# R&D CHALLENGES: BATTERY ELECTRIC VEHICLE 2021+

## POSITION

Battery-powered electric vehicles (BEV) represent an outstanding opportunity to make mobility more energy-efficient and to decarbonize and move away from fossil energy carriers (requires that electricity is produced sustainably) and to reduce pollutant emissions.

All components (electric motor, transmission, battery, cooling system, control units (VCU, BMS …), power electronics, and charging system) of the electric vehicle are currently used in different variants and combinations. Several electrification variants (BEV, FCV - fuel cell vehicle, HEV - hybrid electric vehicle) and drive systems are being considered. However, the focus on the BEV chapter is on purely battery electric vehicles as hybrids or FCEVs powertrain solutions are treated in dedicated chapters.

Technologies currently used in series production still need innovation to achieve lower cost, higher efficiency and performance. As a result, further research and developments are required regarding the functionality and efficiency of the components in the powertrain and also for manufacturing technology and production processes in order to be able to deliver competitive products with high efficiency, low resource consumption, high reliability and durability as well as low costs.

Modern development processes start with virtual prototyping to save time, money and unnecessary iterations, especially in this currently still imperfect field of expertise. Therefore, simulation tools, continuous validation in mixed development and simulation environments (SIL, MIL, HIL, VIL) and advanced development methods and tools (e.g., co-simulation, data analytics, AI, ML) are used to reach these high-level goals.

In order to enable computationally intensive energy saving features including model-based control and AI, further hardware developments for new high performance centralized control units are essential. This includes flexible functional partitioning and higher computational power. In addition, faster and more efficient integration of new software components is necessary. The development of a virtual integration platform can drastically reduce the development time for introducing such components.

The Austrian research landscape needs to develop the methods and data from component to system level in order to bring advanced products onto the market safely, cost efficient and sustainably.

## REQUIREMENTS ON TECHNOLOGY DEVELOPMENT AND RESEARCH DEMAND

### (HIGH) VOLTAGE LEVEL BEV SYSTEM

**High-voltage systems** with voltage levels in the range of 400-1000 V enable a significant increase in performance (necessary to implement high performance EVs). Additionally, high-voltage systems enable the **implementation of ultra-fast charging** of BEVs - similar to refueling a vehicle with an internal combustion engine. Even without these two "features", a higher voltage level can generate added value: At constant power level, the current is reduced by increasing the voltage level, with the advantage of lower losses in the DC link and in the supply lines. This means that high-quality copper material can be saved.

Since high-voltage systems have the inherent attribute of producing EMC relevant electromagnetic fields, it is essential to consider design and testing methods in order to design high-voltage systems properly and being able to evaluate and test the systems as components or integrated.

The necessary **cost-efficient insulation systems** still **need to be developed** for the automotive industry. Existing and long-established insulation systems (e.g., from the railway and tram sector), were developed for other applications with different requirements. Unfortunately, those requirements do not fit the efficiency, packaging space and cost driven automotive industry.

Further innovation activities must be focused on winding technologies, control algorithm (IM, PMM) and alternative materials (e.g., plastic).

## ELECTRIC MOTOR, POWER ELECTRONICS, GEAR BOX AND ELECTRIC DRIVE UNIT (EDU)

The choice of the machine type (asynchronous, synchronous, reluctance motors, etc.) and the design depend on the respective application and, among other things, on price, volume and efficiency goals. The highest levels of efficiency are required. Different designs are analyzed and optimized regarding their suitability. This applies to classic machines such as internal rotors with the highest possible speed or external rotors with high torque, but also to innovative technologies such as compact in-wheel motors and axial flux machines. The development of directly cooled high-speed machines with a particularly good power-to-volume ratio is very promising. These are special tasks in the field of transmission (NVH, lubrication, bearings, shaft sealing, switching (with several gear ratios), loss minimization ...) and direct liquid cooling of the rotor and stator ...) to be solved. E-motors must have particularly good controllers at speed of around zero up to highest levels, as well as highly dynamic torque vectoring and the generated vibrations and noise-level is especially important for the end-product. Therefore, proper simulation, testing methods, sensor systems and tools are very essential for the construction of new e-machines.

In the field of power electronics, the use of new semiconductor materials (such as SiC or GaN) is of interest, which allow high operating temperatures and thus enable new (cheaper) cooling system solutions as well as more highly integrated powertrain concepts. But also, the aging of power electronic components is a particularly important aspect to be considered when designing and developing new inverters, charging systems, auxiliary power sources or test systems, which all consist of the same sort of power electronics.

Due to the large number of machine types and designs and optimization parameters, the R&D requirements are remarkably high, regarding the design and optimization of the motor (compactness, power and torque density) and the overall system (motor - converter - control and communication), with regard to manufacturing suitability and low manufacturing costs (Windings, sheets, materials ...) as well as the necessary functional safety.

The amount of power electronic components in the vehicles is rapidly increasing. DC-DC converters, Onboard Chargers, Comfort Devices, Devices for automated driving etc. play an increasing role. To compensate the energy demand of the devices for automated driving and comfort functions, the efficiency of all power electronic components in the vehicle must be increased. Synergies between power electronic components must be exploited, Modeling & Simulation is necessary to develop lean code for all power electronic control units to reduce the energy consumption needed for complex calculations.

The integration of the power electronics, control, e-machine and gearbox into electric drive units (EDU) is necessary in order to allow highly integrated powertrain concepts and further improve energy and cost efficiency at high levels of functional safety.

## BATTERY AND CHARGING SYSTEMS

### *BATTERY TYPES*

The major challenge in the development of electrified vehicles is the rapid change in battery technology and the resulting effort and increasing risk with regard to the key aspects for the Austrian supplier industry: the safe integration of new battery cell technologies - such as highly Ni-rich cathodes and lithium (containing) anodes in conventional lithium-ion technology or future all-solid-state cells -, the early detection and avoidance of critical errors in the battery system and drive train, the necessary expertise (cell chemistry, manufacturing process, cost structure) and infrastructure (test benches for electrical but also abuse, misuse and environmental tests) for the development of optimal battery management. This also enables the necessary industrialization competence and the associated quality management to be established.

The success of battery electric vehicles (BEVs) in the automotive sector strongly depends on the development of high-energy batteries at competitive prices. Therefore, the Austrian supplier industry must focus on the development of methods, tools and components to increase the operating range, reliability and safety of BEVs, and to lower their costs in €/kWh and their ecological footprint.

The objective of the R&D portfolio covers the improvement of existing batteries, as well as further research regarding the next generation of battery technology – thus covering materials of generation 3a, b (dominantly NMC (Nickel Manganese Cobalt) based cathodes, Si-graphite composite based anodes) as well as 4 (solid-state dominated) and 5 (post-Lithium chemistries, such as Li-air and poly-ionic Li substitutes).

In addition to the focus on the development and manufacturing of modules or packs, the opportunities also lie in battery cell, module and pack production. New cell types and technologies allow much higher variation and optimization of battery modules and packs. Therefore, it is essential to expand the necessary skills and competencies in Austrian industry and research in this area as well.

### *CHARGING TECHNOLOGY AND INFRASTRUCTURE*

When vehicle traction batteries are charged fast, energy with high power (typically 100 kW and more) is transferred via a suitable interface using direct voltage (DC). Suitability for daily use and user-friendliness are essential for acceptance on the market: short charging times, increased convenience in the charging process (partially automated or robot-supported conventional charging cables, inductive charging and vehicle to grid-functionality), standardized interoperable interfaces, simple authentication and billing. This consequences in a high R&D demand on the one hand and demand for harmonization on the other hand.

Demand-oriented charging and a corresponding electric power distribution infrastructure (including solutions for load management)  will be essential to ensure a scalable and stable energy supply infrastructure which enables the high share of battery electric mobility in the future.

## THERMOMANAGEMENT

Batteries, power electronics and electric motors for electric vehicles require complex thermal management in order to survive cold and heat (e.g., during fast charging) without thermal damage (service life, early shutdown...). There is an increasing demand from OEMs for fast charging possibilities, which result in a high demand for new ideas for efficient cooling using innovative heat exchangers, as well as a need for new manufacturing processes. In addition, new "safety regulations" must be met, which place increased demands on the components and therefore require new component solutions. Any waste heat generated can be used via suitable technical processes (e.g., heat pumps). Heat storage concepts have to be developed (especially using new chemical latent heat storage devices that can hold heat without loss for any length of time). Especially innovative cooling concepts (e.g., direct cooling of battery modules) will be more and more in the focus. To use these concepts effectively, highly precise simulation methods and new measurement methods for simulation validation are necessary.

This results in a high need for research on thermal and control engineering issues. It is essential to include all components of the whole vehicle system that are relevant from an energy perspective (in addition to the energy storage and drive system, in particular the areas of air conditioning, cooling and conditioning and operating strategies). This also means that control units and software functions for previously independent subsystems either have to be combined to form a central control unit or have to be increasingly networked with one another.

The consideration of predictive data in the control of thermal components is important for further efficiency improvements, to overcome the latency times of thermal systems by preparing for events in advance.

In addition to the development of intelligent energy, heating and cooling concepts, modular thermal architectures have to be developed which meet different requirements (e.g., country-specific requirements), performance requirements (e.g., power levels of e-machines or fast charging) and different comfort requirements. This requires modular architectures at the system and component level.

The implementation of modular systems, which quickly helps to define the most efficient system architecture at the beginning of a development phase, can be supported by means of scalable simulation models and further by scalable, seamless testing environment for the individual components, especially if not all components are available at the beginning of the development.

There is a high need for research and development in the methodical development of scalable thermal models for all relevant components and an electrified powertrain (electric machine, inverter, battery and cables).

## ESSENTIAL LEGAL FRAMEWORK

Creation of an EU-wide legislative framework and directives for rapid implementation of an efficient and climate-neutral mobility allowing the EU-industry the introduction of new technologies as a result of R&D activities described in this position paper.

An important topic is the legal framework for the disposal and recycling of batteries as well as for the handling and transport of damaged batteries especially in emergency situations.

De-escalation of thermal runway effects require deep understanding and cross functional R&D efforts in order to ensure health and safety, environmental protection and economically acceptable procedures after accidents of BEVs fostering acceptance of e-mobility solutions.

Still, existing payment procedures make charging unnecessarily difficult, especially when using charging stations abroad. Therefore, a non-discriminating charge&pay procedure/standard (payment per credit card, bank card or cash) need to be established EU-wide/worldwide.

## LIFE CYCLE ASSESSMENT

Life Cycle Assessment (LCA) of BEVs involves a large range of influencing factors, such as the electricity supply (incl. intermediate storage of fluctuating renewable electricity) for BEV operation, as well as energy supply for battery manufacturing (share of renewable energy sources), the cell chemistry and related extraction and refining of critical raw materials (e.g. Nickel, Cobalt, Lithium) as well as the production of materials for battery casing (e.g. Aluminum) and the electric motor (e.g. rare earth metals). End-of-life involves the topics second use of batteries (e.g., for stationary storage), (and/or reuse of battery cells) and related allocation of environmental impacts between first and second use, as well as recycling. Battery recycling is an important element to (partly) close “critical” material cycles, however challenges such as (global) used battery collection, diversity of cell chemistries, and recycling process efficiencies remain to be solved.

## RESEARCH REQUIREMENTS

### ELECTRIC MOTOR, POWER ELECTRONICS, GEAR BOX AND ELECTRIC DRIVE UNIT (EDU)

- E-motor
  - Optimization of the dimensioning of electric motors of all suitable types regarding compactness, power and torque density, and efficiency
  - Optimization of cooling systems and requirements (e.g., direct liquid cooling of the rotor and stator)
  - High speed machines (good performance-volume ratio), NVH optimization, reduction of losses in the transmission
  - Innovative motor windings: hair-pin, i-pin,… (great manufacturing potential)
  - Cost-effective insulation systems for high-voltage machines (600-1000V) which is necessary for fast or ultra-fast charging
- Power electronics
  - New power electronics based on SiC or GaN with higher permissible operating temperatures and switching frequencies
  - On-board charger (DC/DC- and AC/DC converter) as well as power electronics for inductive charging
- Electric drive unit (EDU)system – "e-axle"
  - Increased efficiency of the overall system (gearbox - motor - converter - control / communication), increased functional safety (e.g. redundancy)
  - Integration Gearbox, E-Motor, Inverter,
    - Cooling system (Inverter, Gearbox + E-Motor)
    - Complex machine models: e.g. for sensor less controls, thermal modeling
    - Simulation of best in dimension / class EDU (match gearbox, inverter, E-Motor)
    - Increased efficiency of the overall system (gearbox - motor - converter - control / communication), increased functional safety (e.g. redundancy)
    - Cyber Security und Functional Saftey
    - Testing (virtual, real, Subsystem and System, Simulation Validation/Calibration)
- Development tools and methods
  - Measurement instruments and test benches for the development of highly integrated electric motors including power electronics (sensors, data management ...)
  - Test equipment for development, test and repair center service of highly integrated e-motors including power electronics
  - Simulation and optimization tools and methods for the development of highly efficient e-motors and their mechanical, electrical and thermal overall system integration

### BATTERY, BATTERY MANAGEMENT, CHARGING AND RECYCLING

- Development of advanced electrode materials. (e.g., capable for high power charging, post lithium technology-all solid state, industrial manufacturability)
  - Both anode and cathode active materials, with a special focus on high-energy electrode materials – (HE cathode material coatings and protective layer coating for pre-lithiated Si anode materials), focus on high-power charging
  - Fundamental research on post-Li technology (Mg-ion, All-solid-state)
  - Optimization of industrial materials production steps (e.g., optical equipment for inline quality inspection)

- Development of improved battery systems and modules based on lithium-ion cell technology with a focus on
    - Capacity and power
        - Increased volumetric energy / packing density while at the same time significantly reducing the overall height
        - Lightweight construction concepts and fully integrated battery housings with improved crash safety
        - Over-the-air update strategies for updating degradation models (based on real driving data) but also optimizing the vehicle operating strategy
        - Predictive operating strategies (e.g., optimal thermal management using predictive cooling)
    - Durability and reliability
        - Improved lifespan especially with regard to cell swelling by optimizing the module design
        - Improved thermal concepts and integration of new materials and cooling media
        - Improved safety, especially regarding avoiding / delaying the thermal runaway (including simulation, test methodology, new constructive approaches and sensors)
        - Components and technologies that contribute to "Battery Safety". (e.g., pyro fuses, heat sinks to reduce thermal runaway, ...)
        - Smart Cells: internal (optical fiber) and external (impedance spectroscopy microchip and thermal) integrated sensors
    - Costs and circular economy (recycling and reuse)
        - Cost optimized battery system development and manufacturing methods and tools, including simulation and test.
        - Interoperability and (downward) compatibility of interfaces (e.g., through adapters) as well as vehicle-to-grid interfaces
        - Implementation of recycling processes and concepts for high number of batteries from old electric vehicles which is expected in the future
        - Modular packaging design (eco-design) for good recycle-ability
    - Development tools and methods
        - Development of quality management and corresponding measures
        - Test systems for the development phase and for testing failure cases and characteristics (e.g., released heat, gas composition and generation rate, toxicity, electrical and thermal behavior as well as ageing)
        - Test and diagnostic devices for new battery systems in the workshop service and in development and testing phases
        - Cell diagnostics: performance degradation (aging) and failure analysis (postmortem and thermal analysis methods)
        - Validation of battery cells and modules (continuous improvement to stay up to date with test procedures)
        - Balancing & Battery Management System (BMS) – (continued improvement of BMS development in line with state of the art and customer demands)
- Development of technologies and solutions for demand-driven charging
    - Fast and ultra-fast charging technology (> 100kW to 350kW)
    - Vehicle (incl. battery) to grid functionality with standardized interoperable interfaces to support the grid
    - Local battery storage to reduce load peaks for the grid
    - Load management solutions to prevent charging load peaks for the grid (incl. wallboxes)
    - Secure reliable scalable charging infrastructure to enable large scale E-Mobility (“sector coupling”)

## VEHICLE SYSTEM INTEGRATION AND THERMOMANAGEMENT

- Interaction of electric powertrain components (including battery) and thermal systems and auxiliaries
- Concepts for waste heat utilization (e.g., heat pump) and heat storage (e.g., latent heat storage)
- Efficiency in conductive energy transmission through reduction of thermal losses: cooling of the charging infrastructure on the vehicle side between the socket and the HV battery, liquid-cooled charging cables and charging stations
- New, innovative, fast-charging heat exchangers / heat sinks for battery packs and modules.
- Innovative complex control concepts for thermal management of the battery and the entire vehicle
- Development of vehicle and operating strategy, simulation and testing environment (e.g., environment, efficiency, driving performance, NVH)
- Virtual and highly automated physical development tools for fast and efficient creation of BEV with lowest possible impact on the environment.
- Vehicle Control Unit hardware and software
    - Development of high performance and scalable hardware with flexible base software concepts
    - Flexible integration platform for cross domain function centralization (e.g.: drive control, brake control, thermal management, charging, operation strategy …)
    - Virtual test environment including virtual control units (ECU) and vehicle plant models

## LIFE CYCLE ASSESSEMENT

- Creation of a reliable data base for optimization of production (knowledge of environmental effects) and for comparing different drive technologies
- Reduction of pollutant and greenhouse gas emissions during the entire product life cycle (from design, development, manufacturing to vehicle usage, second life usage and recycling)
- Recycling / reuse: reuse of components (e.g., second life of batteries, magnets) and reuse of its raw materials