AVL Battery Tech Day: Redrawing the Lines of Electrification

Thursday 6th July 2023

Tech Day Agenda

08:30 – 09:30	**Check-In and Refreshments**
09:30 – 09:45	**Welcome Session**
09:45 – 10:30	**Cell Technology, Overview and Trends** *Jon Caine*
10:30 – 11:15	**Battery Systems Integration and Manufacturing Technologies** *Pedro Gomez*
11:15 – 11:30	**Coffee Break**
11:30 – 12:15	**AVL Virtual Twin for Battery Energy Assessment** *Juergen Schneider*
12:15 – 13:00	**Battery Modelling** *Mark Holdstock*
13:00 – 13:45	**Battery Recycling** *Saikat Ghosh*
13:45 – 14:00	**Closing** *Jon Caine*
14:00 – 15:00	**Lunch and Networking**

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

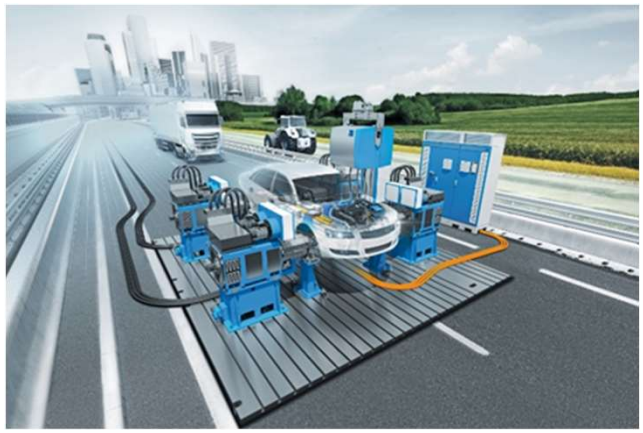
Jon Caine

- Jon Caine believes in the importance of green transportation for the future. He has been working in the automotive industry for over 30 years in the field of propulsion systems, working initially for Rover and then Ford. The bulk of his career has been the selection and implementation of new technology.
- For the last 4 years he has been working at AVL UK, now as Technical Director involved a wide range of projects most notably in batteries and fuel cells .
- He has a BSc in electrical and electronic engineering and an MSc in engineering business management. A keen advocate of a broad range of solutions to the environmental challenge, he embraces the change and is excited about the future.

Three Disciplines Under One Roof

ENGINEERING SERVICES

- Design and development services for all elements of ICE, HEV, BEV and FCEV powertrain systems
- System integration into vehicle, stationary or marine applications
- Supporting future technologies in areas such as ADAS and Autonomous Driving
- Technical and engineering centers around the globe



INSTRUMENTATION AND TEST SYSTEMS

- Advanced and accurate simulation and testing solutions for every aspect of the powertrain development process
- Seamless integration of the latest simulation, automation and testing technologies
- Pushing key tasks to the start of development

ADVANCED SIMULATION TECHNOLOGIES

- Indispensable tools for knowledge generation and decision making
- Simulation Software Solutions for all phases of the powertrain and vehicle development process
- High-definition insights into the behavior and interactions of components, systems and entire vehicles

Battery Development

Industrialized solutions from concept to SOP

Battery systems evolved to a decisive component of modern vehicles in all different forms of transportation. For over a decade AVL is the independent market leader in battery technology.

Development and Integration

- Cell2Pack
- Integration of new cell technology Immersion cooling
- Flexible, modular BMS (HW & SW)
- Functional integration and production process innovation
- Turnkey battery solutions incl. industrialization

Testing and Validation

- Consultancy on validation programs
- Turnkey solutions for battery labs
- Data and test field management
- Stand-alone products or complete test solutions

Simulation Tools and Services

- Empirical-based and electro-chemical models
- 1D & 3D solutions
- Aging models for lifetime prediction

Battery prototype build and test facilities

AVL Global Battery Competence Team


HQ Graz, **AUT**


Steyr, **AUT**


Budapest, **HUN**

Reggio Emilia, **ITA**


Neuenstadt, **DE**

Regensburg, **DE**

Remscheid, **DE**


Munich, **DE**


Södertälje,**SWE**


Istanbul, **TUR**


Basildon, **UK**


Coventry, **UK**


Ingolstadt, **DE**


Stuttgart, **DE**


Gothenborg, **SWE**


Massy, **FR**

Europe
Austria*
Hungary
Italy
France
Germany
Great Britain
Sweden
Turkey

Lake Forest, CA, **USA**

Ann Arbor, MI, **USA**


Plymouth, MI, **USA**

North America
USA

Asia
China
India
Japan


Delhi-Gurgaon, **IND**

Shanghai, **CHN**


Tokyo, **JPN**


Tianjin, **CHN**

> 450 engineers worldwide

> 10 years of experience

Focus Areas:

AVL Battery Development Competencies

Technology Competence
From electrode to pack integration

Project execution
from advanced development to SOP handover


Cells


Modules

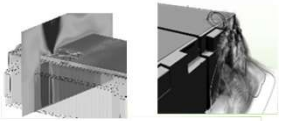

Housing

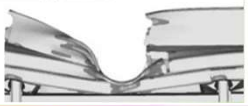

EE &HV path

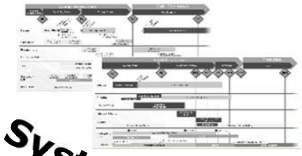

BMS & Harness


Cooling / Heating & Safety


Labels







SOP – New Battery System

SOP – Derivative

Concept

Advanced development

DVP&R / Testing / Validation

Demonstrator

Benchmarking

BATTERY TECH DAY
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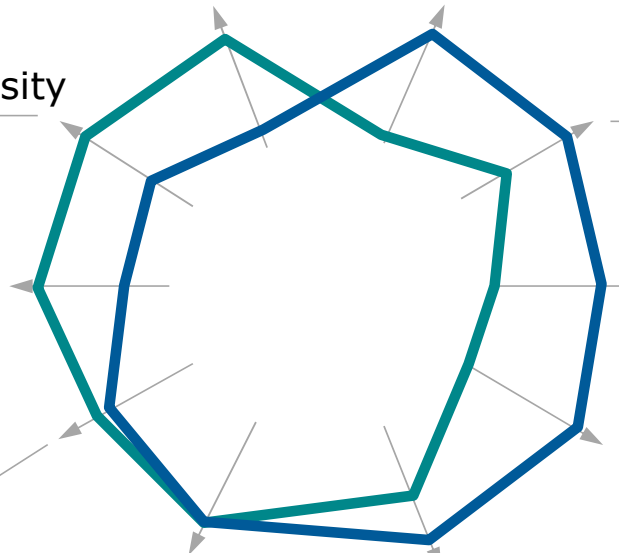
Market and Technology Trends

Public

Key Performance Targets for AVL Battery Development Services and Featured Competences

Technology & Innovation / Series Development Support



CO_{2e} Regulation

- Analyzing, measuring and reporting of CO_{2e} footprint
- Life Cycle Analysis
- Reducing CO2e footprint

Time2SOP

- Model based Systems Engineering for battery
- Virtual validation capability

Energy Density

- Reduction of parts
- Light weighting
- Module2Chassis
- Integration of new electrodes Si-anodes
- Integration of ASSB

Cost

- LFP based systems
- Cost management for bottom-up target cost calculation and cost monitoring
- Innovation2cost
- Hand-in-hand functional design & process design

Efficiency

- Optimized cell designs
- Optimizing thermal pathways
- Thermal syphon cooling
- >900V electric systems

Supply Chain

- Cell supplier management for technical validation and delivery quality
- Scouting and building supply chains from raw material to finished product
- Enabling local or in-house supply chain for critical elements

Robustness

- Next Gen BMS systems
- AVL Load Matrix™ and generic battery validation planning
- EMC handling
- Robust EE integration and component development

In-Use & Recycling

- Cell & battery design for recycling & circularity
- Battery lifecycle management tools
- Cloud based battery fleet management
- Serviceability concepts for batteries (with AVL DiTest)

Safety

- No Propagation design
- Battery Test & Validation
- Own testbeds and build of test equipment (with AVL ITS)

Production Ready

- Production process and quality system development
- Module and battery assembly automation (AVL BIC)
- Design2production

Challenges for Future

New Mobility

Circular Economy

Affordability

Local Emissions

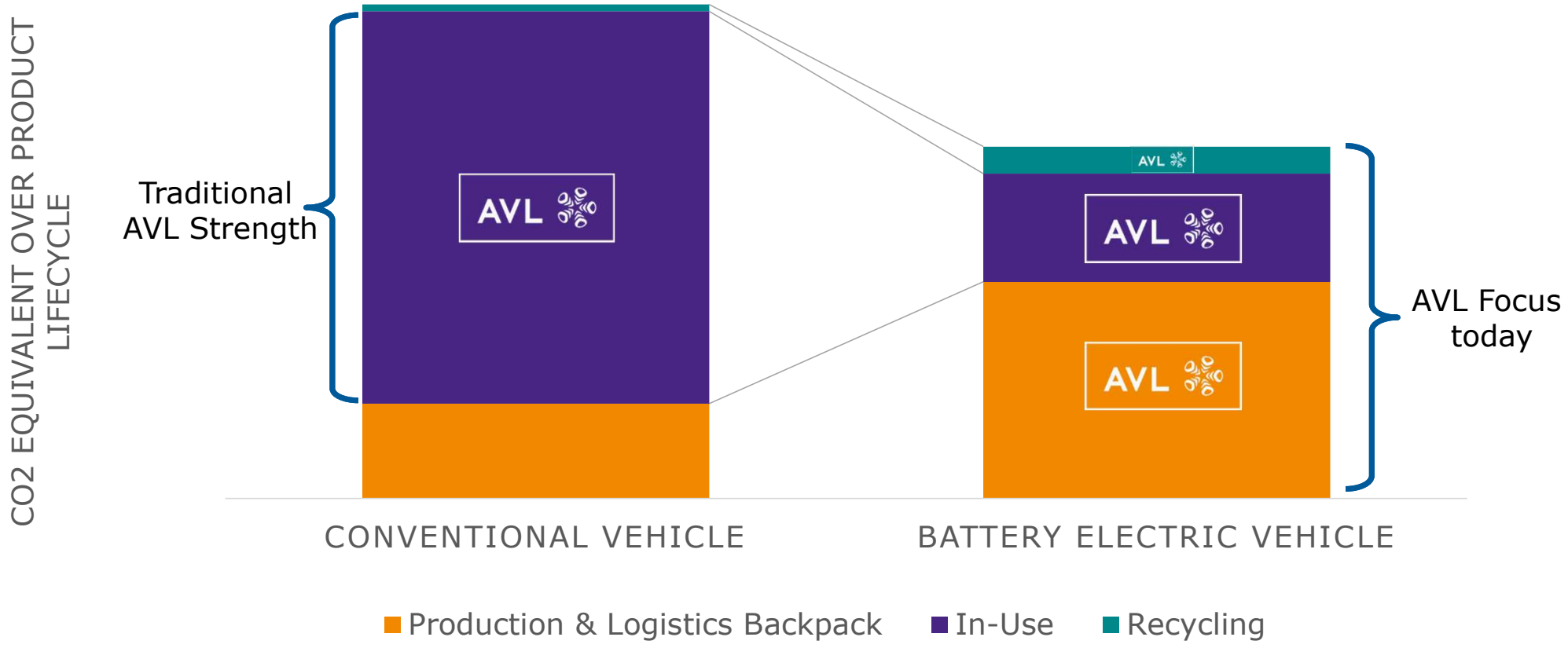
Sustainable
Product Lifecycle

Zero Impact Emissions

Global Emissions

Production & Logistics
Backpack

Majority of GHG Footprint shifts to Production



EU Proposal Sustainable Batteries Regulation
Requirements for EV Batteries

Calculation based on PEFCR – framework is being implemented

Battery manufacturing

- **Carbon footprint**
- *Carbon footprint of electric vehicle batteries and rechargeable industrial batteries – Article 7*
- Rules on the carbon footprint of electric vehicle batteries and rechargeable industrial batteries. The requirements are staged in such a manner that there first is an information requirement in the form of a carbon footprint declaration. Thereafter, the batteries shall be subject to classification into carbon footprint performance classes. Ultimately, and informed by the results of a dedicated impact assessment, the batteries will need to comply with maximum life cycle carbon footprint thresholds.

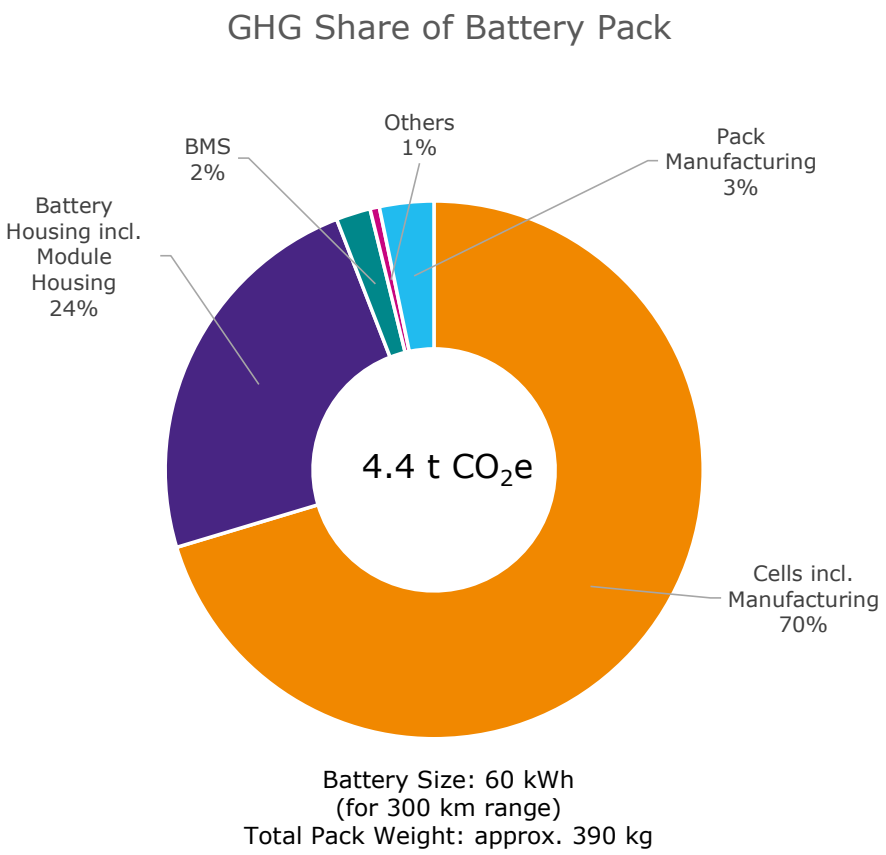
➡ **carbon footprint declaration** requirement shall apply as of **1 July 2024**

➡ **carbon footprint performance class** requirements shall apply as of **1 January 2026**

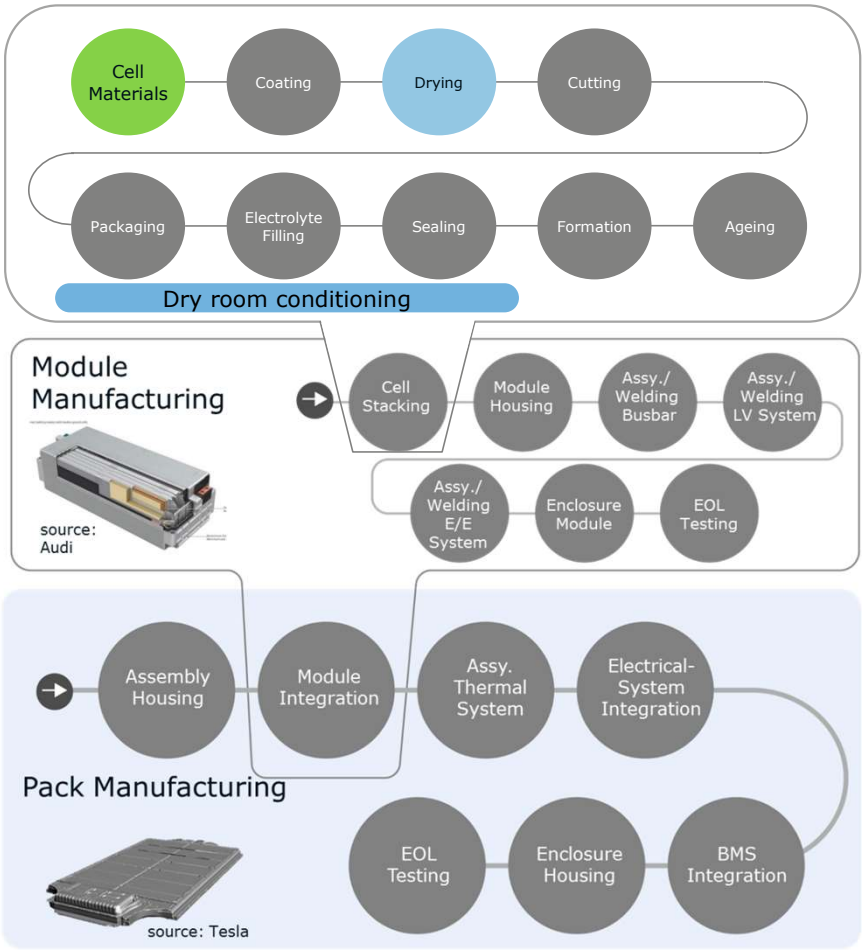
➡ requirement for a **maximum life cycle carbon footprint thresholds** shall apply as of **1 July 2027**

Source: 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;

Battery Pack Production GHG Emissions

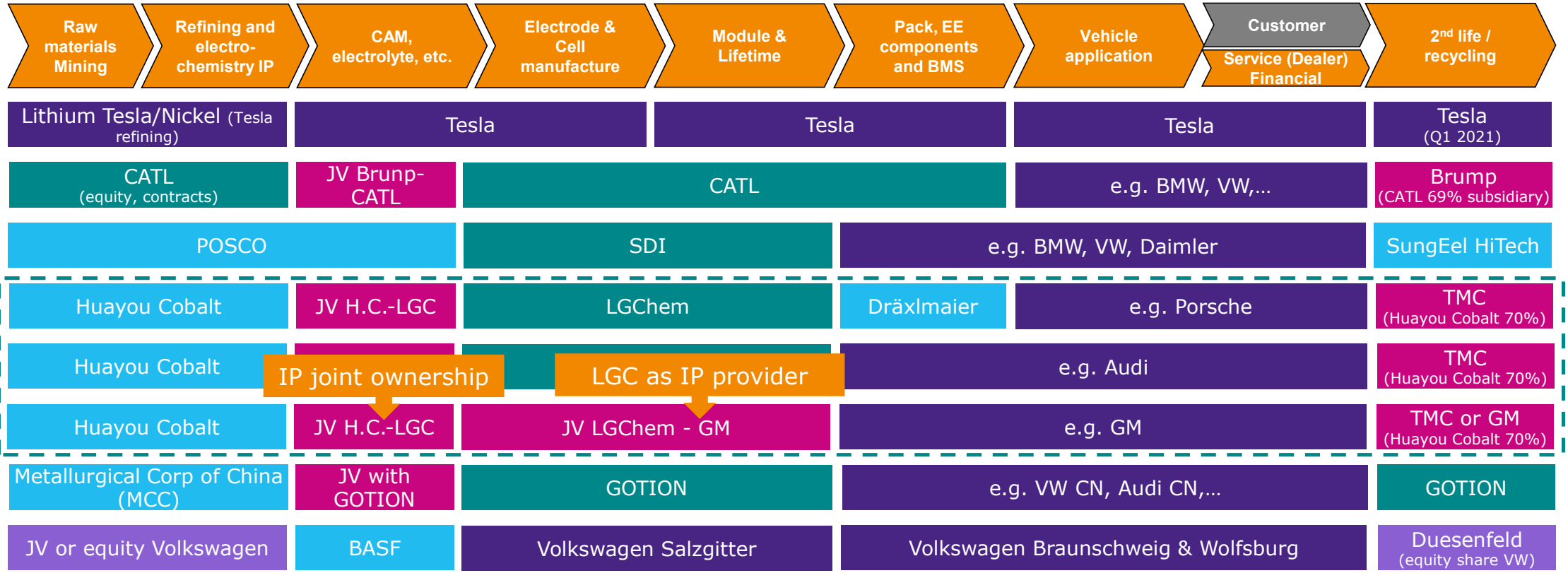


Battery Size: 60 kWh
(for 300 km range)
Total Pack Weight: approx. 390 kg



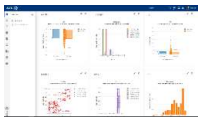
Battery Supply Chain Command

Back-integration as factor to commercial success in fast technology adoption and large scale production shift



AVL Solution
Modular system offers

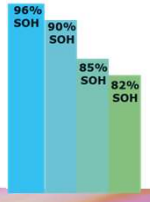
Fleet Monitoring & Analytics Platform
Monitor battery condition
Analyze data



Digital Twin
Real-time simulation based on vehicle signals

Data collection
Secure data transfer

Battery lifetime methodology
KPI Generation
Battery State of Health
Battery Degradation
Battery Remaining Value



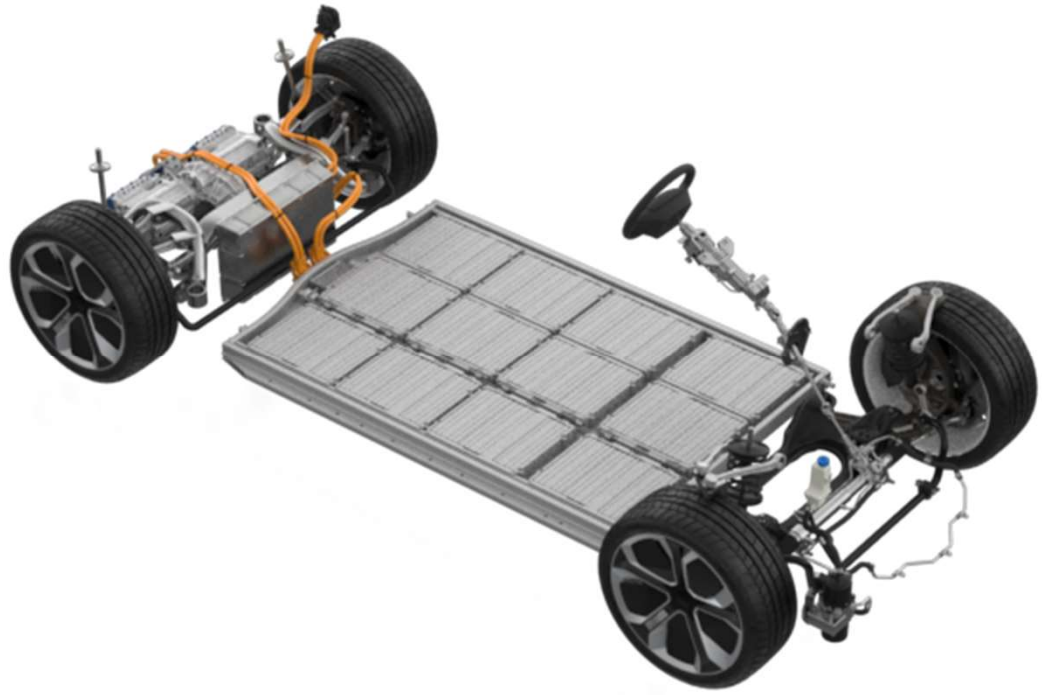
- ✓ Improve **battery value** & profitability
- ✓ Optimize **charging strategy**
- ✓ Increase **workshop efficiency**
- ✓ Reduce **total cost of ownership**
- ✓ Optimize **warranty** claim process
- ✓ Cost-efficient battery **replacements**

References 2021

- Advanced Development
  - **Immersion Cooling** for performance batteries for multiple OEMs EU & US
  - **No-Propagation** for 5 out of Top 6 OEMs worldwide
  - **Cell2Pack / Module2Chassis** for multiple OEMs worldwide
  - **All solid state cell design & module integration** for multiple OEMs in EU & US
- SOP projects active in 2021 @ AVL
  - BEV sports car battery pack lead development concept – **SOP 2022** for EU OEM
  - BEV battery family (3 variants) development from concept to **SOP 2023** for EU OEM
  - BEV battery derivate development from delta study to market homologation **2023** for German OEM
  - BEV battery derivate development from delta study to market homologation **2021** for German OEM
  - HEV super sports battery pack derivate development from delta development to **SOP 2022** and build & supply of small racing series (<100 pcs) by AVL Battery Innovation Center
  - PHEV battery family development (2 variants) from concept to **SOP 2024** and series support with Tier1
  - BEV commercial battery pack & module from concept to **SOP 2023** for US Tier1
  - BEV Performance Battery Pack from feasibility to **SOP 2024** for US OEM

Gain Factors

- Process Optimization from Cell to battery
- Durability Improvement
- Efficiency = Range Improvement
- Energy Density of active materials
- Battery Architecture
- Eco-Design / “Design to CO2”
- Cell Chemistry

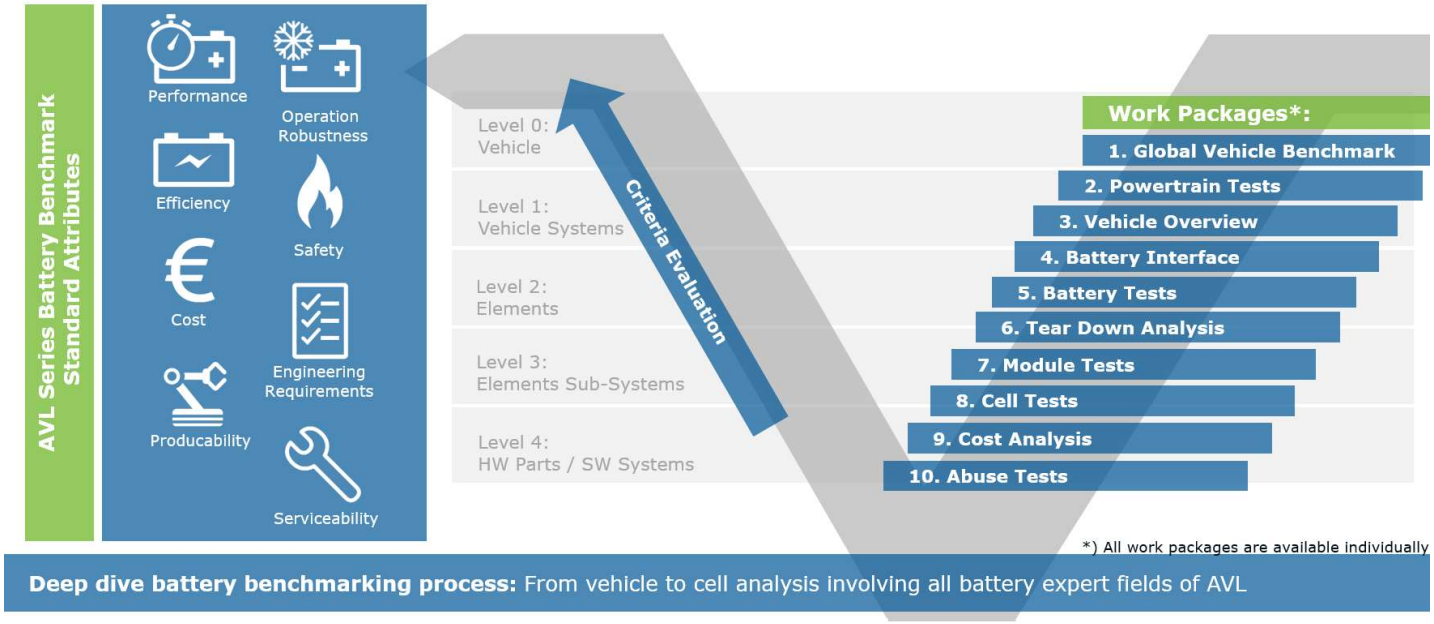


The Battery Development process

Public

Series Battery Benchmarking

With a continuous benchmark program of automotive battery systems, AVL enables a **deep understanding in current battery module and pack technology.**



Deep dive battery benchmarking process: From vehicle to cell analysis involving all battery expert fields of AVL

Reversing the V-process:
From vehicle to screw

Reports, test data, workshops "off-the-shelf" available

4 new vehicles per year:
From low budget to luxury xEVs

Series Battery Benchmarking

With a continuous benchmark program of automotive battery systems, AVL enables a **deep understanding in current battery module and pack technology.**

Reports available:

- Tesla Model S
- Renault ZOE
- Tesla Model 3
- Mitsubishi Outlander PHEV
- VW e-Golf
- Chevrolet Bolt
- Hyundai Kona
- Tesla Model X
- Hyundai Nexo (FC & Battery)
- Jaguar I-Pace
- Nio ES8
- Audi e-tron
- Porsche Taycan
- VW ID.3 (in Progress)

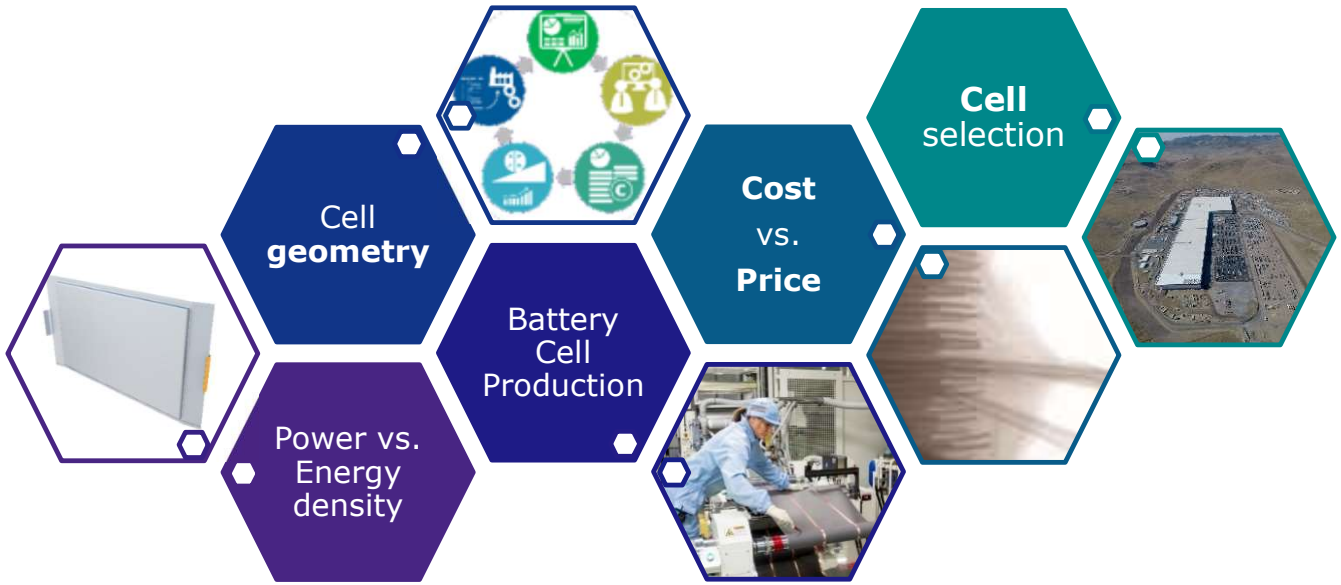
Reversing the V-process:
From vehicle to screw

Reports, test data, workshops "off-the-shelf" available

4 new vehicles per year:
From low budget to luxury xEVs

Battery Cell Selection and Development

AVL's Battery cell research and cell analysis activities enable to support with **battery cell selection** and consulting in **future battery cell technologies.**



Battery cell expertise from raw material to cell integration

Ongoing joint research to **influence future cell chemistry**

NDAs with cell supplier in place to enable **technical cell selection support**

Battery Cell Design
Example for cylindrical cell

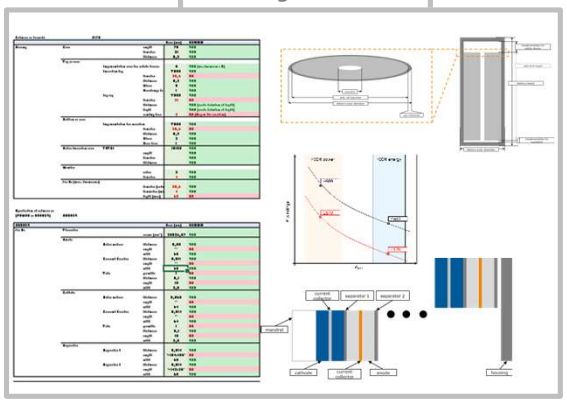
CAD Model Development

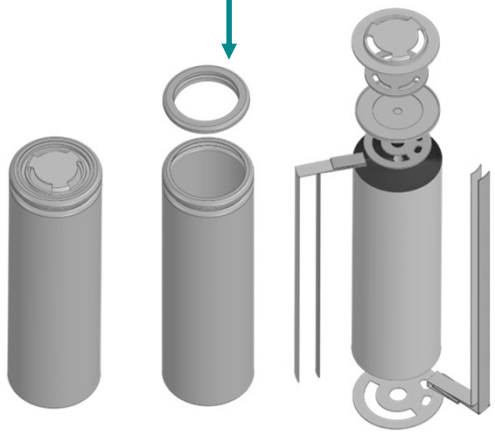
User input

Cell Format: **2170**
Cell Type: **ENERGY**

engineering background

creo · PLM Software SIEMENS NX · CATIA





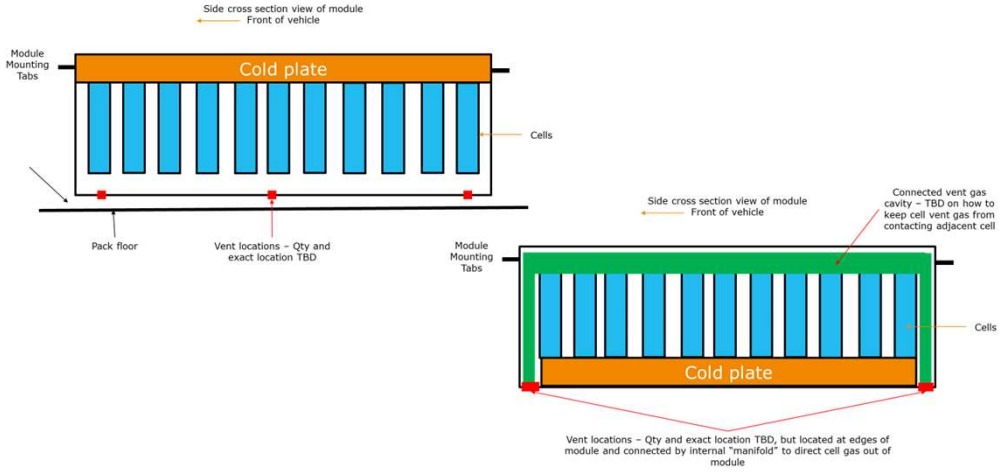
parametric cylindrical cell model

CAD model development for regular & "tabless" cell design for power & energy cells. Similar activities for pouch and prismatic cell formats.

Cell-to-System Integration

Defined system (pack or module) level performance targets

- nominal and maximal voltage
- maximal current
- power & capacity

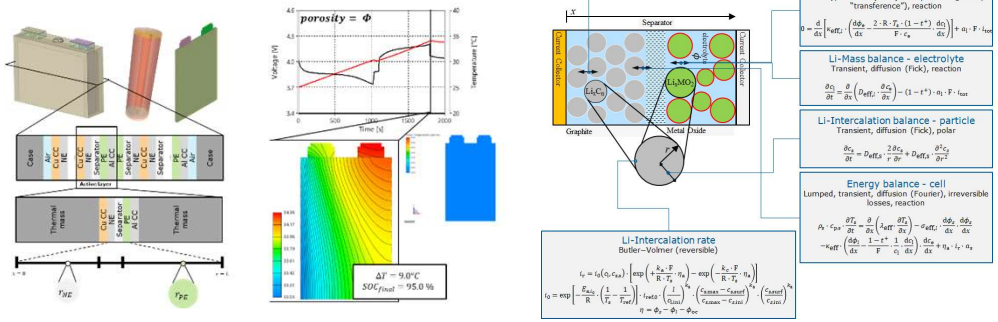


- CAD optimized design according to the defined targets
- Mechanical integration
- Thermal integration

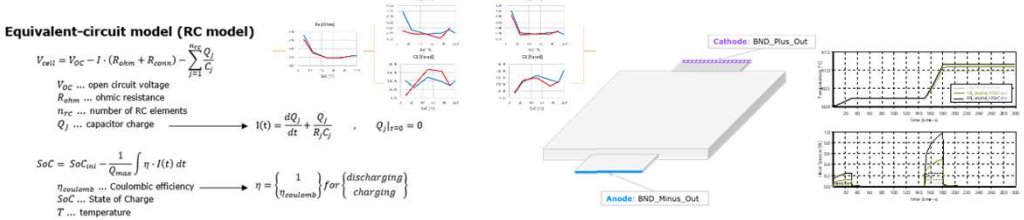
Battery Cell Modeling & Analysis
Example for cylindrical cell

Electrochemical & Electrothermal Analysis

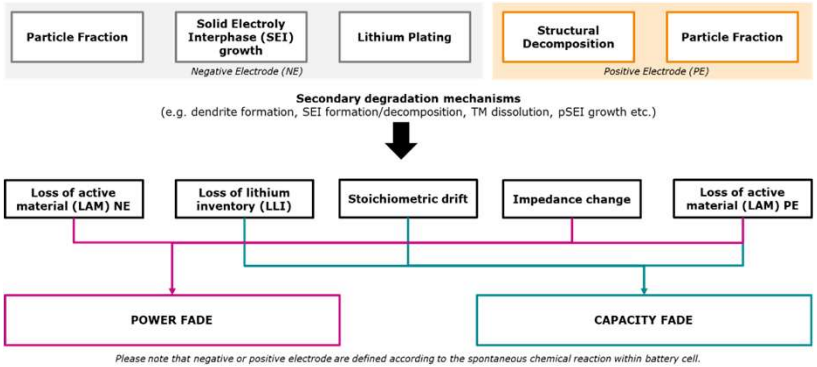
Electrochemical Analysis based on Doyle-Fuller-Newman (DFN) Model:



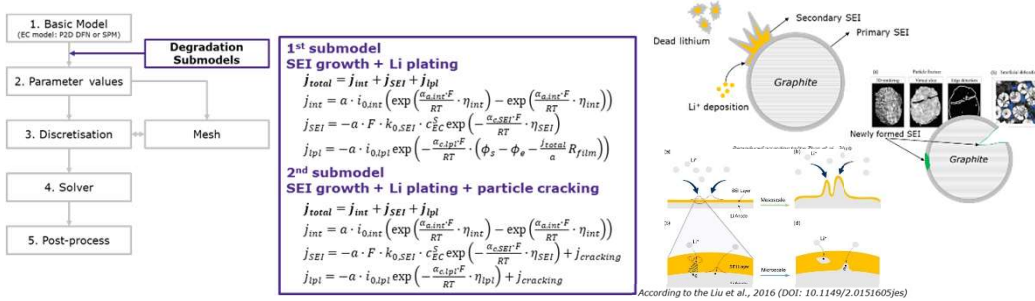
Electrothermal Analysis:



Degradation Analysis



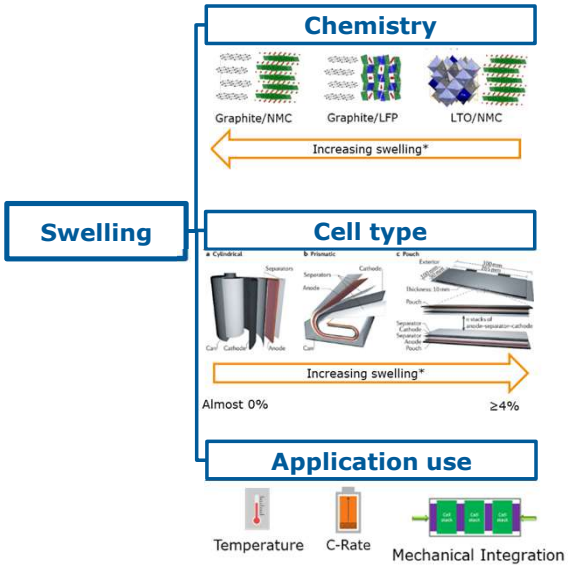
Degradation models for e.g., SEI formation, irreversible Lithium plating and particle cracking

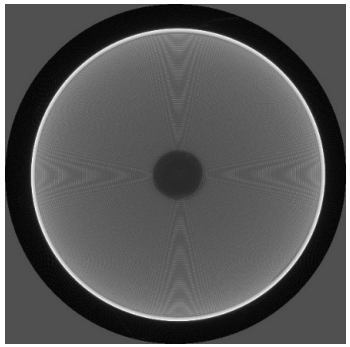


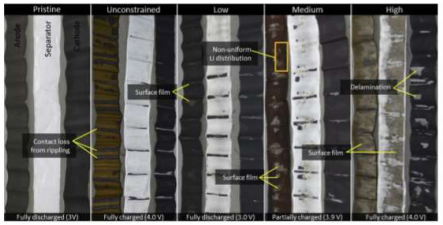
Battery Cell Modeling & Analysis
Example for cylindrical cell

Mechanical Analysis

Swelling and mechanical performance:
Swelling & Breathing Analysis
Crash & Crush performance and associated failure modes







Thermal Runaway Analysis

Heat release (chemistry dependent)

$$Q_{total}(t) = Q_{generated}(t) + Q_{\text{electrical}}(t) - Q_{dissipatio}\ (t) + Q_{heating}(t)$$

$$\dot{q}_{abuse} = H_{SEI}W_{SEI}\left|\frac{dc_{SEI}}{dt}\right| + H_{NE}W_{NE}\left|\frac{dc_{NE}}{dt}\right| + H_{PE}W_{PE}\left|\frac{d\alpha}{dt}\right| + H_{E}W_{E}\left|\frac{dc_{E}}{dt}\right|$$

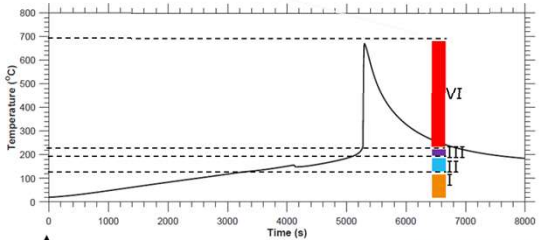
$$Q_{dissipation} = Q_{convective} + Q_{radiative}$$

$$Q_{heating} = \mathrm{A}\cdot h\cdot(T - T_{hea}\ \ )$$

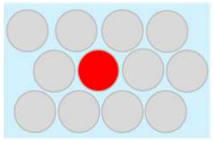
Gas release (chemistry dependent)

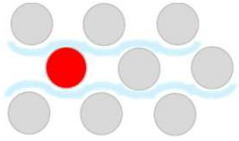
$$\frac{dm_i}{dt} = \dot{m}_{i,vent} + \sum \dot{m}_{i,g}$$

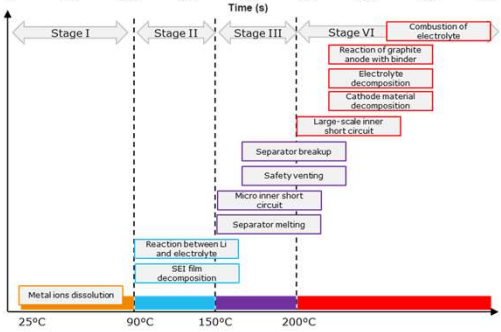
$$\frac{dm_{ventGas}}{dt} = \dot{m}_{ventGas,vent} + \sum \dot{m}_{ventGas,g}$$



Case study for cylindrical cell tabbed vs. tables design: Evaluate thermal propagation time, pressure increase heat transfer within the system, cooling system influence.



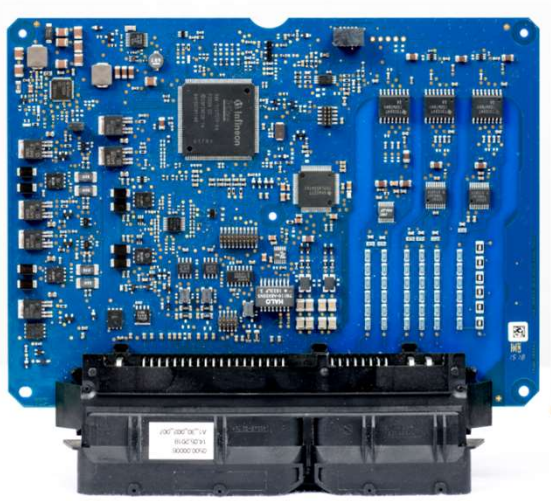




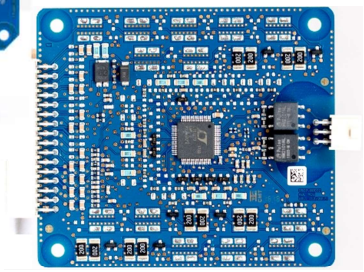
Battery Management System

AVL developed battery management system hardware (4th generation) and software is **proven in various customer projects** and available for **immediate integration,** also as white box.

Hardware

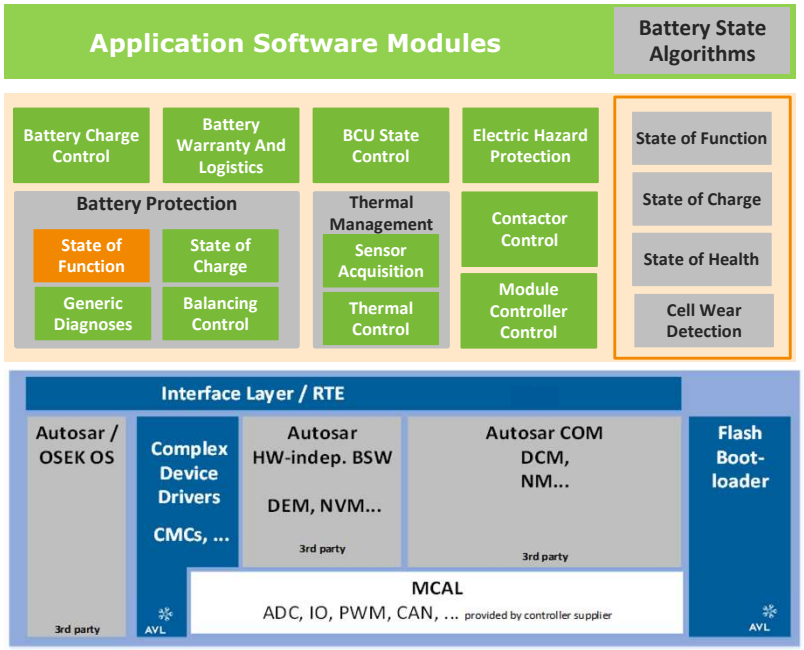


HV Battery control unit (HV BCU)



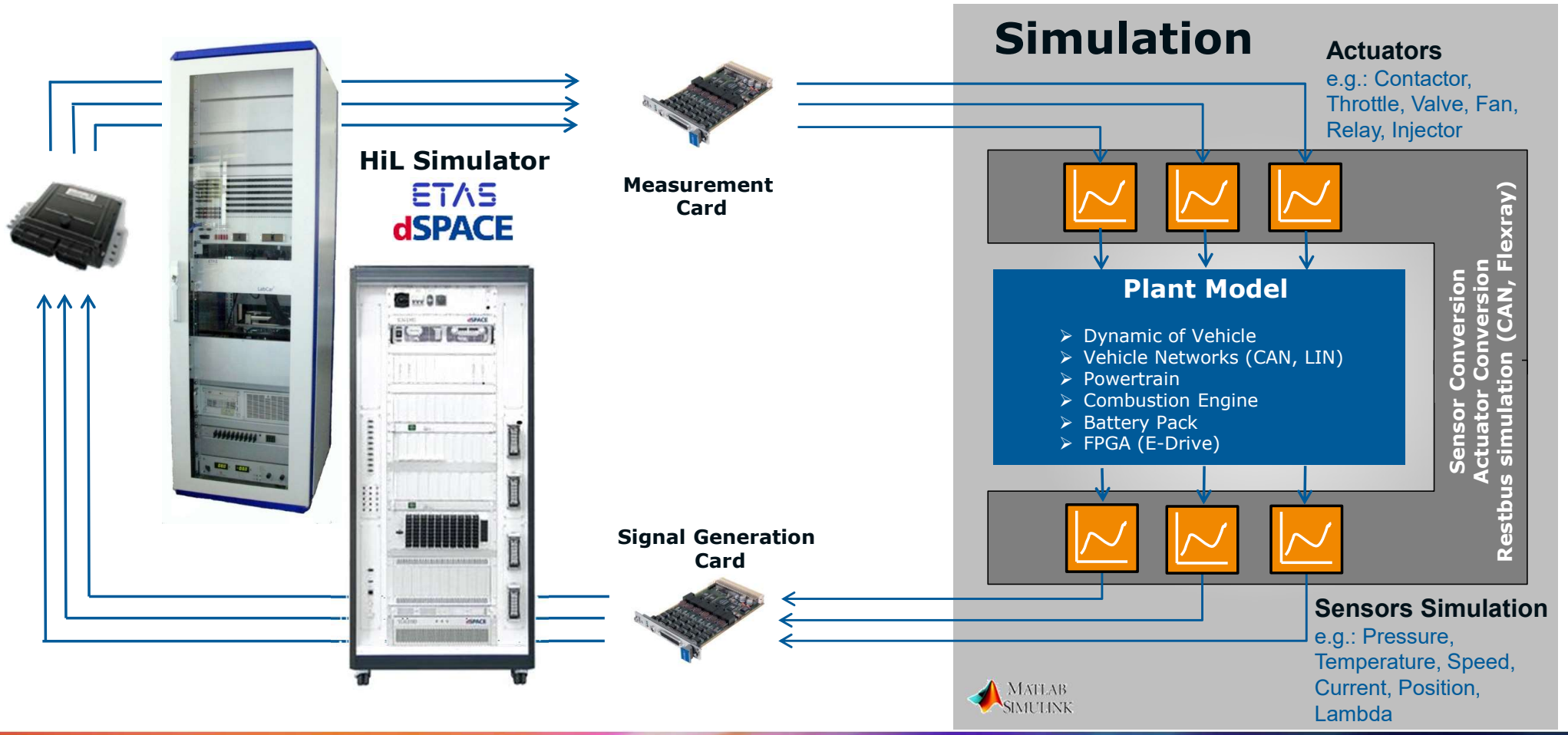
Battery module control unit (MCU)

Software

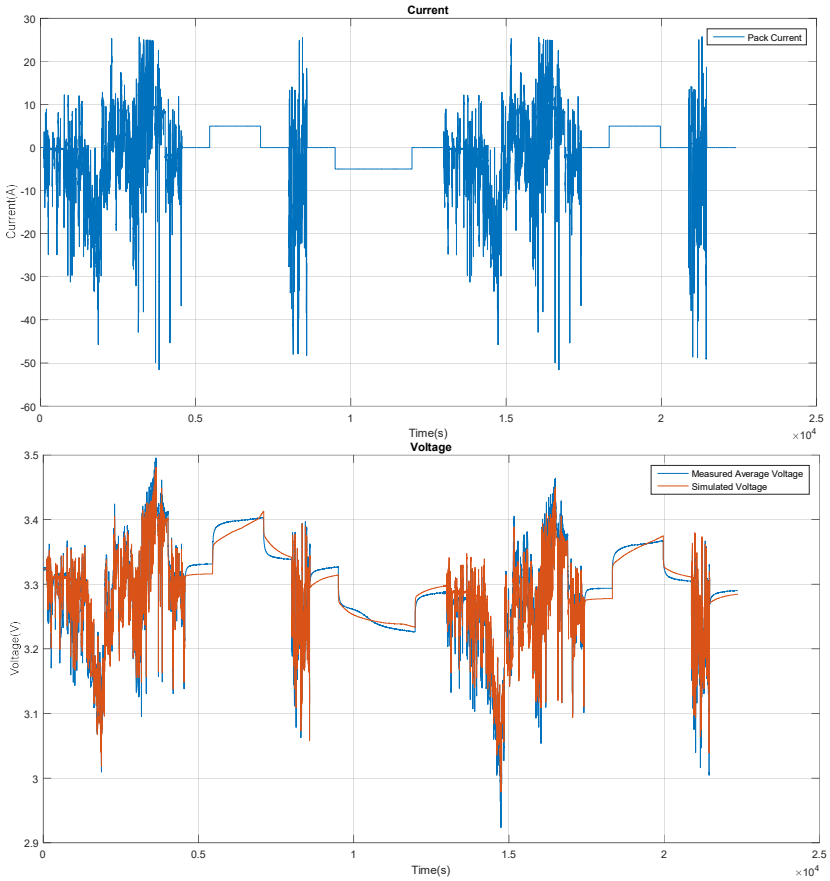


AVL BMS

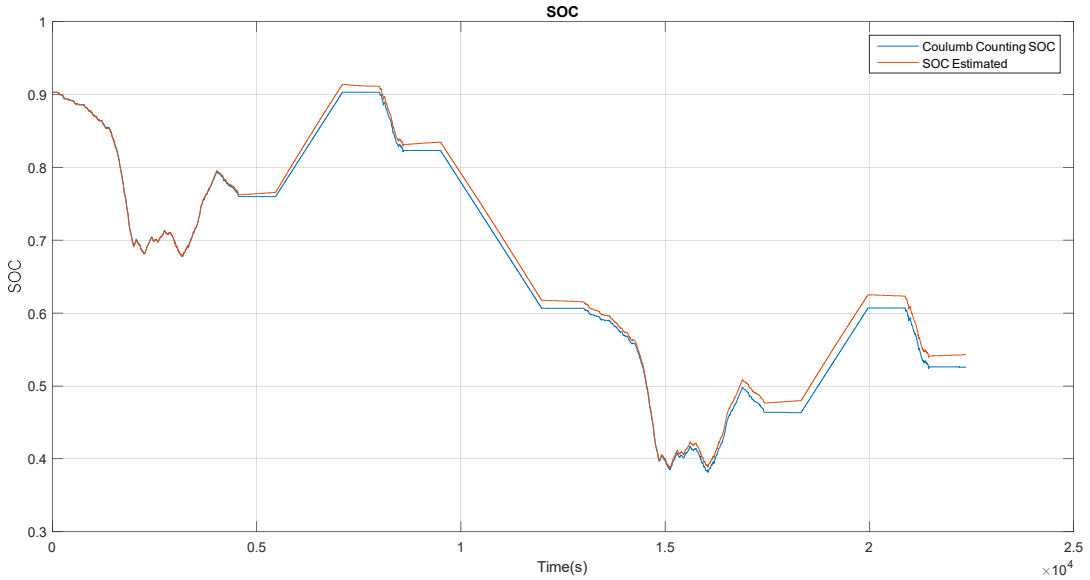
HiL Testing Overview BMS



Results for SOC Estimation
25 degree results-LFP Type of Cell



This is an on-going project uses LFP cells. The obtained results are preliminary results and the development and improvement is on-going.



Next Generation Core functions

➢ Project goals

- Improved accuracy of SOC estimation for LFP based chemistry
- Lifetime prediction modeling.
- Predictive strategy on calculation of power limits.

➢ State of charge estimation

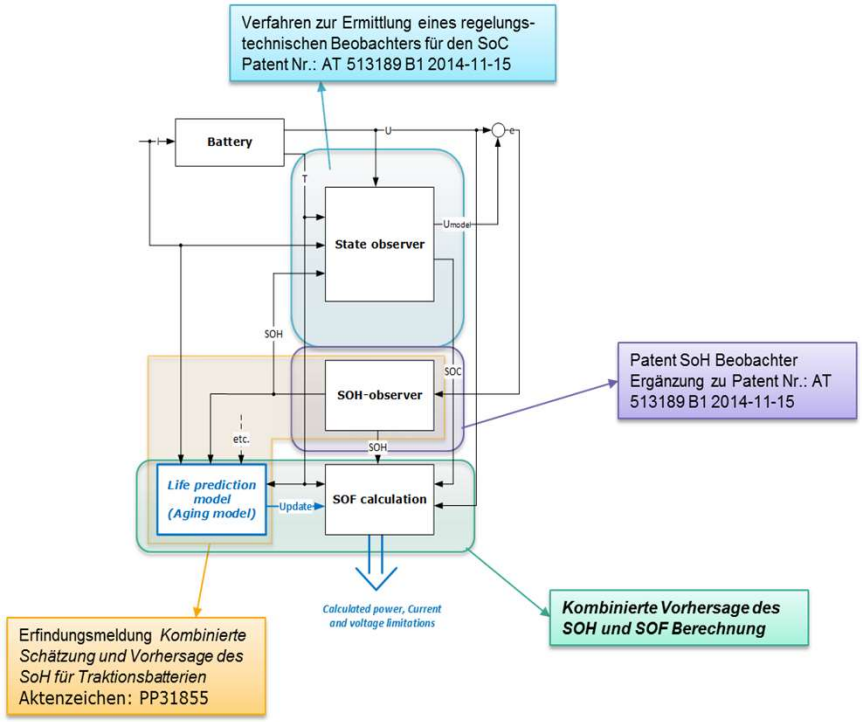
- Nonlinear dynamic modeling
- Optimum design of experiment to reduce testing and calibration

➢ State of health and lifetime prediction

- Implementation of aging/lifetime prediction model
- Combination of SOH observer and lifetime prediction model to increase accuracy and robustness

➢ State of function calculation

- Optimization of operating strategy to e.g. reach lifetime target
    - Adaptation of SOF based on predicted lifetime and SOH estimates



Main Drivers in BMS Development

Cost, Performance, Modularity and Flexibility

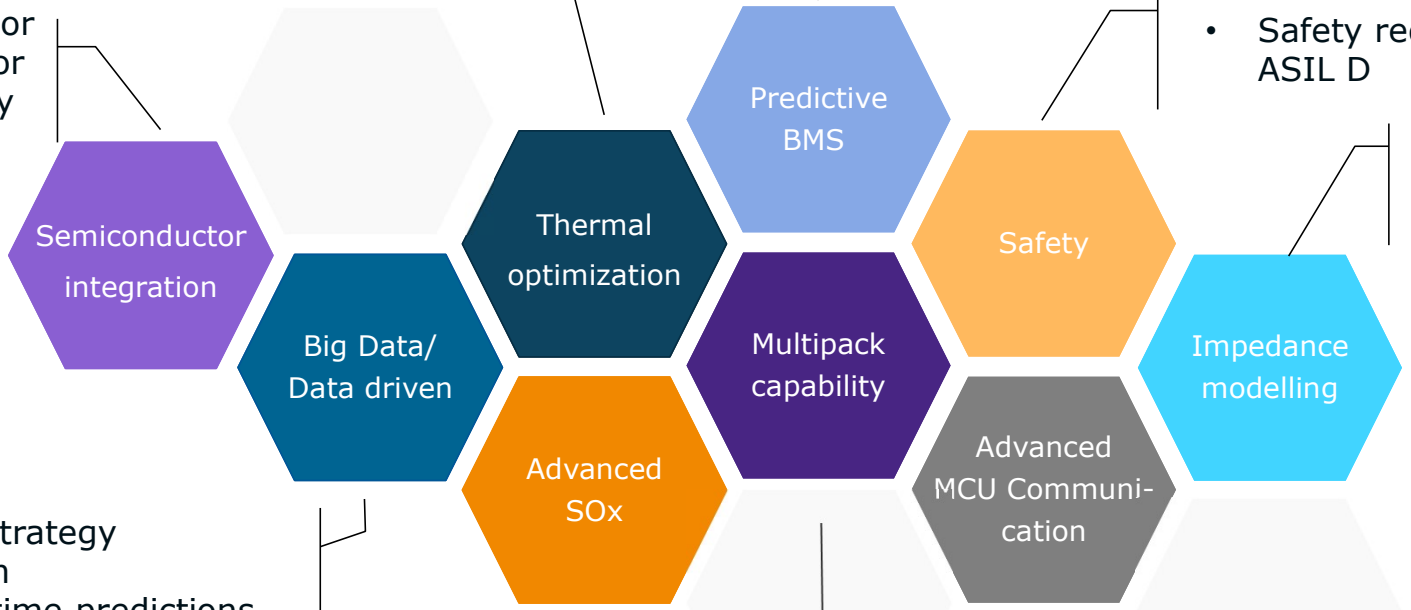
- Battery modelling incl. thermal modelling
- Model predictive control

- Prediction of power demand and adaptation of limits based on infrastructure data

- Semiconductor integration for smart battery switching

- Safety requirements up to ASIL D

- Accurate calculation of inner resistance
- Optimization of cell operating control



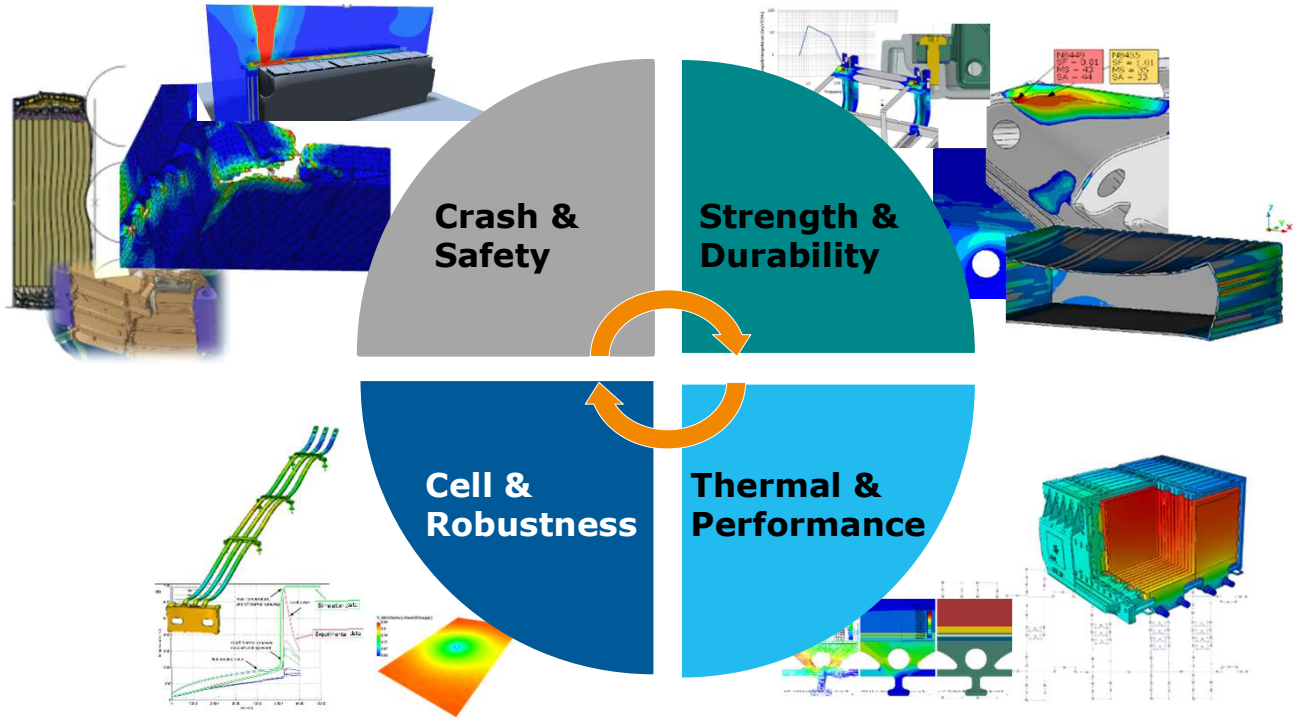
- Operation strategy optimization
- Battery lifetime predictions

- Easy adaptation of parallel battery packs

- Powerline or Wireless
  - Less connections, wiring, etc.
  - Possible cost savings

Battery Virtual Development incl. Simulation

AVL's long time expert competencies in simulation execution and tools ensure most **efficient development** with front loading of development tasks and **early and quick validation.**



Thermal-electrical and mechanical simulation for design validation

EMC and NVH simulation and full virtual validation environment

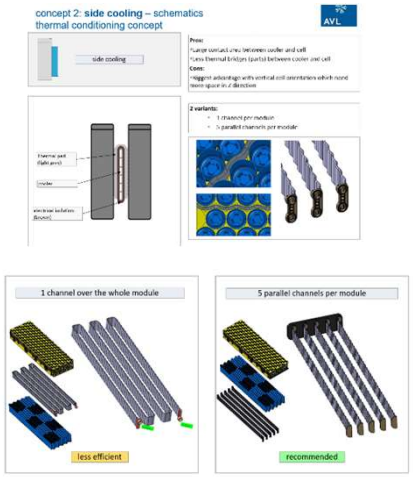
Unified model chain from system integration model to detail model (1D to 3D)

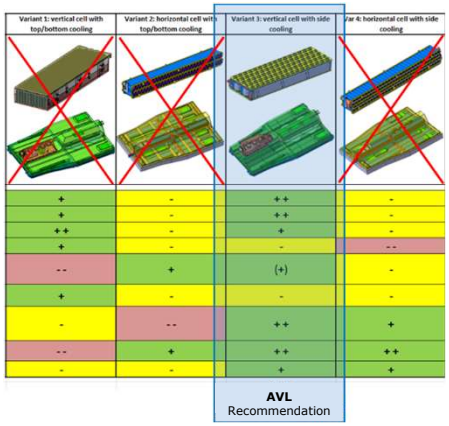
Virtual validation on all legal/standard tests R100.2, UN38.3, GB/T, ISO, SAE,… (except short circuit)

Battery Concept Development

With AVL's concept development methodology **quick start, time efficient** execution and **on point results** support answering the key development questions.

Concepts generation and evaluation phase → Variant generation phase → Variant down-selection phase





Standardized 8 weeks process: From idea to proven solutions

Program supports **quickest start into series battery development**

Proven competencies in various customer projects for different applications!

Series Development
the “not so new challenge”

Public

Pedro Gomez

- Fully committed to finding sustainable solutions to our transportation needs. Now and in the future. Working in the automotive industry for over 14 years in the field of propulsion systems, industrialization, SOP projects and project management. Focus on taking technologies from the concept stage into production readiness.
- Working at AVL UK and AVL List for the last 12 years, now as Design department manager involved a wide range of projects spanning across ICE, Batteries and fuel cells.
- BSc in mechanical engineering and an MSc in automotive engineering. A keen advocate for “right sizing” and enabling technologies into serial production.

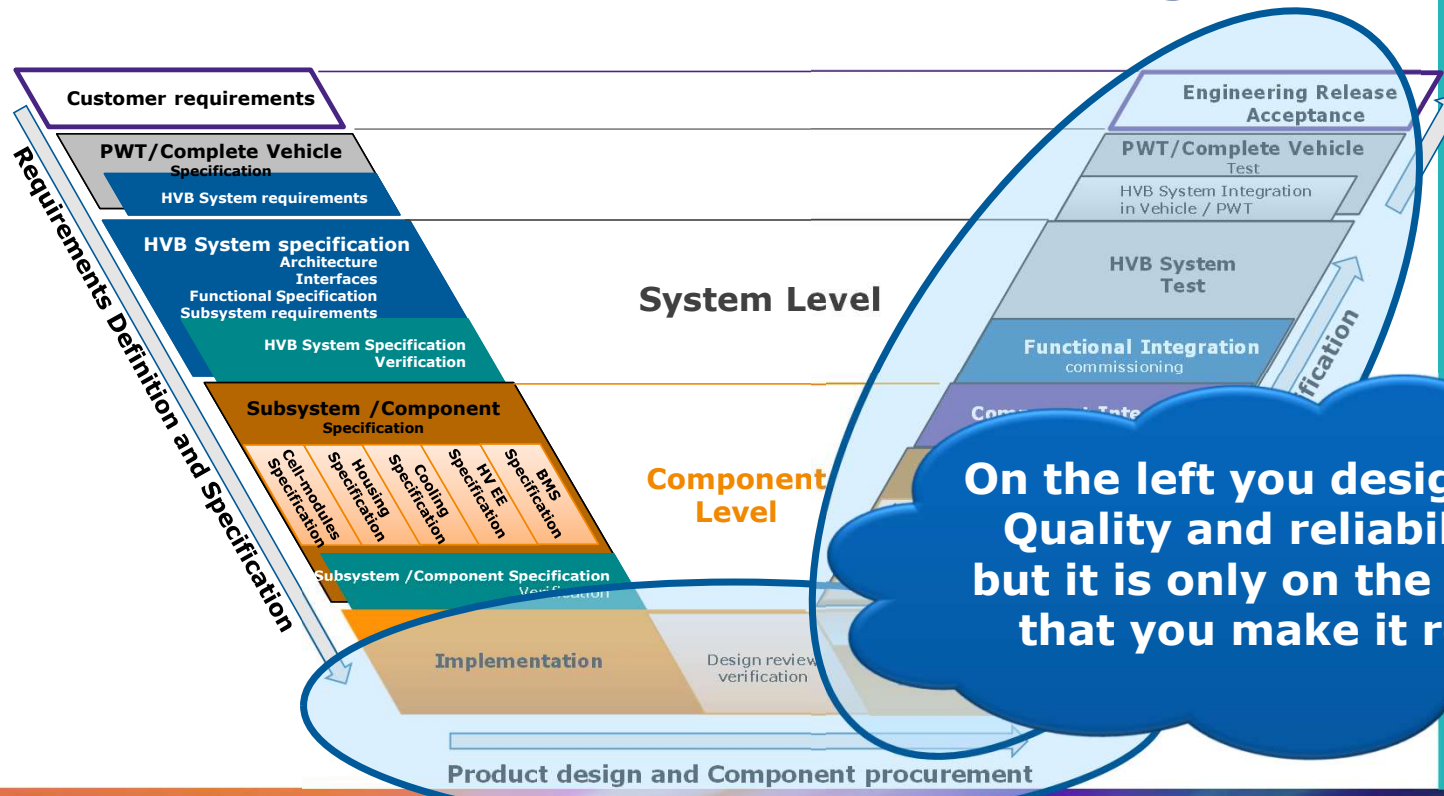
Jon has engineered a really nice concept for us, we just need to produce it.

What can go wrong?

Battery Series Development

This is applicable for the process **from concept to SOP** with or without **battery module** and **pack development**, as well as **BCU software and hardware.**

Let's have a look at the V again



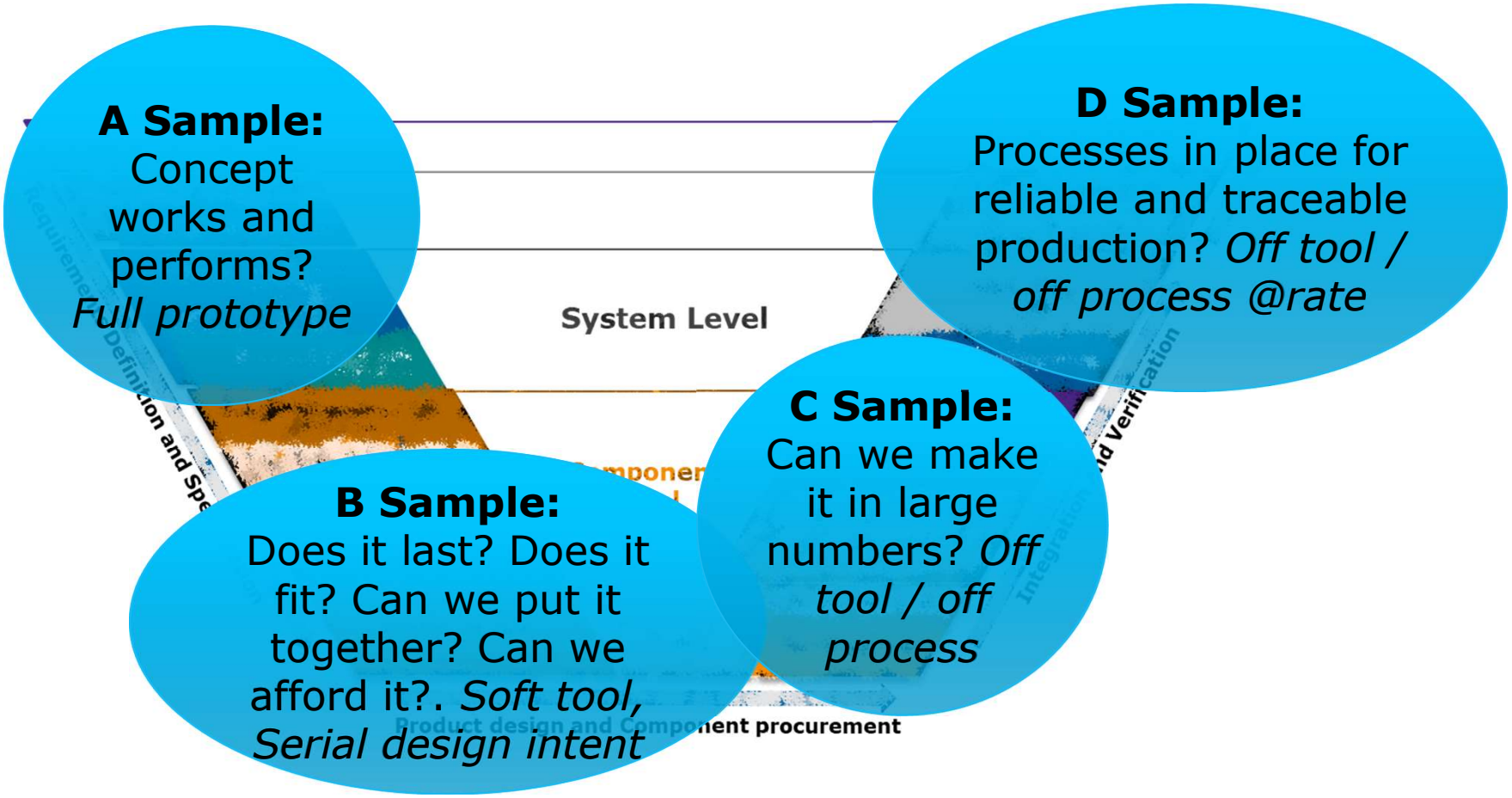
Battery Series Development needs:

Methodology

Combination of risk assessment, simulation and validation plan

On the left you design for Quality and reliability, but it is only on the right that you make it real

Re cap. What are we trying to achieve in each part of the V



ther, remember
"shape of the V"
is a great
d all days when the
n was needed.
me more power!

Engineers: no problem, we got you covered

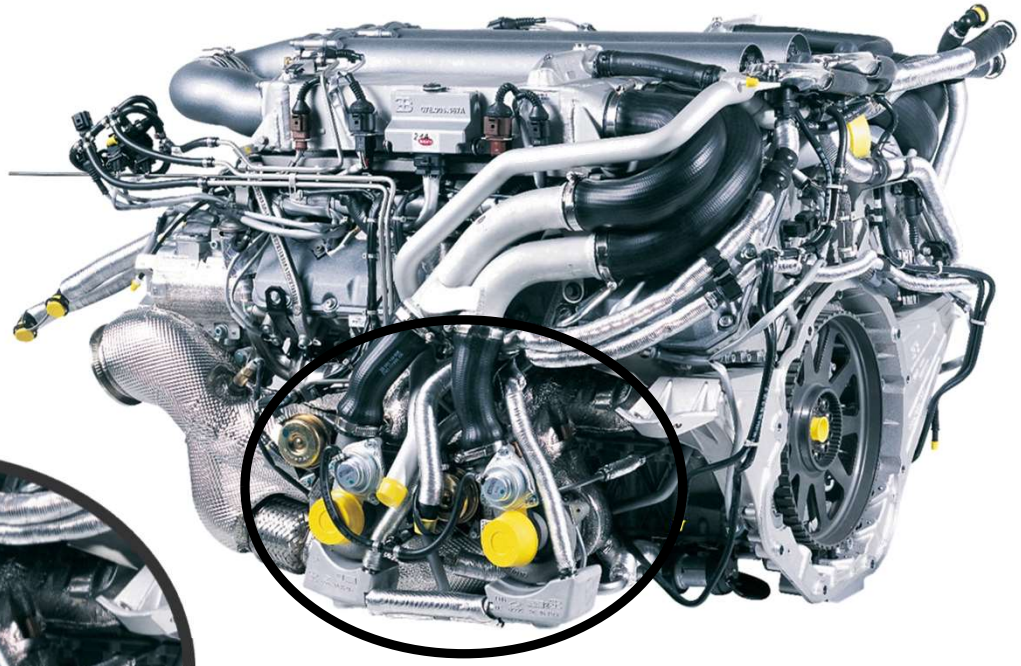
https://precisionturbos.co.uk/

https://www.thedrive.com/news/31540/this-gigantic-turbo-thats-rated-for-5500-horsepower-exists-and-of-course-you-need-it

A turbocharger, even if not easy, meant that most of the physical components remained untouched

++ Bigger turbo / revised Cal/ Cyl head Gasket / Cooling

+ Bigger turbo / revised Cal

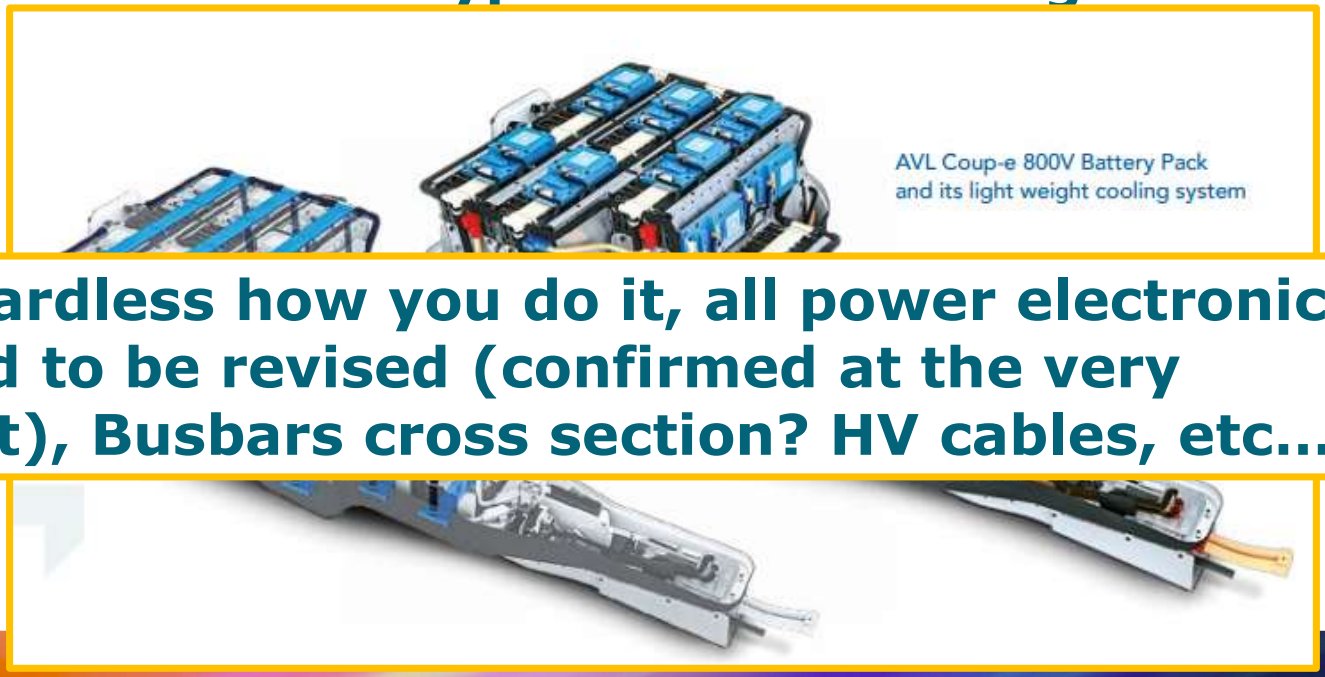


Main variant

Challenges for a Battery variant

Let's say we want a higher performance variant (more energy / more power)

More cells? **Different Type of cell?** **Change HV architecture?**



Regardless how you do it, all power electronics need to be revised (confirmed at the very least), Busbars cross section? HV cables, etc.…

Challenges for a Battery variant

Let’s say we want a Lower performance variant (less energy / less power). It should be “easier…

We want to reduce cost by reducing number of cells. We would also reduce weight and complexity?

Not so quick…

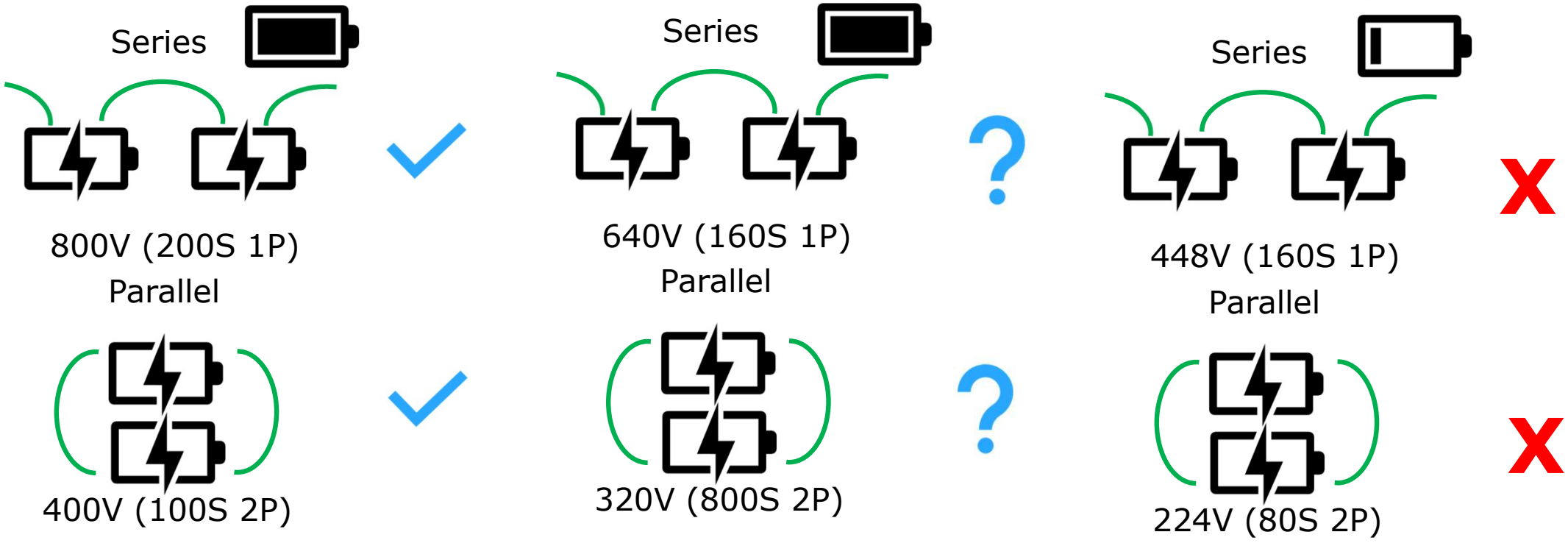
Challenges for a Battery variant

Less cells messes up the XsYp configuration (Pack voltage becomes a problem). The lead variant is most likely at either 400V or 800V

Chemistry determines voltage. XsYp is all we can do. How many in series determines the pack voltage. More in Series higher voltage.

Challenges for a Battery variant

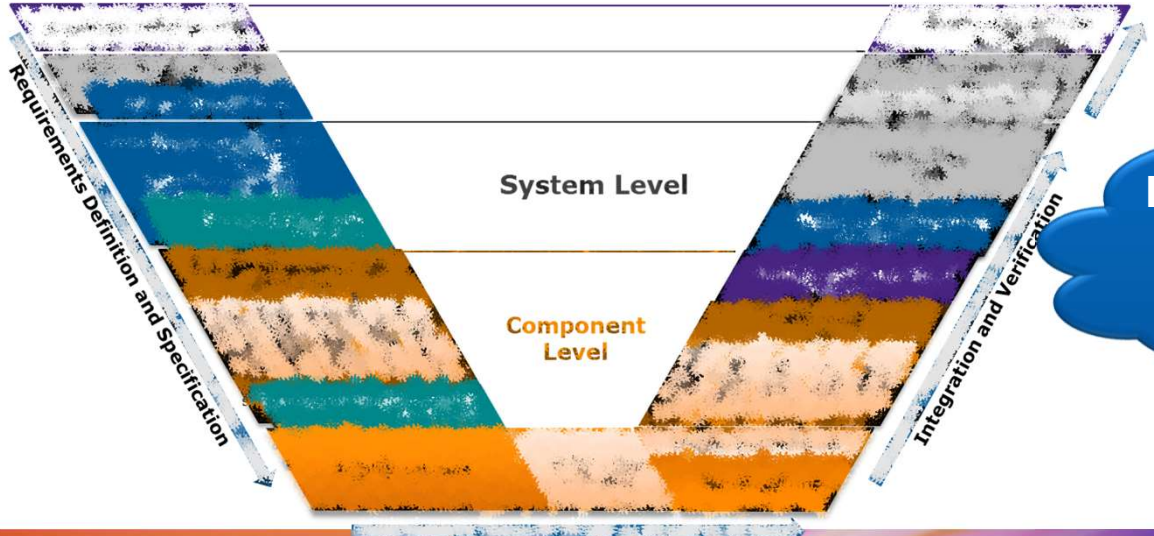
Now, for ease of math, consider a lead variant of a pack with 200 cells with a Chemistry of 4V nominal per cell.



Challenges for a Battery variant

Low SOC - you can fall well below the operating range of your EE components. Extra expensive and difficult to package DC/DC?

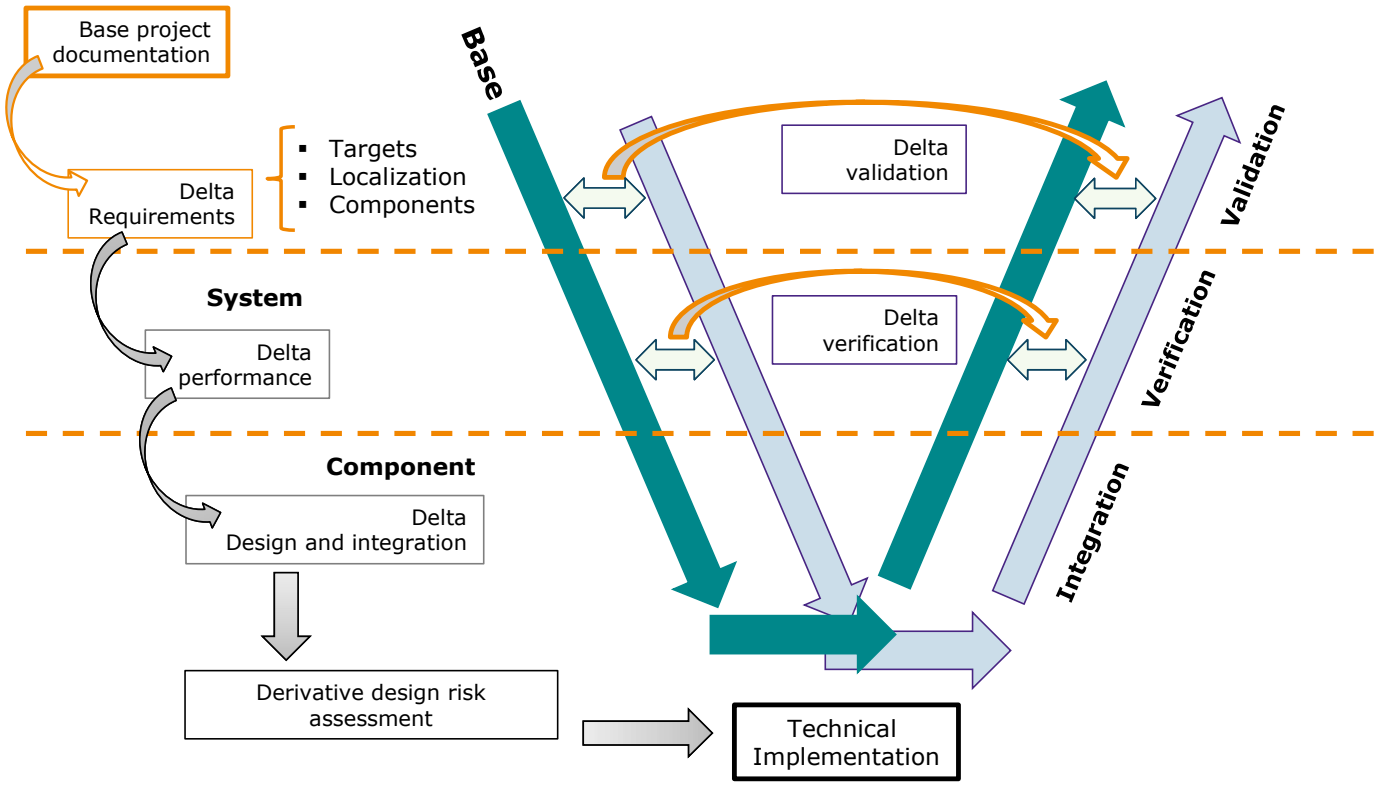
Do you keep the 800V rated components e.g Inverter while you reduce the Voltage? (or de-rate)



Message: yes, it can be done, but don't cut the "V"

Battery Series Development - Derivative

Battery **derivative-development approach** requires **early risk assessment** and **front loading**



Battery Series Development needs:

Methodology

Combination of risk assessment, simulation and validation plan

Cost and time efficiency

We resolved the "Concept " challenge

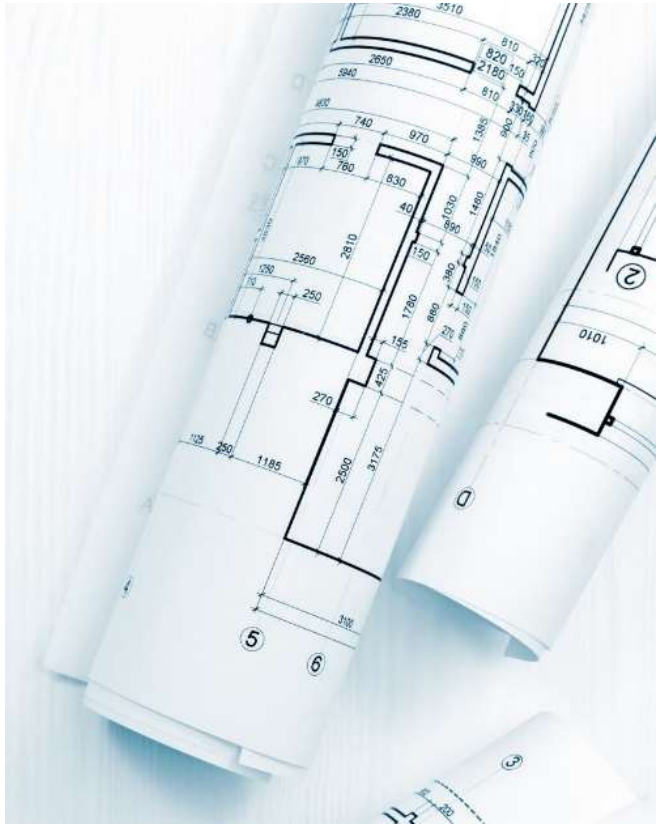
Now let's implement

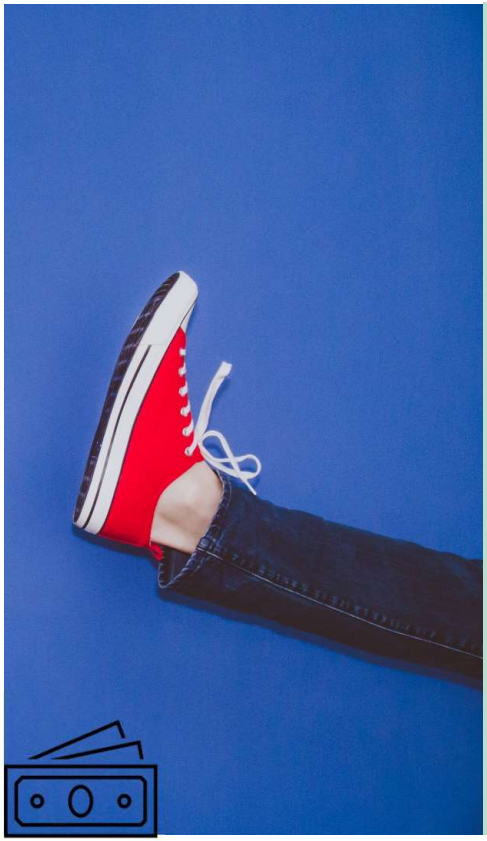
Spoiler alert: **the business of moving electrons around brings many new concepts and technologies…**
But:

Same skill set for industrialization

We resolved the “Concept “ challenge

Now let’s implement

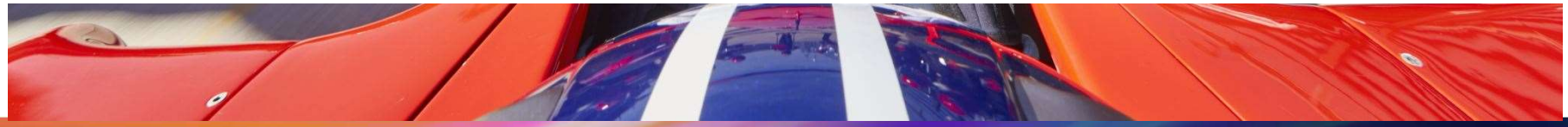




It is Teamwork

Step one in implementation: engage with all suppliers (internal and external). Confirm technical feasibility,

EASY… how many times have you had a project where all components can be done at cost, time, performance and weight?

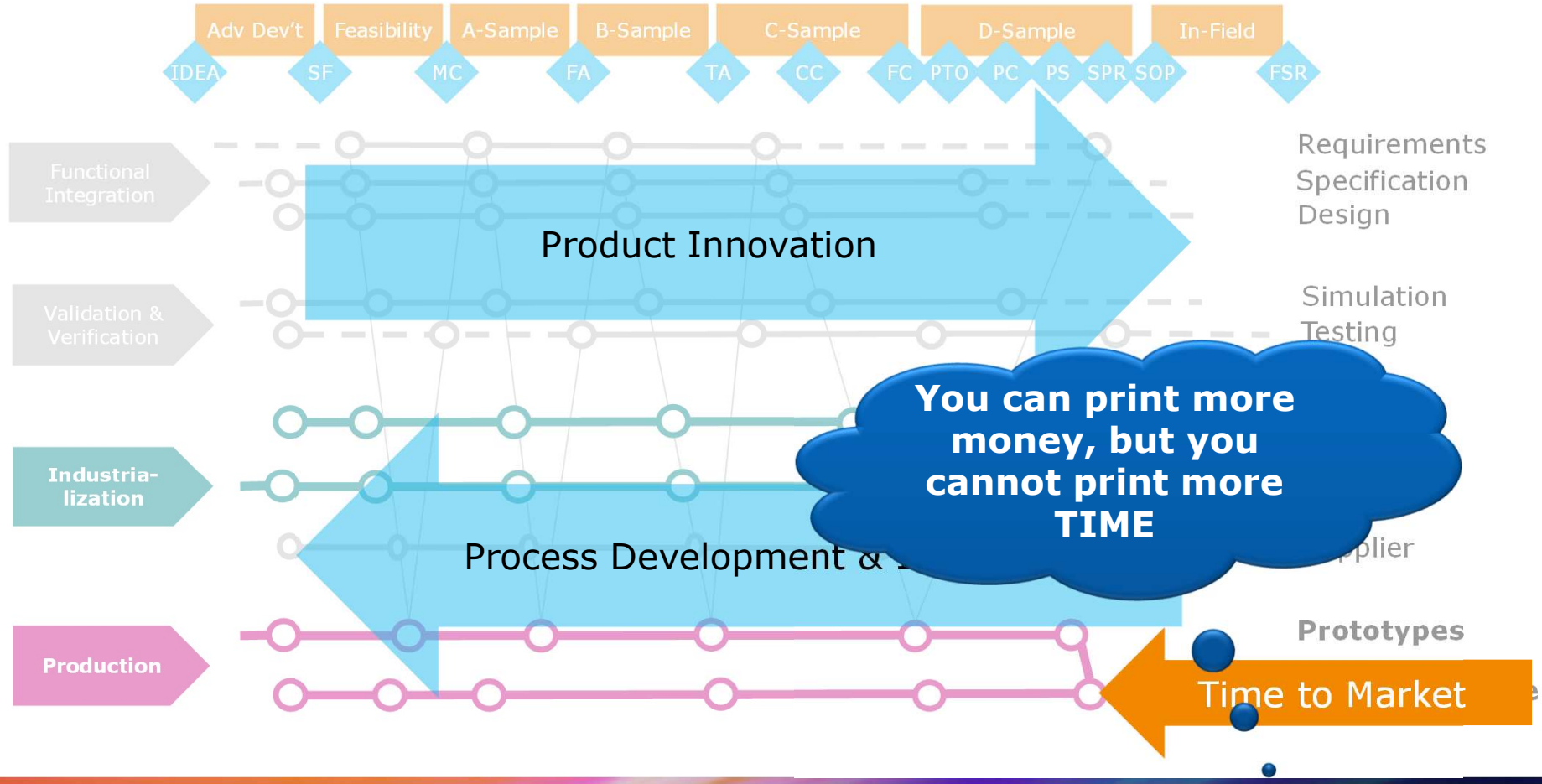


It is Teamwork

What can we negotiate:

- Increased robustness
- Manufacturability
- Assembly
- Cheaper
- Faster

A lot is about timing. Accelerating Time-to-Market



Let’s make stuff. Battery Prototype Hardware Built

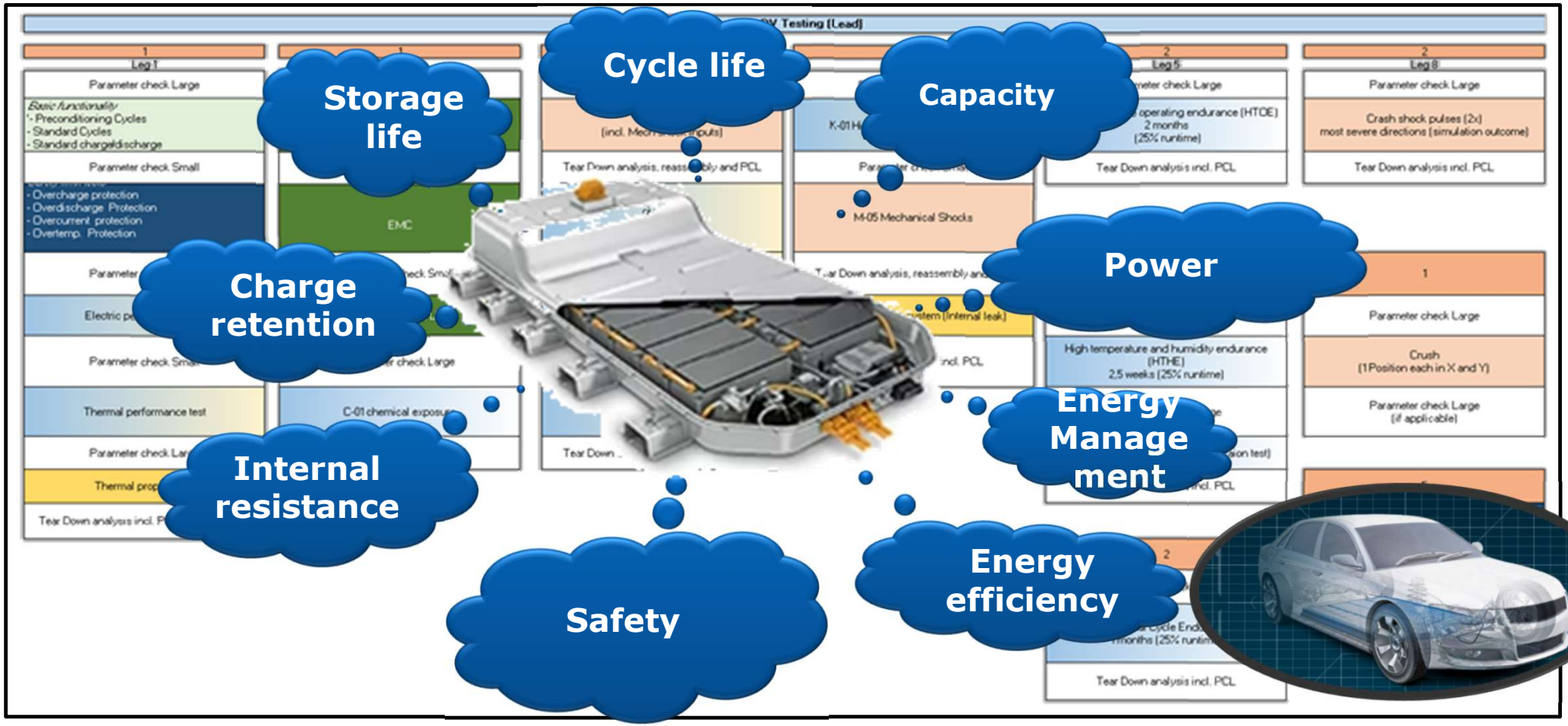
Procurement, assembly and **end-of-line testing.**

B sample: “Final design intent”.

Procurement and assembly team with full equipment

Components will be made from prototype or soft tooling while ensuring that design as close as possible to the one that will go into serial production.

Do we fulfil all the targets? DVP



Battery Production Engineering – C sample

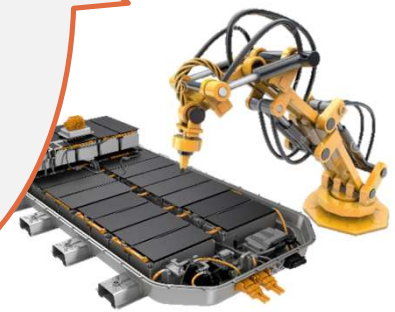
Involvement of production and cost engineering experts from early concept to SOP ensures **production ready development** including **manufacturing planning.**

"Design for Assembly"
Simultaneous Production Engineering

"Design to Cost"
Cost Engineering

Improvement Engineering

Manufacturing and Factory Planning



Off tool / Off process

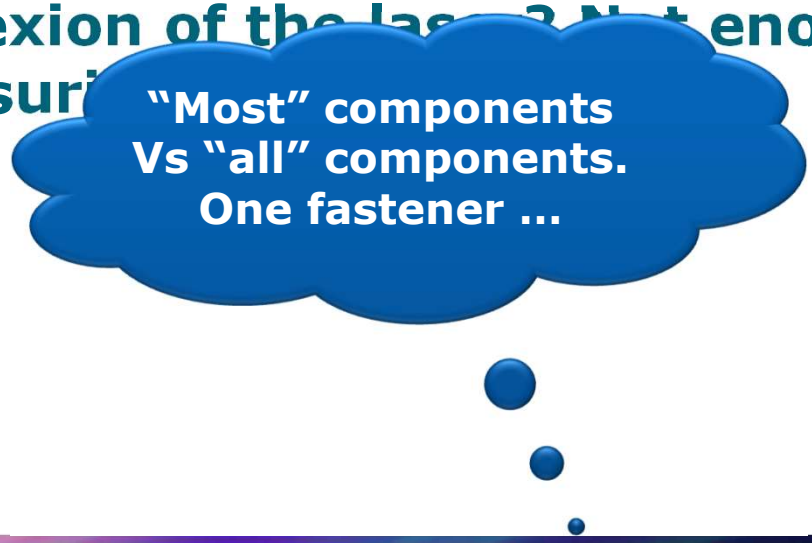
Stack up analysis, DFM/DFA/DFC are frozen

Bill of design and Bill of process are stablished

Getting ready for production release

Inevitably, we will find improvement potential

Example: Busbars aluminium / Cu welding.
Coating? Impurities, reflexion of the las[illegible]? N[illegible]t enough penetration, difficulty ensuri[illegible]

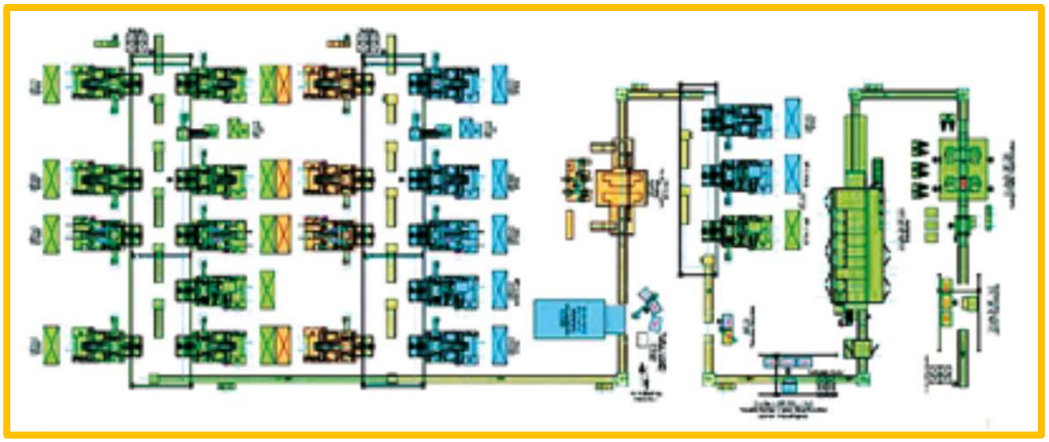


Industrialise. Ready for serial production?

Frozen geometry, materials, BoD, BoP:
Suppliers and manufacturing produce hard tools and final assembly process.

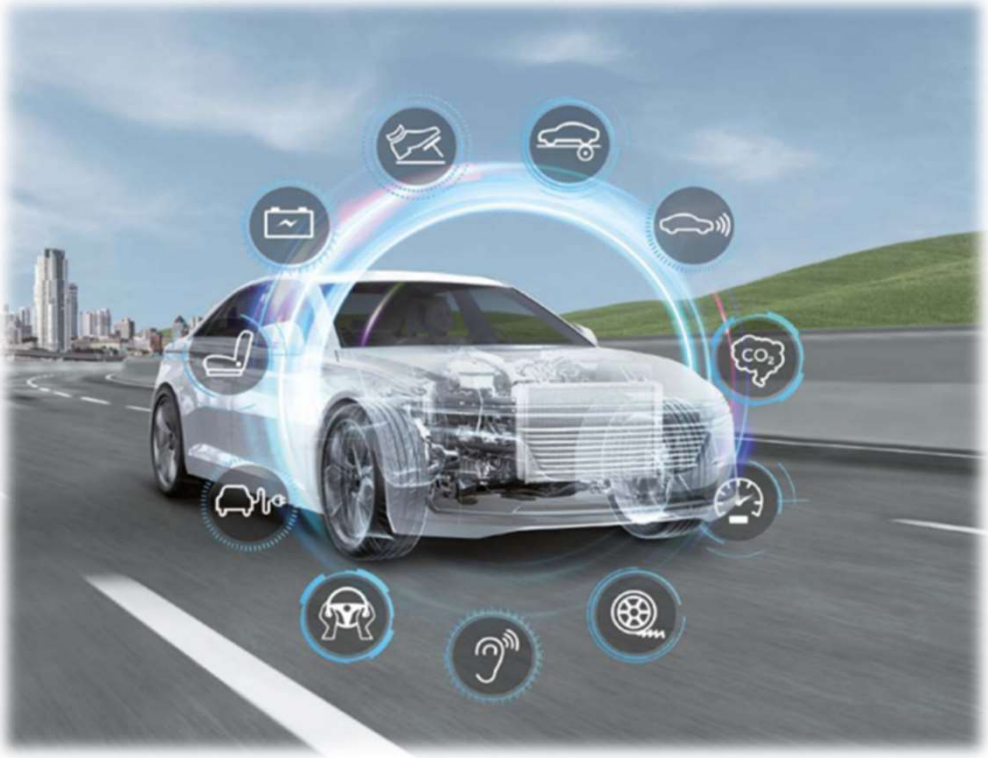
Lead times – Simultaneous engineering

Casting
Extrusion
Stamping

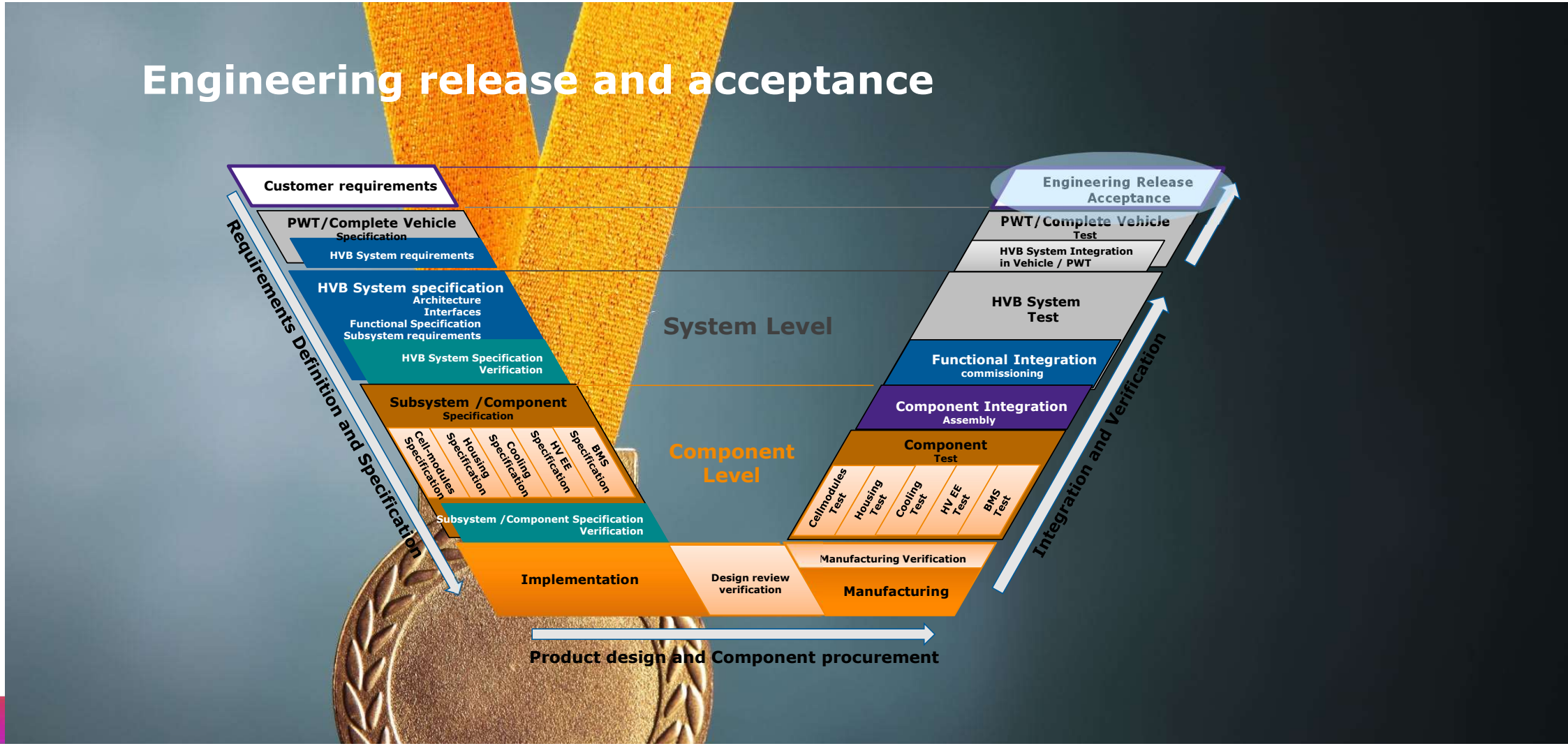


Completing the V – D sample

- All DVP completed and documented (At component, system and pack level).
- Homologation achieved for all intended markets
- PPAP ready
- All documentation completed
- Project handed over to production and service teams



Battery Series Development. Closing the loop.



Thank you

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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

Tech Day Agenda

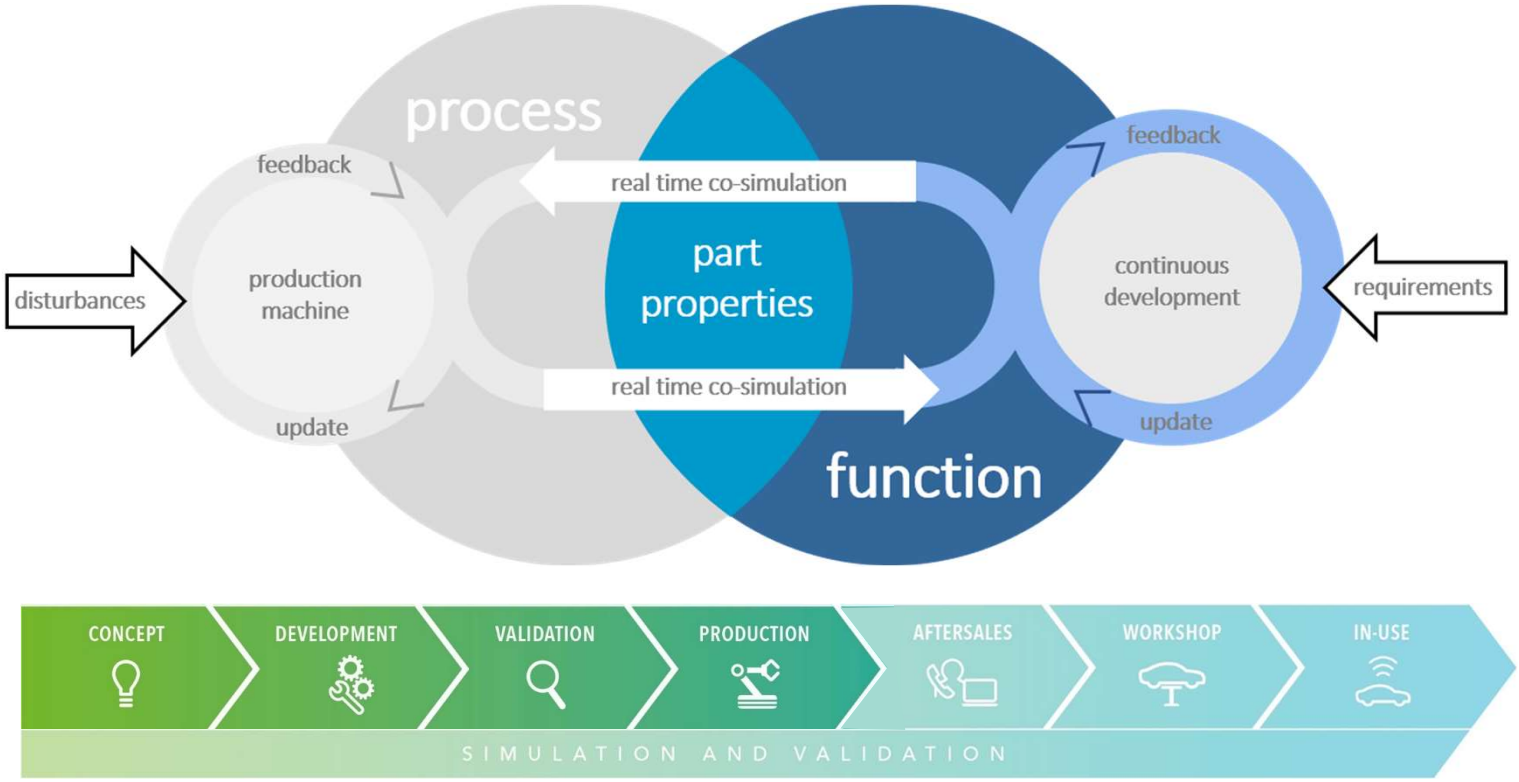
08:30 – 09:30	**Check-In and Refreshments**
09:30 – 09:45	**Welcome Session**
09:45 – 10:30	**Cell Technology, Overview and Trends** *Jon Caine*
10:30 – 11:15	**Battery Systems Integration and Manufacturing Technologies** *Pedro Gomez*
11:15 – 11:30	**Coffee Break**
11:30 – 12:15	**AVL Virtual Twin for Battery Energy Assessment** *Juergen Schneider*
12:15 – 13:00	**Battery Modelling** *Mark Holdstock*
13:00 – 13:45	**Battery Recycling** *Saikat Ghosh*
13:45 – 14:00	**Closing** *Jon Caine*
14:00 – 15:00	**Lunch and Networking**

Back up slides

Bringing together functional and process development: Simultaneous Industrialization

Focusing on rapid industrialization:

- Co-simulation framework for real-time process optimization
- Systematic approach for adaption of simulation models Use of simulation models from PDP and PPP for real-time model-based control of production processes
- Continuous Integration / Continuous Deployment (CI/CD) strategies



AVL Battery Innovation Center

an IPCEI (FFG Austria) supported initiative

Fusion of Function & Process Development

- Serve higher volumes in A- & B-sample prototypes, field test fleets, racing series and C-samples

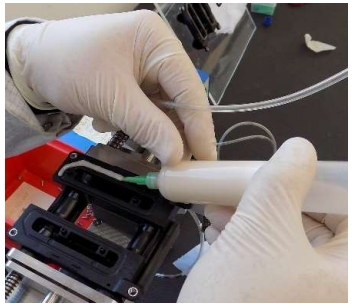
- Assembly process development for battery production with production-representative quality
- Closed-loop to product dev't (DfM - Design for manufacturing)

- Provide industrialized designs and processes "ready for ramp-up"
- including ultra-large modules, Cell-2-Pack, Cell-2-Chassis, Module-2-Chassis

- Serve as open platform for the industry & scientific partners
- Accelerate digitalization in battery production
- Verify Eco-Design products in cost and circularity

New processes require development and validation

Machine and Material Trials



- Trials within core technologies are key for a robust product development including DfM

- Production intent automation from beginning on

→ improves product design

→ less loops in industrialization

This approach requires highest flexibility

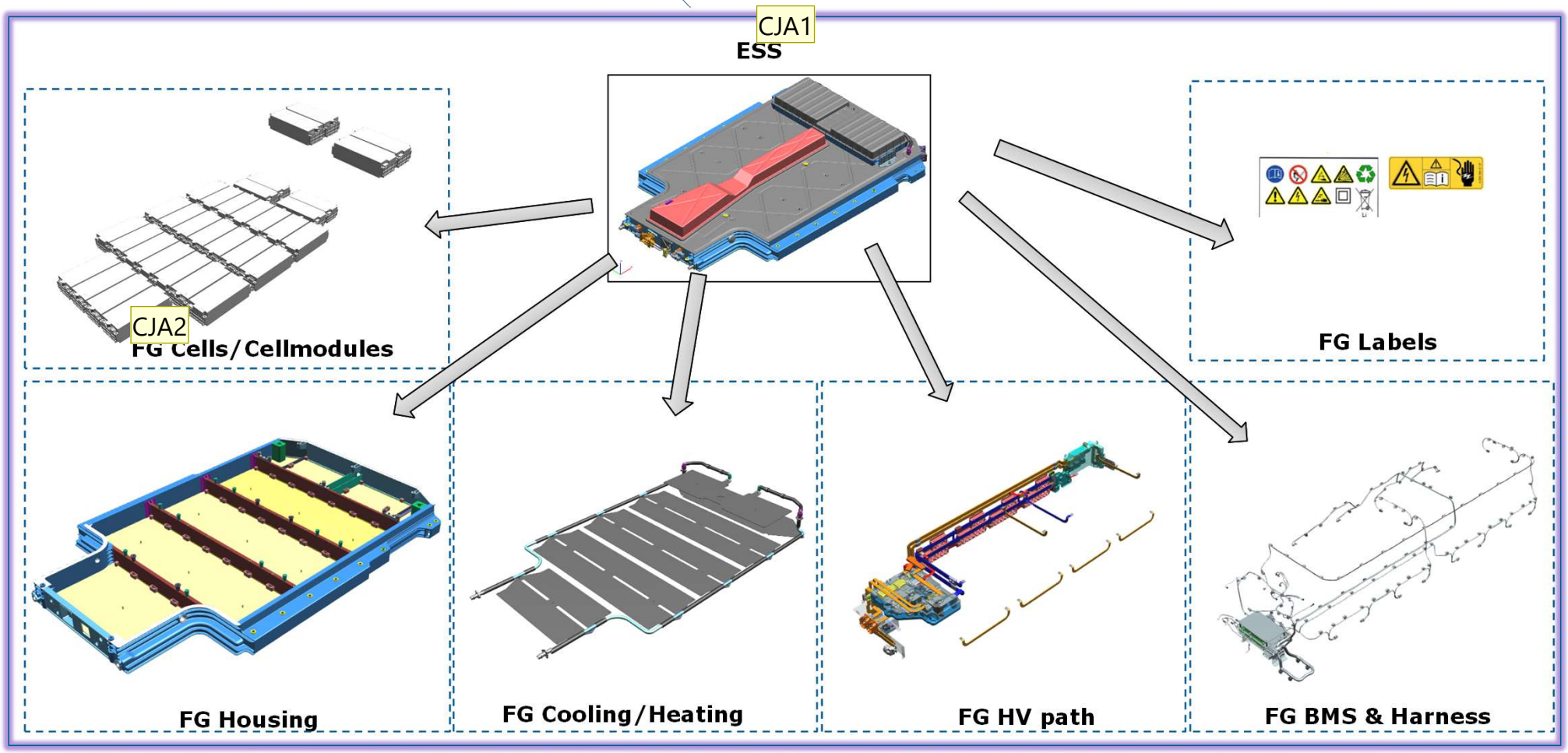
- High Automation
- Easy variation of process parameters
- Adaptable concepts for grippers and jigs
- Simplified programming and teaching
- Processability of various materials

- Challenge design by running trials in series cycle times

→ Discover improvements in early stages

All this is driven in the new AVL Battery Innovation Center

HV Battery Subsystems



Slide 66

CJA1 What is ESS (Energy Storage System?)
Caine, Jon AVL/UK, 20/04/2020

CJA2 What does FG stand for. It is not needed, just used Cells & Modules
Caine, Jon AVL/UK, 20/04/2020

Different phases

- **Development generation / Sample stages:**

	Mule Vehicle/ MP / Gen0 / A-Sample
Purpose	Functional /Feasibility Prototype for: - limited functional demonstration - concept evaluation & feasibility check - concept decision / functional verification of concept
Description	Baseline development and evaluation of concept virtual and/or on test bed and/or in vehicle (i.e. main functions as e.g. performance & emissions, mechanical / thermal /electrical function and NVH)
Component Geometry	Function and effort driven, **"serial design intent" not required** (no representative design), initial package considered. Serial parts may be used and modified as base for concept prototypes.
Materials	Dependent on requirements - "serial intent" material usually not required
Tooling	**Prototype tooling** - (e.g. rapid prototyping, 3D-Print, CNC machined...) - key focus on quick delivery and low tooling cost
Process	**Prototype manufacturing** - (e.g. rapid prototyping, 3D-Print, CNC machined...) - main focus on quick delivery and low tooling cost, low administration effort.
Supplier	**Prototype suppliers,** critical sub-systems (=AVL Cat I components) may be from later serial suppliers (e.g. in case of concept competitions)
Functional Capability	Capability for **limited defined functions** for In-Vehicle or test bed testing required. No or limited diagnostics, only basic safety functions.
Testing Capability	**No durability testing** capability required; functional testing under defined / limited operation conditions
Use on Public Roads	Usage on public roads is not permissible

	PTO Vehicle/ PTO / Gen3a / C-Sample
Purpose	Tooling Tryout/Production Tryout **with 100% "off tool" parts to validate Serial Tooling**
Description	Focus on validation of 100% serial tooling. No design changes allowed except due to tooling issues. Start of PV Testing (Production Validation)
	Like Gen 2 / B1-Sample, in addition
Component Geometry	**100% final serial design** out of serial tooling including 100% serial tolerances and dimensioning suitable for measuring and process control.
Materials	100% serial material from serial source and location out of serial tooling
Tooling	**All parts** with **100% serial production tooling** – "Off Tool" at serial production or toolmaker location
Process	Serial intent assembly, serial production processes @ serial location or @ tooling / equipment supplier. Pilot assembly line as well as manual assembly is possible.
Supplier	**100 % serial production suppliers ("off tool")**
Functional Capability	100% of functions incl. diagnostics, safety, EOL etc. fully implemented & verified; from here on only bug-fixing. with this HW stage, calibration will be completed
Testing Capability	Validation of product with focus to **sign off final product with off tool components**
Use on Public Roads	Public road tests capability limited. Use on public roads is possible with a special permit and once street clearance has been granted by the competent authority

	PT 1 Vehicle/ PWT 1 / Gen1 / B-Sample
Purpose	Development Prototype: **with full "Serial Intent Design" to prove Concept and Serial Design, Functionality, Quality and Industrialisation**
Description	Focus on functional development and testing under test bench and vehicle driving conditions. Change Management Process of targets and requirements implemented (at latest). Change Management Process of design implemented beginning with TA/CA.
	First Serial Design
Component Geometry	**"Serial design intent"**; 100% Simultaneous Engineering fulfilment: All DfM, DfA, DfS, DfQ, Cost Down measures and preventive actions / Lessons Learnt implemented. Full representative SERIAL design, package requirements 100% fulfilled, full CAE validation in several optimization loops.
Materials	"Serial intent" material - mechanical properties as close as possible to serial material
Tooling	**Prototype tooling** (for selected durability relevant parts serial technology "soft tooling" / "production intent tooling" may be necessary e.g. forging, casting, powder sintering)
Process	**Prototype manufacturing -** ("serial production intent" technology may be necessary e.g. forging, casting, powder sintering for selected durability relevant parts). For selected PT technologies tradeoff between tooling and parts cost has to be found (volume driven).
Supplier	**Main sub-systems** (=AVL Cat I & II) / **components must be from serial supplier;** other parts from prototype suppliers
Functional Capability	**Full functional capability** for functional development, test bed and In-Vehicle testing; diagnostics limited to main functions.
Testing Capability	**Serial design validation** and **durability testing** on sub-system and system level - test bed and In-vehicle.
Use on Public Roads	Public road tests capability limited. Use on public roads is possible with a special permit and once street clearance has been granted by the competent authority

	PS Vehicle/ PS / Gen3b / D-Sample
Purpose	Pre-Production /Pre-Series **100% "off tool" and 100% "off process" parts to validate Serial Processes and Logistics**
Description	Focus on final validation of 100% serial processes. All parts, components and systems must be produced under full serial conditions including required maximum process speed, production transfer linking and serial packaging and conservation. 100% PPAP/ Initial Sampling of Supplied Parts is mandatory. Completion of PV Testing (Production Validation)
	Like Gen 3a / C-Sample, in addition
Component Geometry	**100% final serial design**
Materials	100% serial material from serial source and location out of serial tooling under 100% serial conditions.
Tooling	**All parts** with 100% serial production tooling **100% at serial production location** in serial production environment
Process	**100% serial production & assembly** incl. all serial processes & logistics in serial process cycle time and assembly takt time– **"Off Process"**
Supplier	**100% "off process" at supplier** **100 % PPAP / Initial Sampling status "green" confirmed, R@R passed**
Functional Capability	100% Bug-fixing completed. Calibration verification & validation
Testing Capability	Final **validation** of **100% serial conditions.** Final durability tests with "off process" parts/components/systems usually finished several months after SOP. Start of fleet testing with selected end customers feasible.
Use on Public Roads	Type approval sample for approval by a registration office