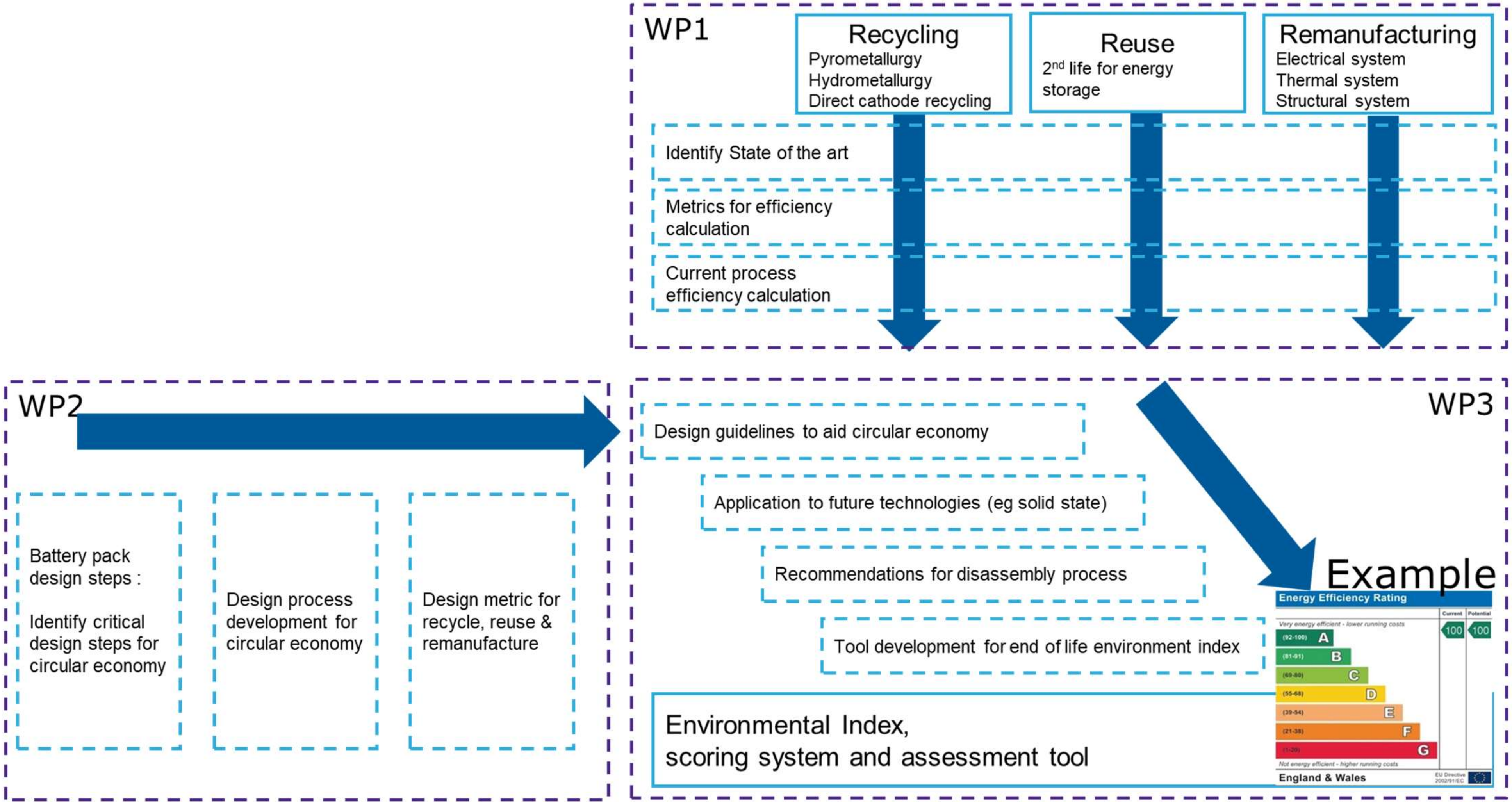
Design of Battery Packs for Reuse, Remanufacture and Recycling

Project Number : 80893

Project Partners : AVL Powertrain UK Ltd

Public

Project Summary



WP1

Recycling
Pyrometallurgy
Hydrometallurgy
Direct cathode recycling

Reuse
2nd life for energy storage

Remanufacturing
Electrical system
Thermal system
Structural system

Identify State of the art

Metrics for efficiency calculation

Current process efficiency calculation

WP2

Battery pack design steps :

Identify critical design steps for circular economy

Design process development for circular economy

Design metric for recycle, reuse & remanufacture

WP3

Design guidelines to aid circular economy

Application to future technologies (eg solid state)

Recommendations for disassembly process

Tool development for end of life environment index

Environmental Index,
scoring system and assessment tool

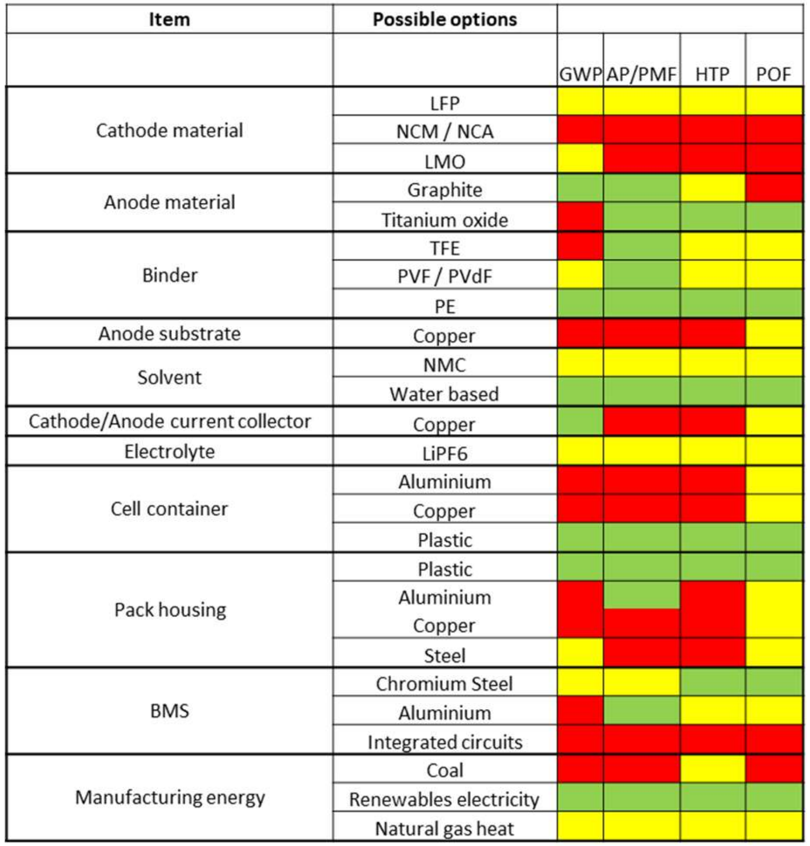
Example

Performance Assessment of Battery Pack Circular Economy Processes

Process	Energy intensity	Value recovery	Commercial maturity	Scalability
Remanufacturing	Low	High	Low	Low
Reuse	Med	Med	Med	Med
Recycle	High	Low	High	High

Recycling Process	Energy intensity	Complexity	Commercial maturity	Input Sensitivity	Material purity
Pyrometallurgy	High	High	High	Low	Med
Hydrometallurgy	Med	Med	Med	Med	High
Direct Recycling	Low	Low	Low	High	Low

Qualitative Analysis of Battery Production LCI



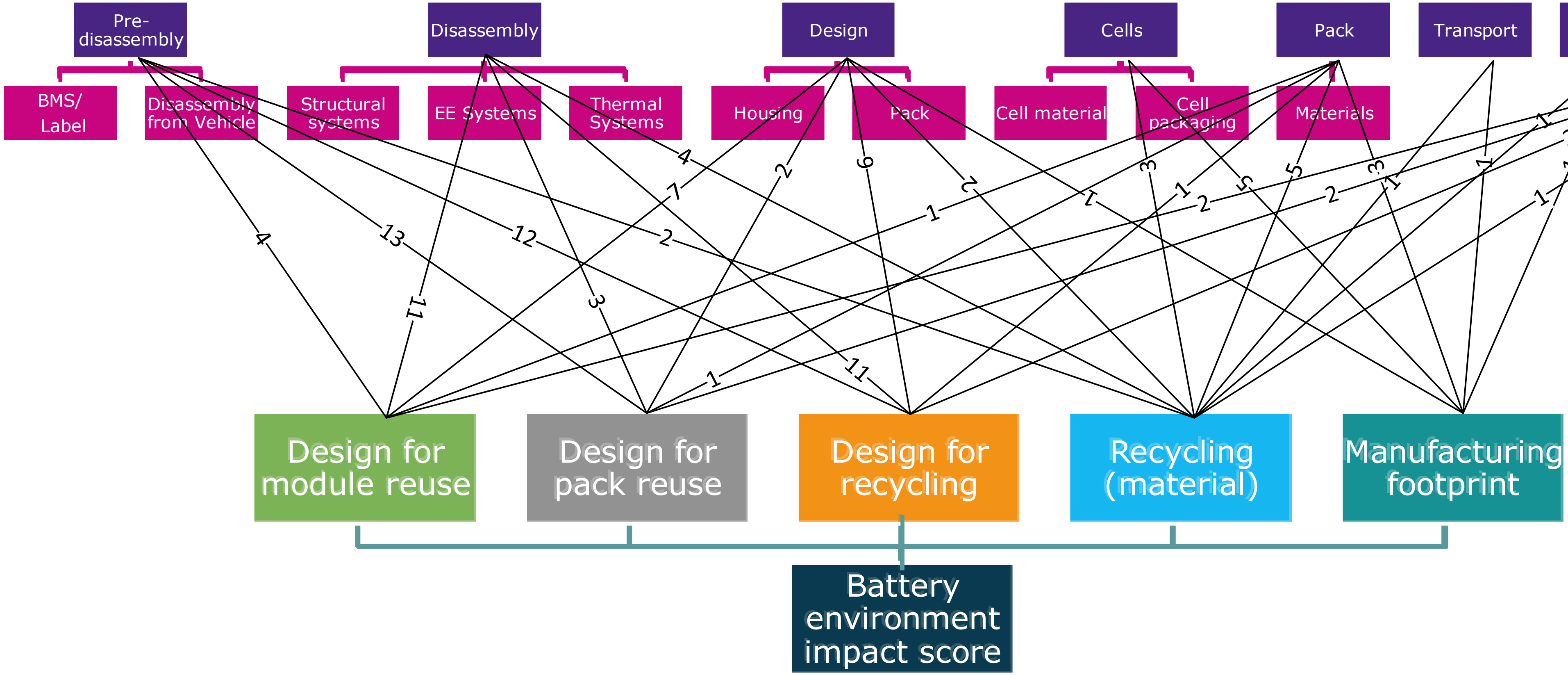
Item	Possible options				
		GWP	AP/PMF	HTP	POF
Cathode material	LFP	🟨	🟨	🟨	🟨
	NCM / NCA	🟥	🟥	🟥	🟥
	LMO	🟨	🟥	🟥	🟥
Anode material	Graphite	🟩	🟩	🟨	🟥
	Titanium oxide	🟥	🟩	🟩	🟩
Binder	TFE	🟥	🟩	🟨	🟨
	PVF / PVdF	🟨	🟩	🟨	🟨
	PE	🟩	🟩	🟩	🟩
Anode substrate	Copper	🟥	🟥	🟥	🟨
Solvent	NMC	🟨	🟨	🟨	🟨
	Water based	🟩	🟩	🟩	🟩
Cathode/Anode current collector	Copper	🟩	🟥	🟥	🟨
Electrolyte	LiPF6	🟨	🟨	🟨	🟨
Cell container	Aluminium	🟥	🟥	🟥	🟨
	Copper	🟥	🟥	🟥	🟨
	Plastic	🟩	🟩	🟩	🟩
Pack housing	Plastic	🟩	🟩	🟩	🟩
	Aluminium	🟥	🟩	🟥	🟨
	Copper		🟥		
	Steel	🟨	🟥	🟥	🟨
BMS	Chromium Steel	🟨	🟨	🟩	🟩
	Aluminium	🟥	🟩	🟨	🟨
	Integrated circuits	🟥	🟥	🟥	🟥
Manufacturing energy	Coal	🟥	🟥	🟨	🟥
	Renewables electricity	🟩	🟩	🟩	🟩
	Natural gas heat	🟨	🟨	🟨	🟨

Red= high impact
Yellow = medium impact
Green = low impact

Lowest emissions impact Battery configuration

Parameter	Type	Comments
Cell container	Pouch	Pouch configuration with high % plastic
Cell chemistry	LFP	Cobalt, Nickel free => Lower emissions
BMS	40-60% chromium steel	Steel => Lower emissions but heavier
	20-30% Copper	Lower % of Cu => Lower emission impact
	10% Integrated circuit	Lower % of ICs => Lower emission impact
Electrolyte	LiPF6 with EC solvent	Production of LiPF6 using Li salt lower emission impact
Binder	PE	Preferred over PVdF
Solvent	Water based	Preferred over NMC
Anode material	Graphite	Use renewable energy for graphite baking
Pack housing	Plastic	Avoid Copper parts
Manufacturing energy	Renewables, Natural gas	EU, Japan electricity mix most renewable
Transportation	Single production facility	Produce battery pack in one facility to avoid transportation of raw materials

Tool - Outline



Pre-disassembly
BMS/ Label
Disassembly from Vehicle

Disassembly
Structural systems
EE Systems
Thermal Systems

Design
Housing
Pack

Cells
Cell material
Cell packaging

Pack
Materials

Transport

Energy mix

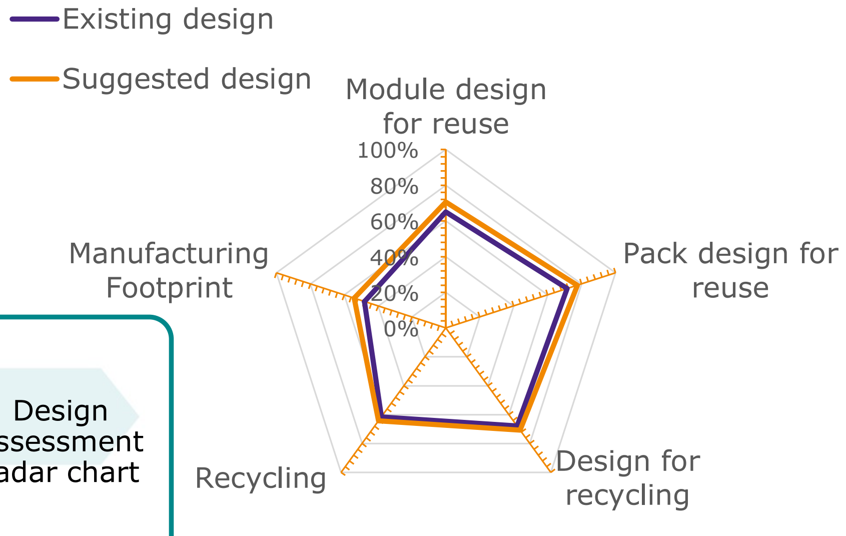
2nd life

Design for module reuse
Design for pack reuse
Design for recycling
Recycling (material)
Manufacturing footprint

Battery environment impact score

Tool DEMO

- 50 MCQ – Answer from dropdown list
- Battery environmental impact score
- 5 sub scores
- Improvement suggested for each sub area
- Design assessment radar chart



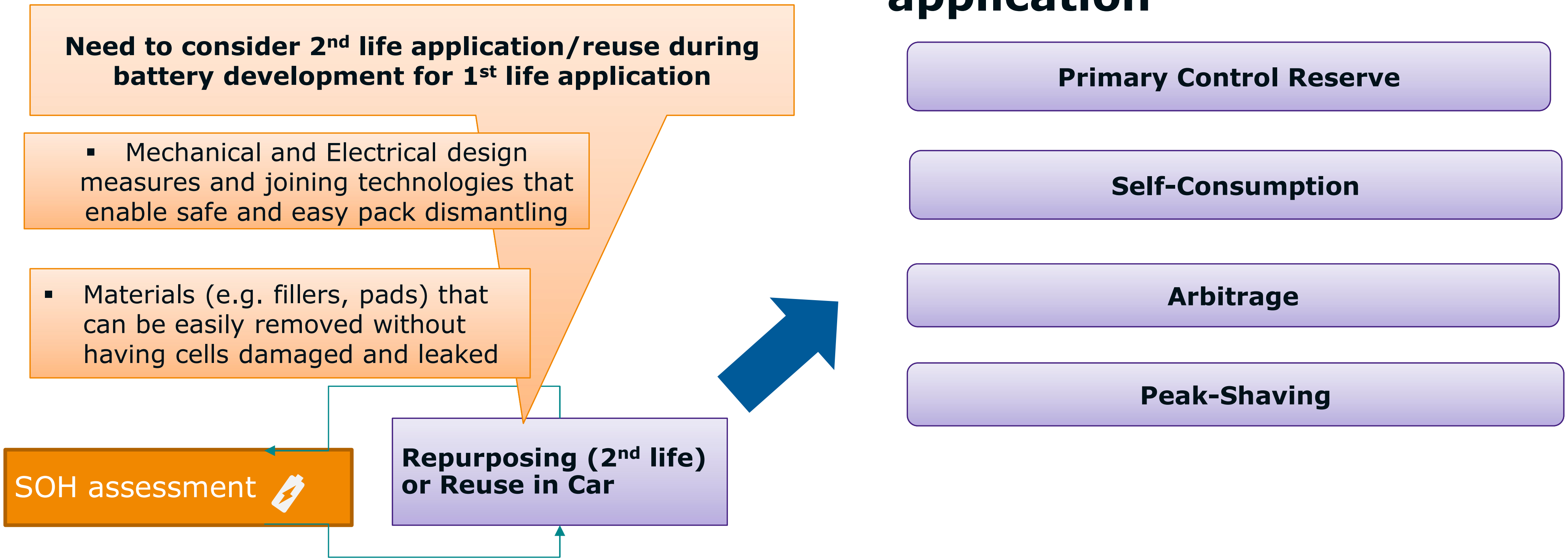
Design Assessment Radar Chart

	Final Score				
	B				
	Module design for reuse	**Pack design for reuse**	**Design for recycling**	**Recycling**	**Manufacturing Footprint**
	B	B	B	B	C
Priority	3	5	4	2	1
Improvement	Is insulation failure detectable in BMS protocol?	Is insulation failure detectable in BMS protocol?	What type of thermal interface materials have been used between modules and thermal system?	What cell type is used ?	What is the cahode material of the cells ?
Exisitng Choice	Measurement required	Measurement required	Thermal pads with adhesives or thermal paste	Pouch	NCA
Suggested change	Yes - insulation value readable	Yes - insulation value readable	Thermal pads with no adhesives	Prismatic	LMO

Second Life Batteries 4 Storage

Conference Slide – Abfall_der_Zukunft_Vienna_190925

Reusability Evaluation
for Rating System & Design Guideline



Need to consider 2nd life application/reuse during battery development for 1st life application

- Mechanical and Electrical design measures and joining technologies that enable safe and easy pack dismantling

- Materials (e.g. fillers, pads) that can be easily removed without having cells damaged and leaked

SOH assessment

Repurposing (2nd life) or Reuse in Car

Stationary 2nd life application

Primary Control Reserve

Self-Consumption

Arbitrage

Peak-Shaving

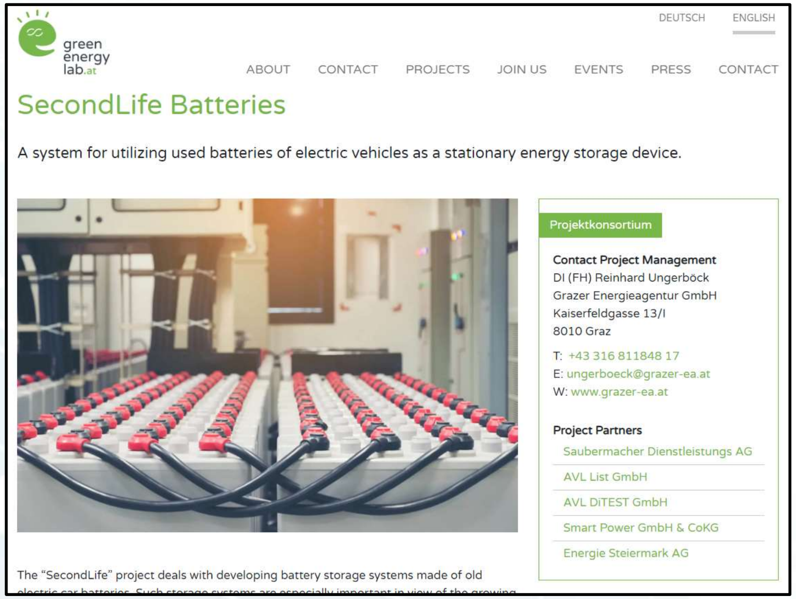
Different LIFETIMES & SOH degradations need to be considered for the 2nd Life BUSINESS CASE

Source: Model-based Lifetime Analysis of 2nd life Lithium-ion Battery Storage Systems for Stationary Applications, M.Wieland, S.Gerhard, A.Schmidt and internal AVL

Remaining Battery Value
Value Chain Costing (1st life => SOH => 2nd life/recycling)

AVL Methodology References

- AVL is part of research project “Second Life Batteries”
- One focus area is the development of a tool for the complete analysis of the **remaining value** of a battery after usage in the vehicle



SecondLife Batteries

A system for utilizing used batteries of electric vehicles as a stationary energy storage device.

Contact Project Management
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8010 Graz

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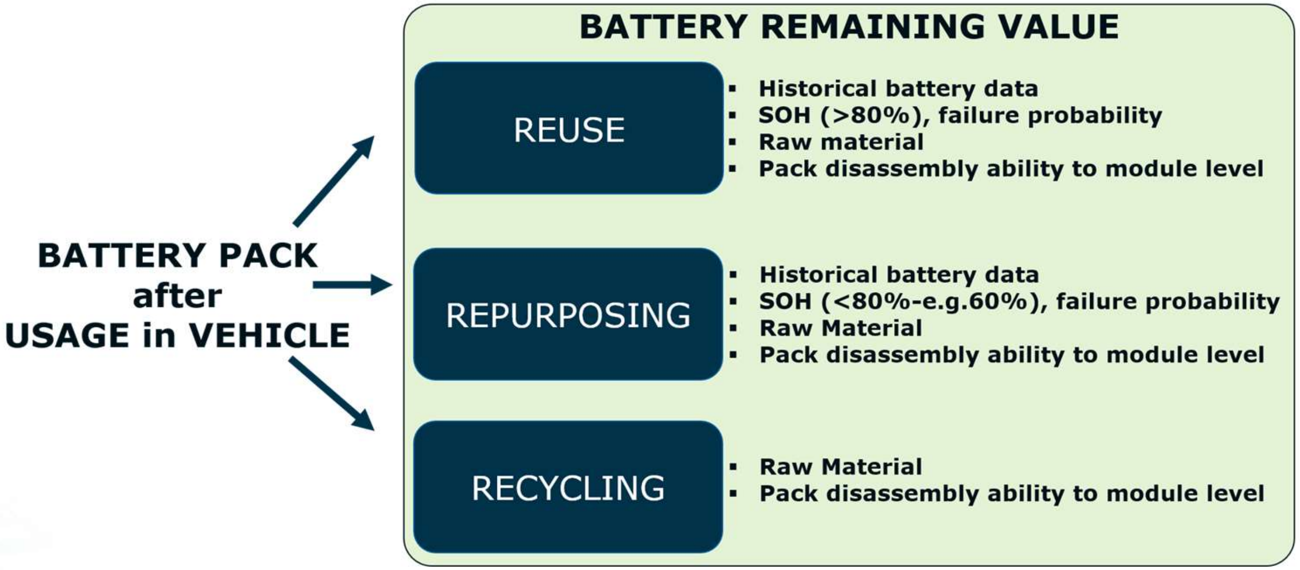
Project Partners
- Saubermacher Dienstleistungs AG
- AVL List GmbH
- AVL DiTEST GmbH
- Smart Power GmbH & CoKG
- Energie Steiermark AG

The “SecondLife” project deals with developing battery storage systems made of old



BATTERY PACK after USAGE in VEHICLE

BATTERY REMAINING VALUE

REUSE
- **Historical battery data**
- **SOH (>80%), failure probability**
- **Raw material**
- **Pack disassembly ability to module level**

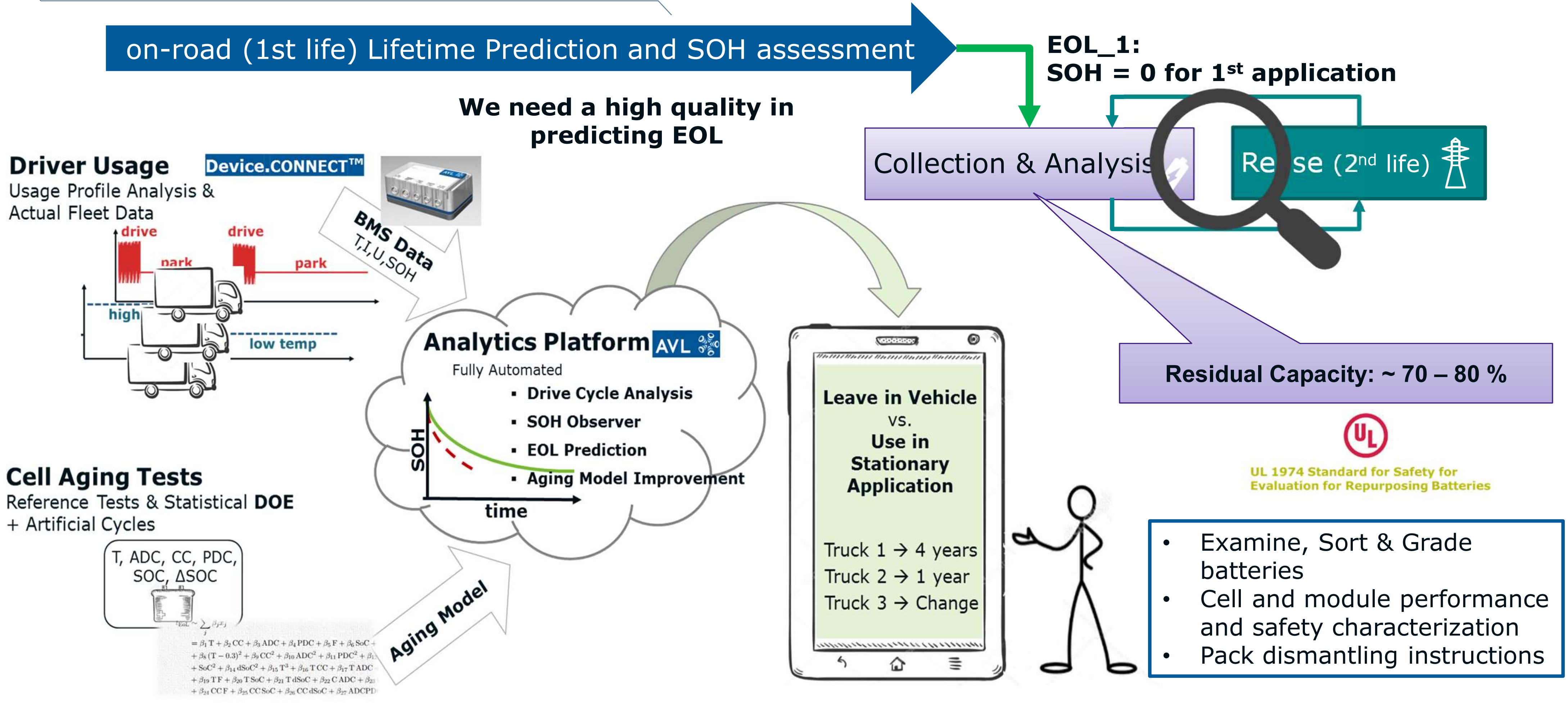
REPURPOSING
- **Historical battery data**
- **SOH (<80%-e.g.60%), failure probability**
- **Raw Material**
- **Pack disassembly ability to module level**

RECYCLING
- **Raw Material**
- **Pack disassembly ability to module level**

https://greenenergylab.at/en/projects/secondlife-batteries/

Input: Conference Slide – Abfall_der_Zukunft_Vienna_190925

AVL DiTest with AVL List-Support Collection & Analysis



on-road (1st life) Lifetime Prediction and SOH assessment

EOL_1:
SOH = 0 for 1st application

We need a high quality in predicting EOL

Collection & Analysis

Re se (2nd life)

Driver Usage **Device.CONNECT™**

Usage Profile Analysis &
Actual Fleet Data

Analytics Platform AVL

Fully Automated

- **Drive Cycle Analysis**
- **SOH Observer**
- **EOL Prediction**
- **Aging Model Improvement**

Cell Aging Tests

Reference Tests & Statistical **DOE**
+ Artificial Cycles

T, ADC, CC, PDC,
SOC, ΔSOC

$$t_{\mathrm{EoL}} \sim \sum_j \beta_j x_j$$
$$= \beta_1 \mathrm{T} + \beta_2 \mathrm{CC} + \beta_3 \mathrm{ADC} + \beta_4 \mathrm{PDC} + \beta_5 \mathrm{F} + \beta_6 \mathrm{SoC}$$
$$+ \beta_8 (\mathrm{T} - 0.3)^2 + \beta_9 \mathrm{CC}^2 + \beta_{10} \mathrm{ADC}^2 + \beta_{11} \mathrm{PDC}^2 +$$
$$+ \mathrm{SoC}^2 + \beta_{14} \mathrm{dSoC}^2 + \beta_{15} \mathrm{T}^3 + \beta_{16} \mathrm{T\,CC} + \beta_{17} \mathrm{T\,ADC}$$
$$+ \beta_{19} \mathrm{T\,F} + \beta_{20} \mathrm{T\,SoC} + \beta_{21} \mathrm{T\,dSoC} + \beta_{22} \mathrm{C\,ADC} +$$
$$+ \beta_{24} \mathrm{CC\,F} + \beta_{25} \mathrm{CC\,SoC} + \beta_{26} \mathrm{CC\,dSoC} + \beta_{27} \mathrm{ADCPD}$$

Leave in Vehicle
vs.
Use in Stationary Application

Truck 1 → 4 years
Truck 2 → 1 year
Truck 3 → Change

Residual Capacity: ~ 70 – 80 %

UL 1974 Standard for Safety for Evaluation for Repurposing Batteries

- Examine, Sort & Grade batteries
- Cell and module performance and safety characterization
- Pack dismantling instructions

Conclusions:

- Sustainability goals & geo-political factors heavily influence regulation(s).
- Recycling is mandatory : Even though as of now some of the materials i.e. Li does not make an economical case.
- Pyrometallurgy is well established – less efficient. Hydro-metallurgical processes are way forward to meet the upcoming demanding targets.
- End of Life (EoL) process must be baked into the concept design – even before Beginning of Life (BoL). Design features – i.e., application of glue, material mix can greatly influence recyclability efficiency
- 2nd life of battery is a growing field - with more focus on more renewables in the grid – grid storage solutions become mainstream. All 2nd life application is not the same.
- 1st life use and history influence 2nd life value of the battery pack. Harmonized data sharing (along with usage history) will be crucial to make 2nd life use successful.

Thank you

www.avl.com

Tech Day Speakers

Cell Technology, Overview and Trends

Jon Caine, Technical Director

Battery Systems Integration and Manufacturing Technologies

Pedro Gomez, Design Department Leader

AVL Virtual Twin for Battery Energy Assessment

Juergen Schneider, Senior Solution Manager, Virtual Battery Development

Battery Modelling

Mark Holdstock, CAE & Data Science Team Leader

Battery Recycling

Saikat Ghosh, Lead Engineer, System Engineering