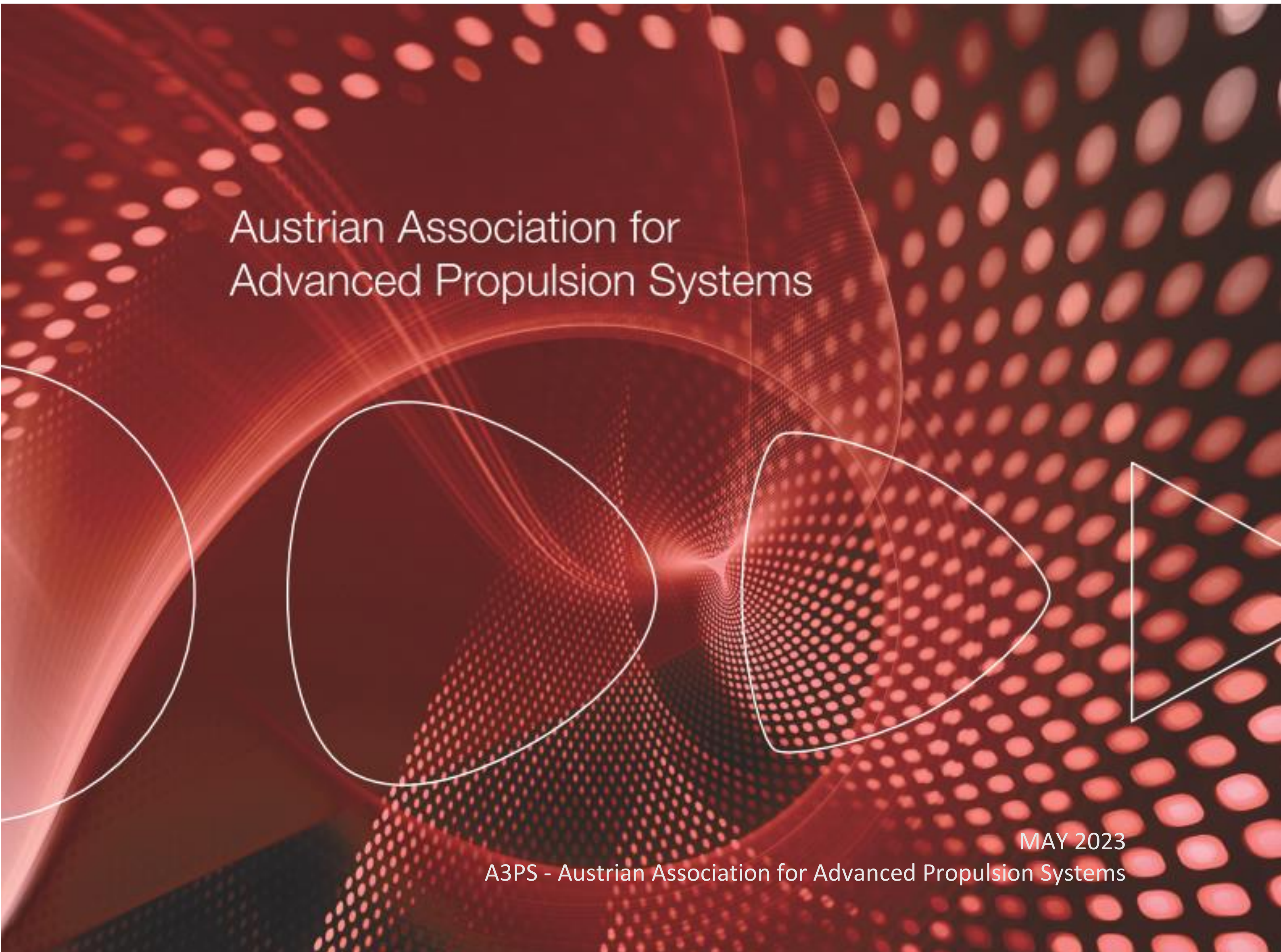
Rethinking Propulsion.

# AUSTRIAN POSITIONS FOR ADVANCED PROPULSION TECHNOLOGIES

A3PS Position Paper R&D Demand 2023+




MAY 2023

A3PS - Austrian Association for Advanced Propulsion Systems

# Content

# Introduction

The present A3PS position paper **"R&D Challenges 2023+"** summarizes envisaged developments and trends, as well as priorities of the industrial and scientific A3PS members. Furthermore an overview of R&D challenges in the coming years and the necessary R&D activities to strengthen Austria as a business location is provided.

A3PS expert groups have updated and identified actions and measures towards a climate-neutral, sustainable, efficient and safe transport system via:

1) **Technology-neutral support of mobility and powertrain innovations** in Austria, taking a holistic view of the value creation process, considering **LCA** requirements ("from cradle to grave") in order to meet the 2030 targets and to enable EU mission 2050 targets in full.
2) **Determination of the need of a legal framework**, norms, standards and a strategy, both for R&D activities, the rapid implementation of R&D results and for regular operation (street / off-road / rail).
3) **Fostering of core competencies** in the field of mobility and powertrain innovations in Austria with a strong focus on value creation in Austria.

The A3PS position papers should support the orientation of national R&D activities and technology policy impulses, as a supplement to those priorities set at European level.

Goal:
To empower the Austrian industry & academia in R&D regarding a global perspective → keep Austria competitive

All R&D topics presented in the A3PS area comprise only $CO_2$-neutral solutions, global oriented

As a "living document", the **position papers** are regularly checked for topicality and revised if necessary. The present position paper provides a **short-term outlook** for 2023-2025 (please see also download at https://www.a3ps.at/a3ps-position-papers

A more extensive list of research requirements including mid-term (2025-2023) and **long-term** (2030+) topics can be found in the **A3PS Roadmap** at https://www.a3ps.at/a3ps-roadmaps.

The position papers cover all advanced propulsion systems: battery electric powertrain technologies, fuel cell technologies and hybrid automotive powertrains with combustion engines using sustainable liquid or gaseous energy carriers. Life cycle assessment serves as method to find the best solution for different mobility applications depending on available energy carriers.

A technology-neutral approach considering all sustainable technologies is essential to reach the ambitious climate goals. This includes sustainable energy carriers also for the existing fleet of vehicles. In contrast, narrowing down the technology options for a GHG-neutral road sector available delays the ramp-up of a carbon-neutral vehicle stock and leads to higher than necessary cumulated GHG emissions by 2050.[1]

---

[1] FVV (2022), "Future Fuels: FVV Fuel Study IVb: Transformation of Mobility to the GHG-neutral Post-fossil Age", https://www.fvv-net.de/fileadmin/Storys/Wie_schnell_geht_nachhaltig/FVV_H1313_1452_Future_Fuels_FVV_Fuel_Study_IVb_2022-12.pdf, retrieved 8 May 2023

## Circular Economy

Circular economy must be considered in all technology sectors. This increases the research demand since beside of functional efficiency, safety, security, durability, etc., recyclability and second life must be considered. This is essential for the overall vehicle, components, batteries, bearing parts, etc.

A circular economy is "a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible".[2] Circular economy aims to tackle global challenges like climate change, biodiversity loss, waste, and pollution by emphasizing the design-based implementation of the three base principles of the model. The three principles required for the transformation to a circular economy are: eliminating waste and pollution, circulating products and materials, and the regeneration of nature. Circular economy is defined in contradistinction to the traditional linear economy.[3]

As climate change increasingly highlights the limits of the environmental devastation of a linear economy, many companies and consumers are moving towards implementing a global circular economy[4], which is a systems solution framework tackling issues such as waste, pollution, and diminishing biodiverse ecosystems. The 9R's are a circular economic framework that examines how materials can be used and reused at their highest value while minimizing waste and environmental destruction. They are *Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle* and *Recover.*[5]

## A3PS – Austrian Association for Advanced Propulsion Systems

A3PS, founded in 2006 as initiative of Austrian ministry of technology, discussed, phrased and prioritized with members from industry and research institutions the contents of this position paper in early 2023. A3PS is the **strategic platform** of the Austrian technology policy, industry and research institutions and stimulates the development of advanced propulsion systems and energy carriers – to build up common competence and to accelerate market launches.

A3PS addresses all **advanced powertrain technologies** contributing to the improvement of energy efficiency and to the reduction of emissions and supporting the whole innovation cycle (research, development, deployment).

A3PS members congregate in four thematic expert groups. These expert groups elaborate positions, trends, R&D demands and demands concerning the essential legal framework for prospective technologies as for this document.

A3PS's goal is to empower the Austrian industry and academia in R&D regarding a global perspective in order to keep Austria competitive. All R&D topics presented in the A3PS area – such as this positon paper – comprise only $CO_2$-neutral solutions, global oriented.

---

[2] https://www.europarl.europa.eu/news/en/headlines/economy/20151201STO05603/circular-economy-definition-importance-and-benefits, retrieved 8 May 2023
[3] https://ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview, retrieved 8 May 2023
[4] https://medium.com/topangasupply/defining-circularity-is-sustainable-a-dirty-word-a47bb5ce5ef9, retrieved 19 April 2023
[5] https://www.topanga.io/post/how-the-9r-framework-can-change-our-economy, retrieved 19 April 2023

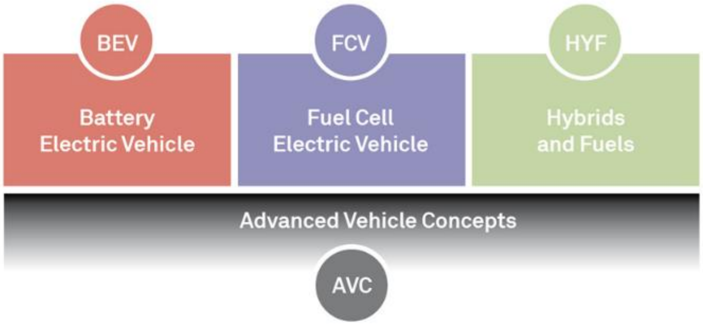



*Fig. 1: 4 A3PS thematic expert groups*

## BEV – Battery Electric Vehicle

Expert group BEV focuses on strong scientific and informative public relations work about **battery electric vehicles**. The group analyses strengths and weaknesses of battery electric vehicles and points out research and development needs.

## FCV – Fuel Cell Electric Vehicle

FCV expert group's focus is on hydrogen **fuel cell electric vehicles**. Besides, the group also deals with **hydrogen** production, infrastructure and storage, since sustainable production, price and availability of hydrogen play a key role for the success of fuel cell vehicles.

## HYF – Hybrids and Fuels

Expert group HYF concentrates on the identification of needs for research on efficient **hybrid** technology, **sustainable energy carriers** for vehicles as well as **internal combustion engines**. The strengths of Austrian institutions in this field are discussed and highlighted.

## AVC – Advanced Vehicle Concepts

Expert group AVC deals with **advanced and future vehicle concepts** comprising **new lightweight materials, innovative production technologies & digitalization of processes** and **digitalization & automation of vehicles and infrastructure**. The group links to the other three expert groups and focuses on a system perspective and integration.

# R&D Challenges: Battery Electric Vehicle 2023+

## Position

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

Technologies currently used in series production still need innovation to achieve lower cost, higher efficiency, performance and solutions for circular economy. Further research and developments are required regarding the functionality and efficiency of the drivetrain components as well as for manufacturing technologies and production processes in order to be able to deliver competitive and sustainable 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)[6] and advanced development methods and tools (e.g. co-simulation, data analytics, AI, ML) are used to reach these high-level goals.

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

## Requirements on Technology Development and Research Demand

### Energy Storages

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, the early detection and avoidance of critical errors in the battery system and drive train, the necessary expertise (cell chemistry, manufacturing process, cost structure, low environmental impact) 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 safe 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, but also higher voltage solutions such as NMO (Nickel Manganese Oxide) materials for cells voltages above 4.5V; Si-graphite composite based anodes and pure silicon anodes) as well as 4 (solid-state dominated) and 5 (post-Lithium chemistries e.g. Na-Ion).

---

[6] Software in the Loop (SIL), Model in the Loop (MIL), Hardware in the Loop (HIL), Vehicle in the Loop (VIL)

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. Battery technology to enable fast charging capability to reach charging times in comparison to combustion engines pump stop in the area of 5-10 minutes. This includes the reduction of the carbon footprint of the cell production in particular, which has major opportunities to lower energy demand as well as the need for (toxic) organic solvents.

## Electric Components

### *(High) Voltage Level BEV System*

**High-voltage systems** with voltage levels towards 1200 V and above enable a significant increase in performance. Additionally, high-voltage systems enable the **implementation of ultra-fast charging** of BEVs – getting close to refueling a vehicle with an internal combustion engine. 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 conductor 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 to design high-voltage systems properly.

The necessary **cost-efficient insulation systems** and adjacent cooling system, to optimize package and enable higher integrated sub-components, still **needs to be developed** for the automotive industry.

**Further innovation activities** must be focused on highly automated manufacturing and assembling processes (e.g. winding technologies), alternative E-Motor technologies (e.g. SSM), power electronics, control algorithms 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 depends on the respective application and, among other things, on cost, volume (package on vehicle level) and efficiency requirements. An important aspect is the possible **avoidance of critically materials** (avoiding monopoles, etc.). The **highest levels of efficiency** guarantee the optimal use of the battery load and therefore driving range. **E-Motor research** 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 high power-to-volume ratio is crucial.

Due to the outstanding vehicle and consumer requirements to affordability, convenience, traction and safety, a large number of machine designs for different types are possible, which needs remarkably high R&D requirements. The R&D efforts include the optimization of the E-Motor (compactness, power and torque density) and the system level (E-Motor - converter - control and communication), addressing the unsolved problems of optimal system design. Equally, also the manufacturing and assembling excellence and the necessary functional safety and system (cyber) security.

There are **special tasks also in the field of transmission** (NVH, lubrication, bearings, shaft sealing, actuation (with several gear ratios), loss minimization, torque vectoring, park lock, etc.) and direct liquid cooling of the rotor and stator using a single cooling circuit, which must be solved. E-motors must have particularly good controllers at speeds of around zero up to highest levels. High dynamic torque vectoring capability, the generated vibrations and the resulting noise-level are 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 rather new semiconductor materials** such as silicon carbide (SiC) and gallium nitride (GaN) and the construction of integrated power modules is of high interest. It's higher switching speeds and better thermal performance allows for higher operating temperatures as well as **lower losses** especially in partial load conditions, thus enabling **new (cheaper) cooling** system solutions as well as more **highly integrated powertrain concepts**. Also, the aging and reliability 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. The perfect match of the passive components to the new electronic circuit performances needs further development of them.

The amount of **auxiliary power electronic components** in the vehicles is rapidly increasing. DC-DC converters, Onboard Chargers, HVAC, Comfort Devices, Devices for automated driving etc. play an increasing role in vehicle developments. To compensate the energy demand of the devices, the **efficiency** of all **power electronic components** in the vehicle must be increased and 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 and (cyber) security. The vast R&D amount to tackle and secure the 9R concept will be explained in a separate capital of this paper.

### *Vehicle Control Unit – Hardware and Software*

Almost all vehicle manufacturers are planning to change their E/E vehicle architecture from a decentralized function-oriented to a zone architecture. The detailed design of the E/E architecture itself is very OEM-specific with partly diverse requirements.

This transformation requires new scalable and high-performance HW platforms that rely on µ-controllers as well as on µ-processor technologies with the ability for a scalable partitioning from software functions to hardware resources.

Software functions are no longer tied to a specific hardware (VCU) and software domain but are flexibly distributed across different software integration or hardware platforms, depending on the E/E architecture selected. The implementation according to standards (e.g. AUTOSAR, COVESA, etc.) and the use of harmonized interfaces and exchange formats (containers) for sw function, are essential for a flexible cross-domain integration.

In the area of connectivity (V2G), the future focus will be on the implementation of cross vehicle-cloud functions. The seen trend is to implement demanding optimization algorithm on a backend server (off-board) used for predicted functions, thermal system control, component health management. This reasons a continuous data exchange with requirements regarding safety, reliability, and real time as well as service-oriented communication between vehicle and cloud ("open vehicle API"). The development of open standards and technologies that accelerate the full potential of connected vehicle systems are in focus of future research and innovations.

### Charging Technologies

As the **focus** of this Position Paper **is the Vehicle**, the R&D requirements listed here refer to charging from vehicle perspective including the connection of a vehicle with the charging station but not the electric grid.

Vehicle traction batteries are charged with DC voltage. BEVs have AC and/or DC charging interfaces. AC charging typically takes place at lower power levels (<22kW), mostly in a private environment or at the workplace (during longer vehicle standstill periods). Thereby, an on-board charger converts AC to DC for battery charging. When vehicle traction batteries are currently charged fast, energy with high power (typically 100 kW and more) is transferred via a suitable interface using direct voltage (DC). DC charging usually takes place on the road – at parking lots or service/filling stations – to obtain the necessary energy to reach the destination. 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 and software protocols, simple authentication, and billing. This consequences in a high R&D demand on the one hand and demand for harmonization on the other hand.

The charging time of a car and truck is a relevant parameter and will become more important in the future. High-performance personal car DC charging systems are expected to reach power levels of 1MW – new solutions for power electronic modules with multiple specific features will allow to reduce the footprint of such systems. A draft of the charging interface MCS (Megawatt Charging System) for trucks was presented in 2022 and is expected to enable a charging capacity of almost 4MW. For personal car and truck systems, there is a particular need for research into system configuration/integration. Future high-performance charging interfaces must be further developed. The extremely high charging currents require innovative solutions to avoid high conductor/power-line cross-sections and thus increasing costs and weight. Furthermore, solutions for cooling these conductive charging systems need to be researched.

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 that enables the high share of battery electric mobility in the future.

### Thermal Management and Energy Management

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).

As the number of battery electric vehicles in real-world operation increases rapidly, the availability of in-vehicle/fleet data also increases. An important research topic in this context is the development of concepts and algorithms, which enable an update of battery performance and degradation models, which are typically used for remaining useful life (RUL) prediction, based on fleet data. Specifically, ageing prediction models that are typically parameterized with laboratory data from accelerated ageing tests can thus be improved significantly and a cloud-based digital twin of the battery can be created. Depending on the vehicle use, environmental conditions, topography, driver, etc. the operating (energy and thermal management) and charging strategies can thus be optimized (even for individual vehicles) in order to mitigate degradation (or predict/prevent early failure) and extend battery lifetime.

## 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 reuse, 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.

## Life Cycle Assessment and Circular Economy

Life Cycle Assessment (LCA) of BEVs, applied already during the design phase, involves a large range of influencing factors, such as

- electricity supply (incl. intermediate storage of fluctuating renewable electricity) for BEV operation
- energy supply for battery manufacturing (share of renewable energy sources)
- cell chemistry and related extraction and refining of critical raw materials (e.g. Nickel, Cobalt, Lithium)
- production of materials for battery casing (e.g. Aluminum)
- Electric motor (e.g. rare earth metals).

But also end-of-life treatment of EV batteries influences their life cycle performance. Especially in Europe, battery recycling is an important element to (partly) close "critical" material cycles. However challenges such as (global) used-battery collection, the diversity of cell chemistries as well as metallurgical material recovery rates remain to be solved. Direct recycling, defined as the recovery, regeneration, and reuse of battery components without breaking down the chemical structure, is another important end-of-life strategy that needs to be developed towards the target of a true circular economy in this field. The method of LCA is currently developed to include KPIs (key performance indicators) for circularity.

## Research Requirements

The research requirements listed below are expected to be most relevant within a short-term perspective (2023-2025).

A more extensive list of research requirements including mid-term (2025-2030) and long-term (2030+) topics can be found in the A3PS Roadmap "Austrian Roadmap for Sustainable Mobility – a long-term perspective, Version 2022 (https://www.a3ps.at/a3ps-roadmaps).

### 1. Energy Storages

#### (Structural) Battery Integration from cell to pack to battery system

- High Voltage (up to 1500 V) on pack level with Li-Ion (NMC, LTO, LFP) and higher voltage (more than 4.5V) at cell level
- "Stop thermal propagation" design & simulation
- Short circuit automatic release concepts of DC-separator (e.g. by smart, integrable current sensors)
- Battery management system and battery diagnostics
- Second life applications and design for reuse and recycling
- Optimized integration of real and virtual sensors and diagnostics
- C2S (Cell-to-Structure) integration concepts with higher energy density, long service life and improved re-usability/recyclability
- Structural battery cells (e.g. for aeronautic applications)

- Long service life → Low TCO
- Thermal management (reduced temperature sensitivity) of state-of-the-art batteries and new battery concepts

### Advanced Lithium-Ion Batteries 3rd and 4th generation as well as advanced Battery Technologies

- Both generations
  - Avoiding toxic materials and scarce resources
  - Self-healing materials
  - Higher cell voltage (more than 4.5V)
  - Advanced cathodes & anodes (e.g. pure Si-anodes for 3rd gen.)
- 4th generation Solid State Batteries
- Cell design (material optimization, reproducibility, …)
  - Multilayer cells of several Ah
  - Interface investigation for ageing and Li dendrite growth
  - Manufacturing processes, research and production pilot lines
  - Adaptable processes to existing 3rd generation manufacturing processes
  - Material research (conductivity, electro-chemical stability, usable at temperatures below 60°C and also up to and above 100°C, sulphide and halide solid state electrolytes)
  - Polymer based electrolytes with ceramic fillers
- Advanced Battery Technologies beyond Li – Cells and Modules
  - Multivalent and low-cost ion batteries (e.g. Mg-, Ca-, Na-, Al-ion)
  - Metal-oxygen (metal-air) batteries, Oxygen-ion batteries
  - Aluminum-Graphene batteries
- New Methods and Materials to Improve Performance, Cost and Environmental Impact
  - Assembly and joining process technologies
  - Improved electrical power connection and control (Conductor Materials, Copper Replacement with Aluminum)
  - Green manufacturing and reduction of carbon footprint and energy need during production
  - Highly safe batteries
  - Multiscale modelling (material, cell & system level, processing)
  - Battery design, processes & strategies for recycling and 2nd life

## 2. Electric Components

### Electric Motor

- Advanced materials and manufacturing technologies for cost effective and sustainable E-motor designs
  - Advanced material designs for hard-magnetic materials insulation materials, light-weight conductor materials
  - New 3D magnet shapes and related manufacturing processes
  - Reuse / second use / recycling concepts (system/component analyses, standardization, simulation, assessment and testing, state-of-health tracking with digital twins)
  - Joining, winding and insulation technologies (up to 1500 V) as well laminating and sheet stamping technologies for HV E-motor applications

    - Assembling and disassembling concepts (e.g. in line /closed loop/high automation processes, IIoT[7] concepts)
- Advanced models for powertrain simulation
    - Power electronic components
    - Multiphysics motor simulation (e.g. thermal, electromagnetic, mechanical)
    - Powertrain system optimization
    - Material data driven FEM (Finite Element Method) of components for second life or reuse applications
- Advanced E-Motor architectures and topologies and advanced transmission architectures
    - Functional safe designs for high speeds > 20.000 rpm
    - Novel magnetic encoders/polewheels/resolvers
    - Motors with non-critical materials, e.g. Heavy Rare Earth Element (HREE ) free or non-permanent-magnet E-Motor topologies including Induction and electrically excited motor designs
    - Axial flux technology and in-wheel E-Motors
    - HF-PWM (High-Frequency-pulse-width-modulation) E-motors (e.g. new insulation concepts for primary and secondary insulation)
    - NVH optimization
    - Single Speed with high reduction ratios and 2-speed & multi speed transmissions
    - Advanced cooling concepts (e.g. direct slot cooling, embedding, direct active part cooling or 2-phase cooling or single fluid)
- Advanced Testing and validation methods beyond current standards
    - Partial discharge testing of components and insulation aging
    - Effect of e.g. hairpin forming processes on insulation performance
    - Alternative Peel-off test methods round copper wire

### Vehicle-, Motion-, Drive- or Powertrain-Control, Software & Hardware

- New software and hardware functions & services to enhance safety, security, cyber security, range, comfort and drive ability with continuous and active software maintenance over live time (continuously maintained vehicle)
- Enlarged use of AI methodology and digital twins for predictive and model-based control functions and component maintenance
- Real time health monitoring methods and data management of components and EDUs for reuse applications
- New testing and validation methodologies und systems (e.g. continuous testing, SIL)
- Development of open standards and technologies (vehicle API, vehicle services) to expose and enabling the access to vehicle data (vehicle individual and fleet).
- Software integration platforms efficient for flexible deployment of software functions on different control units.
- Motion/Drive-Controller hardware capable for future demanded applications and extended use of AI methods

[7] IIoT: Industrial Internet of Things

### Inverter, Power Electronics

- Advanced materials (e.g. printed circuit boards, housings, capacitors) and advanced manufacturing technologies
  - Material and component design for reusability and recyclability
  - Jointing technologies
  - High automation assembling technologies for high volume inverters and power modules including disassembling and recyclability (decrease cost, increase quality)
- Increase of performance and packaging density
  - PCB integration of electric components
  - miniaturize passive electronic components
- Advanced wide-bandgap semiconductors
- Improvement of electromagnetic interference and induction for achievement of EMC (electromagnetic compatibility) and reach efficiency goals
- Advanced complex control algorithms (e.g. self-learning adaptive algorithms, model-based controls)

## 3. Charging Technologies

- Comfort charging and automated charging systems (conductive or inductive charging)
- High Power DC-charging up to 1000 kW (passenger vehicle), >1000 kW (heavy duty vehicle) @ high voltage up to 1500 V
  - compact cooling solutions
  - System integration/configuration
- AC Charging <50 kW (conductive)
  - Increase power density / combine functions of on-board-charger
  - Integrated charging
  - Vehicle-to-Home, "home-storage on wheels" – sector coupling
  - Charging authentication & payment PnC (plug-and-charge)
- Integration of electric cars into power grid as mobile energy storage device (V2L - vehicle-to-load)
  - Functional integration in Operating strategies

## 4. Thermal Management and Energy Management on BEV Level

- Access to relevant vehicle information for charging in cooperation with Cooperative, Connected Automated Mobility (CCAM)
  - Use case definition for personalized route planning and charging strategy
- Predictive energy/thermal management of cabin and powertrain components (human behavior)
- Silent cooling and heat loss recovery during High Power Charging (HPC)
- Usage pattern identification from vehicle-fleet-data to derive vehicle and component requirements and optimize system layouts.
- Methodologies for update and optimization of operating strategies based on vehicle-fleet-data
- Energy management on subsystem and system of system's level
- Cloud-based digital twin
  - Over-the-air update strategies for battery degradation models
  - Adaptive operation strategies

## Estimated National R&D Project Volume for “Battery Electric Vehicle”

Starting in 2023, an annual volume of 80 M€ is estimated for R&D projects on battery electric vehicles. The list below is an assessment of project types needed to cover all topics from basic to applied research, demonstration and R&D infrastructure:

- 8 M€ for low TRL research: 8 projects à 1 M€
- 22 M€ for applied & cooperative research: 11 projects à x 2 M€
- 30 M€ for flagship projects or a cluster of flagship projects: 2 projects à 10-20 M€
- 20 M€ for F&E infrastructure (e.g. testing, pilot production, technology laboratory) excl. COMET, CD-Lab, public infrastructure)

This **total R&D project volume of 80 M€** should be supported with a **funding volume of about 40 M€** considering an average funding rate of about 50 %.

Suggested allocation of projects/funding volume defined above to the research areas in this chapter:

| | | |
|---|---|---|
| 1. | Energy Storages: | 3/10 |
| 2. | Electric Components: | 3/10 |
| 3. | Charging Technologies: | 2/10 |
| 4. | Thermal Management and Energy Management | 2/10 |

# R&D Challenges: Fuel Cell Electric Vehicle and $H_2$ 2023+

## Requirements on Technology Development and Research Demand

Hydrogen and fuel cell technology in Austria offers the opportunity to implement the energy transition quickly and efficiently, to expand and use the country's own renewable resources in addition to the import of renewable hydrogen to make an important contribution to greenhouse gas reduction, air pollution control and noise protection - especially in metropolitan areas. Additionally, the external trade balance can be improved while creating higher added value as well as new jobs in Austria.

In order to harness these advantages of fuel cell and hydrogen technologies in and for Austria, this technology needs political support and investments in grants, technical assistance and R&D tools, also including measures for market ramp-up. These are recommendations for actions for the period up to 2025:

- Strengthening Austria as a location by building up hydrogen and fuel cell industry
- Increase of research funding for hydrogen and fuel cell technologies and create a specialized funding instrument with a separate budget focused on R&D of all types of electrolyzers, hydrogen on-board storage and fuel cells
- Accelerated expansion of renewable electricity generation for hydrogen production
- Certification system for green hydrogen - as hydrogen generated by renewable energies
- Decentralized / regional approach to enable use, grid system release and balancing
- Simplified and standardized approval procedures for hydrogen refueling stations and facilities
- Expansion of the hydrogen refueling infrastructure for cars, buses and trucks
- Incentives (e.g. CAPEX (Capital Expenditures) tax and long-term amortization and OPEX (Operational Expenditures) tax type, toll) for the fleet development of fuel cell vehicles that compensate the current additional costs compared to conventional drives
- The Austrian Hydrogen Strategy should strengthen the role of mobility in R&D and also in the roll-out of hydrogen with measures for infrastructure and vehicles implementation for a wide-field of applications (passenger cars, light duty vehicles, heavy duty trucks, busses, trains, aviation, off-road applications etc.)
- A specialized funding instrument with a separate budget focused on hydrogen mobility applications should be installed by the government
- Support for building up references with industrial relevance (fleet size, high number of hours of operation etc.) for various applications in the field and real-world environment

## Position

**Green hydrogen** enables an integrated, efficient and socially sustainable energy system. To achieve the climate goals agreed in Paris in 2015, our energy system must be **carbon-neutral and defossilized**. As a result, EU has defined 2050, Germany 2045 and Austria 2040 as target years for achieving climate neutrality. Green electricity and green hydrogen are zero-emission and carbon-free energy sources for this **energy transition**. They allow climate-neutral product cycles and offer a significantly higher level of efficiency and thus lower energy consumption compared to conventional systems. **Hydrogen is the key to expanding renewable electricity**

**production** from wind, water and sun, as excess energy is used and long-term and efficient energy storage is made possible. Hydrogen enables the different energy and usage sectors (household, industry and mobility) to be interwoven, and at the same time offers the necessary flexibility and grid stabilization for energy systems with a high proportion of renewable energy. As the future energy system relies more heavily on renewables, hydrogen will also play a growing role in integration and storage of renewable electricity. Hydrogen allows to store and transport renewable energy efficiently over long periods of time and is therefore a key enabler of the transition to renewable energies. Hence, it will be also available in large quantities **for mobility**. Fuel cell electric vehicles in combination with hydrogen are offering a possibility for a completely decarbonized mobility system and are perfectly suitable when criteria like long range, high-power, high-energy consumption and fast refueling are targeted.

The European Commission's timetable earmarks net-zero **greenhouse gas** emissions **in 2050**. For this, the conversion of the transport sector from currently over 90% fossil-based mobility to electromobility offers the greatest prospect of success. Action is needed for on-road and off-road vehicles (e.g. 2-/3-wheelers, passenger cars, commercial vehicles incl. heavy/long-distance traffic and off-road applications). The on-board storage of hydrogen in a high-pressure or cryogenic storage system enables significantly higher power densities and therefore higher ranges can be achieved with short refueling times (within similar time requirements as for conventional fuels). For high performance and long ranges, what is of central importance for electromobility for heavy/long-distance transport, electromobility with **Fuel Cell Electric Vehicles (FCEVs)** offers the drive concept of choice. Hydrogen fuel cell vehicles are **locally emission-free** electric vehicles. In particular, **electric vehicles with PEM** (polymer electrolyte membrane) **fuel cells** in combination with **green hydrogen** are of essential importance because they feature **lowest greenhouse gas emissions (GHG)** of all vehicle concepts over the entire life cycle when high driving range is required (production, operation, recycling).[8,9] Moreover, fuel cell vehicles feature potential to achieve competitive costs at high production volumes[10,11] and guarantee ecological advantages regarding rare resources as well as recycling and low emissions of the whole life cycle. However, high improvement potentials especially concerning overall efficiency, costs, industrialization, materials etc. are still existing.

The promising application of high-temperature fuel cells (SOFCs), which can be operated with hydrogen or other renewable fuels, could be used in heavy-duty road and rail vehicles as well as in ships. In any case, every fuel cell vehicle is an electric vehicle. The fuel cell permanently delivers electric power to the high-voltage buffer battery that can be kept much smaller than for pure battery electric vehicles. This synergy allows a favorable vehicle operation including the recuperation of braking energy.

With a small amount of refueling stations, hydrogen enables a nationwide coverage. **Hydrogen** is safely stored at the refueling station and, as with fossil fuels, high refueling capacities are possible. For a nationwide supply of **hydrogen** there are **significantly lower**

---

[8] Umweltbundesamt: *Ökobilanz alternativer Antriebe*, 2018.

[9] Fraunhofer ISE: *„Treibhausgas-Emissionen für Batterie- und Brennstoffzellenfahrzeuge mit Reichweiten über 300 km“*, 2019.

[10] Salman, P.; Wallnöfer-Ogris, E.; Sartory, M.; Trattner, A. et al., "*Hydrogen-Powered Fuel Cell Range Extender Vehicle – Long Driving Range with Zero-Emissions*," SAE Technical Paper 2017-01-1185, 2017, doi:10.4271/2017-01-1185.

[11] Thompson et al: *Direct hydrogen fuel cell electric vehicle cost analysis: System and highvolume manufacturing description, validation, and outlook*, Journal of Power Sources 399 (2018) 304–313, Elsevier, 2018.

**infrastructure investments** than for battery electromobility, which require a higher number of charging stations.[12]

**Power-to-X:** PEM-electrolyzers, powered by renewable energy sources, allow the production of large amounts of green hydrogen, which may be used for the conversion of $CO_2$ to e-fuels, e-methanol and e-methane as well as for the synthesis of ammonia. Additionally, the combination of high temperature electrolysis[13] of $H_2O$ or co-electrolysis of $CO_2$ and $H_2O$ with suitable processes allows the production of these green energy carriers with high efficiency. Required are powerful and aging resistant catalysts, but also innovative LOHC-materials, and efficient polymer- und ceramic membranes for the purification of hydrogen. Solid oxide electrolysis cells (SOECs, PCECs) need new oxygen and proton-conducting ceramic materials (electrodes, electrolytes) with reduced amount of critical raw materials (rare earths) but increased power density and long-term stability, also for operation at lower temperatures.

In general, there is a strong need for research and development of scalable electrolysis (incl. efficient auxiliary units), powered by renewable energy sources like wind, solar or hydropower. Regional and local production of green hydrogen and other energy carriers by electrolysis will significantly contribute to supply hydrogen refueling stations and pipelines.

**Location Austria**: Austrian industry, research institutes and universities have been active for a long time in research and development of fuel cell and hydrogen technologies. Now, developments must be continued, accelerated and results need to be transferred to the market. Overall, the hydrogen fuel cell is the appropriate zero-emission technology for Europe and especially for Austria, because the existing know-how, the production technologies, the industrial and economic sectors as well as the available resources offer ideal conditions for this technology. The training and teaching of this subject area must also be pushed further. In addition to courses, academic theses are an excellent way to create optimal training in this field and to support research.

Specific **research demand** on FCEVs primarily pertains to the further reduction of **costs** and the further increase in **lifetime** and **efficiency**. In addition, the entire production, distribution and user chain based on renewable energies must be optimized regarding maximum efficiency and lowest costs. There is a **need for research funding** for all types of fuel and electrolysis cells, from cell and stack level to complete systems, vehicle concepts, system concepts, hydrogen storage technologies and development tools, as well as measurement and testing technology, and the establishment and expansion of the laboratory infrastructure required for this. In addition to R&D, support for building up references with industrial relevance (fleet size, high number of hours of operation etc.) for various applications in the field and real-world environment is urgently required.

## Life Cycle Assessment and Circular Economy

Life Cycle Assessment (LCA) of FCEVs involves a range of influencing factors, such as hydrogen production (incl. use of co-products oxygen and heat as well as system integration, e.g. grid services) for FCEV operation, which can be supplied by various conversion processes and primary energy sources, the system energy efficiency of hydrogen production and use in the fuel cell, the manufacturing of the FCEV propulsion system and related extraction and refining

[12] Robinius, M.; Linsen, J.; Grube, T.; Reuß, M.; Stenzel, P.; Syranidis, K.; Kuckertz, P. & Stolten, D.(2018): *Comparative Analysis of Infrastructures. Hydrogen Fueling and Electric Charging of Vehicles*

[13] Sitte, W.; Merkle R., (Eds.), *High Temperature Electrolysis - From Fundamental to Applications*, IOP-Publishing 2023

of (critical) raw materials, and the lifetime of the fuel cell in the operation phase. During the life cycle increasing requirements on service, repair and upgrading demands need to be considered to optimize resource and energy usage over lifetime and beyond. End-of-life aspects include vehicle and fuel cell recycling as an important element to (partly) close (critical) material cycles. Additionally, the environmental effects of carbon fibers (CF) for $H_2$ tank systems, and the end of life of CF like reuse and recycling are essential to be analyzed in consistent LCA. In general, a detailed circular economy approach has to be developed for FCEVs.

## Research Requirements

The hydrogen and fuel cell technologies are now in a process of accelerated development, indicating that there is considerable need for research and development with respect to optimization in the long term, particularly in terms of costs, lifetime and efficiency. The research and development needs of the near future (2023-2025) include the following topics (alphabetical order):

- Development tools, measuring and testing technology
    - Optimized test procedures and test benches for all types of fuel cells, electrolyzers and hydrogen storage technologies and their BoP (balance of plant) components
    - Simulation tools and development methods
- Electrolysis (all types) - cell, stack, system and systems coupled with renewable energies
    - Materials and production technologies
    - Process management and control
    - Inexpensive and efficient auxiliary units (BoP components)
    - Hydrogen purification and distribution for mobile applications
    - Optimize coupling of electrolysis with downstream synthesis for renewable fuel production (e.g. e-fuels, e-ammonia, e-methanol, SNG (synthetic natural gas), …) in terms of efficiency, scalability, lifetime and durability
- Fuel cell (all types) - cell, stack and system
    - Materials and production technologies
    - Process management and control
    - Affordable and efficient auxiliary units (BoP components)
- Fuel cell vehicles for various applications ranging from passenger cars via commercial vehicle to off-road vehicles
    - Fuel Cell system optimization in terms of efficiency, lifetime, and durability
    - System and vehicle integration - spatial and functional integration
    - Thermal and energy management
    - Control and regulation of the entire drive train (battery, power electronics etc.)
    - Evaluation of crash situations (Emergency Response Management)
    - LCA, Recycling Concepts, Life cycle optimization
    - Impact of new Eco-design Regulation

- Functional Integration and secure packaging
    - Development of crash models of relevant storage and fuel cell systems
    - LCA, Recycling Concepts, Life cycle optimization
    - Impact of new Eco-design Regulation
- Hydrogen refueling infrastructures for all vehicle categories
    - Process management
    - Safety-related communication between HRS (Hydrogen Refueling Stations) and FCEV
    - Logistics (distribution and storage of hydrogen)
    - More reliable and efficient components and systems
- Hydrogen storage technologies for mobile and stationary applications
    - Materials and production technologies
    - Inexpensive components with low carbon footprint
    - Technologies to provide higher fuel supply pressure if required
- Laboratory infrastructure for research and development work including real-gas, real-size testing infrastructure for hydrogen systems and components with focus on supplier industry

### Requested National Funding Instruments for “Fuel Cell Electric Vehicle and $H_2$”

The topics defined above follow the specific strengths of the Austrian R&D community in this field. Nationally funded research programs should help to further strengthen this know-how and expertise, thus preparing the path for successful participation in European programs such as Clean Hydrogen Europe, the Hydrogen IPCEI or the European Clean Hydrogen Alliance. National programs should also serve as a basis for the development of products to be produced in Austria following-up EU funded projects. Existing national programs such as the Mobility of the Future, the Energy Model Region WIVA P&G or the Energy Research Program have existed in the past and should also be realized in the future as a preferred platform for projects using the following instruments:

- Cooperative projects of oriented basic research
- Cooperative R&D projects, experimental development and industrial research (Fundamental research with low TRL for knowledge expansion, industry-related research for knowledge transfer)
- Flagship Projects (industry-related research for knowledge transfer)
- R&D infrastructure funding (support of laboratory infrastructure)
- Infrastructure funding for demonstration of large fleets
- Funding for participation: creation of an EU-wide legislative framework as well as directives and standards

## Estimated National R&D Project Volume for “Fuel Cell Electric Vehicle and $H_2$”

Starting in 2023, an annual volume of 60 M€ is estimated for R&D projects on fuel cell electric vehicles and hydrogen. The list below is an assessment of project types needed to cover all topics from basic to applied research, demonstration and R&D infrastructure:

- 10 M€ for cooperative projects of oriented basic research: 10 projects à 1 M€
- 10 M€ for cooperative R&D projects, experimental development and industrial research: 5 projects à 2 M€
- 30 M€ for Flagship Projects: 3 projects à 10 M€
- 10 M€ for R&D infrastructure (support of laboratory infrastructure)

This **total R&D project volume of 60 M€** should be supported with a **funding volume of about 30 M€** considering an average funding rate of about 50 %.
Additionally to the necessary funding volume for R&D projects we suggest about 40-60 M€ budget for the implementation of fleets and infrastructure.

# R&D Challenges: Hybrids and Sustainable Fuels 2023+

## Trends on Technology Development and Research Demand

Although this position paper focuses on the automotive sector with on- and off-road vehicles, other mobility sectors such as aviation and inland/maritime shipping will also benefit from the research addressed in this section - particularly on sustainable fuels (sustainable aviation fuels (SAF), sustainable fuels for ships).

**Hybrid powertrains** fueled **with sustainable, renewable liquid and gaseous fuels incl. hydrogen** – i.e. biofuels and so-called RFNBOs (renewable fuels of non-biological origin)[14] – are highly efficient and very well suited for applications where long ranges and short refueling times are of major importance. Small batteries and largely mechanical components of hybrid powertrains lead to a low environmental impact during production and recycling. As a result, hybrid powertrains can very effectively contribute to achieving climate-neutral mobility.

Therefore, research must focus on further improvements of hybrid powertrain and vehicle efficiency and at the same time on fuels with low pollutant emissions and low (fossil) carbon intensity in the life cycle. Such improvements directly contribute to the reduction of GHG and pollutant emissions in the short and medium term. Today, vehicles powered by sustainable chemical energy carriers (renewable liquid and gaseous fuels and hydrogen) can achieve as low GHG emissions as electric vehicles based on the current carbon intensity of national electric power generation mix. Another important aspect of liquid sustainable fuels is that they can be used in existing vehicles as part of the existing fuel supply infrastructure, and their use has an immediate positive impact on the GHG balance. In addition, the use of hydrogen in internal combustion engines (as well as turbines) can help to increase the demand for hydrogen as a transport fuel in the near future. This could make a hydrogen network and hydrogen refueling stations economically viable much sooner.

Fuel-side measures have a high potential for reducing GHG emissions. First, there is the possibility to increase blending ratios of conventional biofuels such as FAME biodiesel and ethanol, leading to immediate further reduction of GHG emissions. Secondly, sustainable advanced biofuels can be based on a broader biological raw material basis and, unlike sugar, starch, oils and fats, are not in competition with food and feedstock production. Residues from agriculture and forestry, industrial residues and waste can be used as raw materials. These fuel paths open new regional value creation potential. However, the corresponding production technologies still need to be developed to market maturity through appropriate R&D and demonstration activities. And finally, RFNBOs, e.g. hydrogen as well as e-fuels from renewable electricity and renewable carbon sources can also be made available as high-quality energy carriers for engines. While these technologies are already quite developed, the respective fuels are not yet commercially produced.

In summary, the following specific research needs for product development for the European and global market (to strengthen the European competitiveness and the European exports) can be identified for the years 2023+:

1) Efficiency improvement of the powertrain system by hybridization, optimal and predictive thermal and energy management, waste heat utilization (e.g. on-board fuel

[14] https://energy.ec.europa.eu/publications/delegated-regulation-union-methodology-rfnbos_en, retrieved 8 May 2023

reforming from waste heat recovery) and loss reduction through electrification of auxiliary units.

2) Continuous development of sustainable fuels - including the efficient production of hydrogen from renewable electricity sources and $CO_2$, or from synthesis gas e.g. by co-electrolysis of $H_2O$ and $CO_2$.
3) Technology research and development on hybrid transmissions to achieve highest powertrain operation efficiency.
4) Overall efficiency improvement of internal combustion engines (ICE) for hybrid powertrains in combination with sustainable liquid and gaseous fuels including hydrogen.

## Essential Legal Framework

As to facilitate the deployment of sustainable fuels and hybrid powertrains, recommendation to policy makers is to:

- Create an EU-wide legislative framework and/with directives for rapid implementation of an efficient and climate neutral mobility, allowing EU-industry the introduction of new technologies resulting from R&D activities described in this position paper.
- Adapt legislation, taxation, codes, and standards, as well as powertrain technologies to allow higher biofuel blends.
- Provide incentives for production or supply of sustainable fuels.
- Adapt the (EU-wide) $CO_2$-regulation to include well-to-wheel GHG emission benefits using renewable energy carriers (biofuels and RFNBOs). This would allow the automotive industry to consider renewable fuels in their targets and would thus encourage the adaptation of ICEs to higher blends of renewable fuels.

These frameworks (i.e., legislation and regulations) should be based on the actual GHG reduction, without favoring specific technologies. This actual GHG reduction depends on the carbon intensity of the energy carriers (fuels and electricity) used and the actual use of these energy carriers in the related vehicles, e.g. plug-in hybrid vehicles that are never charged but always run on fossil fuels do not provide actual GHG emission reductions.

These frameworks also need to be long-term, since otherwise there is great uncertainty for customers and especially for industry and companies. Industry is prepared to make innovative long-term yet very costly investments, but these can only be made on a sound basis.

## Life Cycle Assessment and Circular Economy

Key factor for Life Cycle Assessment (LCA) of hybrid vehicles is the energy demand and efficiency during the entire lifetime of the vehicle from production via operation to recycling. While research focuses on increasing system efficiency, LCA has to consider a “bigger picture”, e.g. taking into account the effect of the additional weight of hybrid vehicles on energy consumption in real world driving.

LCA of biofuels and RFNBOs based on carbon capture and utilization involves a wide range of supply chains of different types of biomass, biomass conversion processes, renewable electricity, hydrogen production, $CO_2$-sources and separation technologies. LCA-results are therefore highly influenced by the $CO_2$ source and the degree of process integration and system efficiency. On top of traditional LCA, also dynamic LCA should be conducted, to assess the impact of EU-wide deployment of sustainable fuels and hybrid powertrains.

In a future fully circular economy, all developments must aim for zero waste, i.e. the recycling and reuse of all materials. Therefore, research is needed to achieve closed-loop materials cycles of future products.

## Research Requirements

The research requirements listed below are expected to be most relevant within a short-term perspective (2023-2025).

A more extensive list of research requirements including mid-term (2025-2023) and long-term (2030+) topics can be found in the A3PS Roadmap "Austrian Roadmap for Sustainable Mobility – a long-term perspective, Version 2022 (https://www.a3ps.at/a3ps-roadmaps).

### 1. Hybrid System

- New hybrid topologies
  - Increase of efficiency (and thus reduce GHG emission)
  - Solutions at optimal costs

- Electrified and on-demand-driven auxiliary units
  - Efficient air conditioning compressor, power steering pump, components of the air management (charging) system
  - Electric machines for electric auxiliary units including control – especially powerful units for commercial vehicle applications

- Energy management (including thermal management)
  - Avoiding cold start losses (heat storage, heat encapsulation)
  - Thermal conditioning of the exhaust gas after-treatment system
  - Optimizing electric energy management of hybrid powertrain systems
  - Thermodynamic waste heat recovery (Rankine cycle, thermo-chemical and thermo-electric heat recovery)
  - Optimal predictive thermal control (e.g. predictive cooling)
  - Combined control of heat and power flux
  - Adaptation of the operating strategy to optimize the life-time of the hybrid system (e.g. the battery)

- Control of the hybrid system
  - Optimal operating strategy and control of hybrids using connectivity Car2X - X2Car (e.g. hybrid system on navigation system); Monitoring and service optimization
  - Software for component control and system control
  - Fast modeling methods and fast, automated control and diagnosis system parameterization
  - Combined physical-mathematical / phenomenological modeling
  - Efficient validation of complex drive systems
  - Automated operating and cutting-edge control strategies
  - Development tools & methodologies (e.g. "simulation on molecular level")

## 2. Sustainable Fuels

- Efficient and “green” (i.e. sustainable) fuel production, on-board storage and fuel use
  - Efficient production of drop-in fuels (biofuels and RFNBOs) to power existing vehicle technologies (and in the current legacy fleet)
  - Production processes of RFNBOs (produced from hydrogen from renewable electricity sources and $CO_2$, or from synthesis gas e.g. from co-electrolysis of $H_2O$ and $CO_2$) in view of efficiency and cost-per-unit impact
  - Processes for capturing $CO_2$ from exhaust gases, flue gases, or other sources
  - Gasification technologies and other thermal processes to produce biofuels (e.g. gasification of biomass followed by synthesis to liquid or gaseous fuels etc.)
  - Integration of biofuel production into refineries through co-processing and upgrading of bio-based intermediate energy carriers such as pyrolysis oils, bio-oils and Fischer-Tropsch-liquids
  - Adaptation of powertrain systems for the application of higher blends of sustainable fuels
  - Efficient energy storage for liquid and gaseous sustainable fuels
  - Measurement and analysis techniques for increased quality requirements as well as for online analysis of the gas constituents for optimal setting of the ICE
  - LCA of sustainable fuels and their application in hybrid vehicles

- Material technology for advanced / new fuels
  - Tank / pipe / sealing materials and fuel metering materials
  - Fuel sensors (on and off board)

## 3. Hybrid Powertrain

- Transmission and clutch technology for hybrid vehicles
  - Variable gear systems
  - Transmissions for high-speed e-machines (including noise reduction)
  - Sinter and coating technologies
  - Lightweight technologies
  - Fast actuators
  - Transmission for highly efficient hybrid topologies
  - Optimal and predictive gear shift control/operation

## 4. Thermodynamics of the ICE including Exhaust Gas Treatment

- Combustion technologies for sustainable fuels incl. hydrogen in compliance with future legal requirements
  - Development and use of "Fully Flexible Direct Injection Systems" for liquid and gaseous fuels
  - New variabilities for efficiency improvements of the engine system
  - Ultimately highly efficient combustion systems aiming at 50 % efficiency
  - Optimal adaptation of engines to hybrid systems
  - Further NVH reduction of hybrid systems

- Enhanced exhaust gas after-treatment for sustainable fuels in compliance with future legal requirements
  - Elimination of ultra-fine particle emissions
  - Sensors and control systems for RDE (real driving emissions) exhaust gas monitoring
  - Direct emission control

- Material technology for engine improvements
  - Improvement of thermal insulation / adiabatic operation
  - Lightweight construction plus the use of new materials
  - Use of sintered components (also for actuators)
  - Reduction of friction and wear (including new bearing technologies especially for future / gaseous fuels …)
  - Design for recyclability, refurbishment, and reuse of materials and components
  - Material, design and production processes for do-no-significant-harm principles

### Requested National Funding Instruments for “Hybrids and Sustainable Fuels”

- Low TRL research
- Co-operative industrial research and experimental development
- Flagship projects
- Funding of demonstration plants, i.e. to produce biofuels or RFNBOs
- Common transnational funding instruments of EU-MS

### Estimated National R&D Project Volume for “Hybrids and Sustainable Fuels”

Starting in 2023, an annual volume of 65 M€ is estimated for R&D projects on the hybrid system and powertrain and sustainable fuels. The list below is an assessment of project types needed to cover all topics from basic to applied research, demonstration and R&D infrastructure:

- 8 M€ low TRL research: 8 projects à 1 M€
- 12 M€ for applied & cooperative research: 6 projects à 2 M€
- 30 M€ for flagship projects / cluster of flagship projects: 2 projects à 10-20 M€
- 15 M€ per year for R&D infrastructure

This **total R&D project volume of 65 M€** should be supported with a **funding volume of about 32,5 M€** considering an average funding rate of about 50 %.

Suggested allocation of projects/funding volume to the research areas in this chapter:

1. Hybrid System: 1/5
2. Sustainable Fuels: 2/5
3. Hybrid Powertrain: 1/5
4. Thermodynamics of the ICE including exhaust gas treatment: 1/5

# R&D Challenges: Advanced Vehicle Concepts 2023+

## Trends on Technology Development and Research Demand

Several major aspects will affect mobility (on & off-road vehicles) in the next five to ten years. In addition to the electrification of the drive train (see the positions on "Battery Electric Vehicle" and "Fuel Cell Electric Vehicle") - and thus change the environmental footprint throughout the entire life cycle. The vehicle is increasingly understood as part of a **system of systems**. **Energy efficiency** and **safety** are leveraged by this new view. Major effort, however has to be put on **digitalization**, **automation** and **connectivity** to reach user acceptance and trust in yet new but necessary concepts.

Content of this chapter is:

- General needs for **digitalization**, **automation** and **connectivity**
- **Optimal control** and associated **off-board functionality**
- Specific research needs for **energy efficiency**, **vehicle safety** and **non-exhaust particle emissions**
- **Life cycle assessment**, which becomes increasingly important for Vehicle Design and Vehicle Concepts

### General Needs for Digitalization, Automation and Connectivity

**Digitalization** and **digital twinning** are key to enable predictive control and bringing components and systems close to their limits, without having to consider production tolerance-based safety margins.

Information and communication technologies open new opportunities in the field of transport and mobility. **ICT-based assistance systems** and **automated**, **connected driving and safety functions** are increasingly going to be used in vehicle technology. These systems will relate to each other and with the infrastructure in the future. Assistance systems for vehicles enhance road and vehicle safety, enable mobility for a wide range of people and enable shared mobility concepts, reduce emissions and used space in cities through improved traffic efficiency and lead to more comfort for vehicle drivers.

To retrieve information that is necessary to feed digital twins during operation and to support the above mentioned benefits and goals, new affordable and sometimes higher precision drift-stable sensor technologies are required that will be augmented with virtual sensors in the control loop.

The way this information is further processed (with the help of AI methods and machine-learning) in an energy-efficient form is challenging and will require more than traditional computing architectures: Edge-Computing, cloud-computing and neuromorphic architectures together will be needed as foundation for the new computing architecture.

On computing level new paradigms have to be considered (edge / cloud / neuromorphic), which enable fast and low-power computation of huge amounts of data that are used for building data-driven models for digital twins.

Considering life-cycle aspects, reuse and recycling, this circular economy requires standardized LCA procedures and data that can be implemented in tools providing context-based information to the designers of new systems.

Overarching above mentioned topics is a system of systems engineering approach, which enables to analyze and optimize complex systems that are composed of several systems. A system of systems approach will lead to more complex systems that are performing better than just the sum of single systems. A methodology for system of systems approach is still incomplete and has to be developed.

For this system of systems approach it is absolutely necessary that standardized methods are developed that tackle the whole process from

- **Data generation**: what data is necessary, in which quality to retrieve the desired information (AI and machine learning cannot compensate for inadequate, incomplete or wrong data but rather request high quality, unbiased data)
- **Virtual Approval**:
  - design of adequate ODDs (Operating Design Domains) on component, system and system of systems level;
  - identification and closing of white spots in test spaces;
  - quantification of remaining uncertainty;

## Optimal Control and Offboard Functionality

### xCU, Advanced Control and Optimization

Great R&D efforts are being made in the field of **control units** (xCU). The term "xCU" encompasses all control units that are relevant for advanced powertrains, including the operating strategy.

For xCUs virtual and automated validation will become increasingly important, in order to make safe and regularly over-the-air software updates reality. Modular software functions that can be validated in respective (well-designed) ODDs will be essential for virtual validation.

V2X capable on-board units will still have to be validated in real-world traffic.

Zone controllers are emerging in the automotive industry as nodes or hubs that solve zone specific tasks, which decreases cabling effort and weight. For these zone controllers to work in a complex system-of-systems self-X capabilities are mandatory (X stands for monitoring, diagnosis and possibly taking over control tasks from other not functional controllers).

Multi-core controllers are needed to handle complex (sometimes model-based) control functions; however their price is still hindering their use in automotive industry. New emerging neuromorphic architectures (e.g. dedicated in distributed environments to deal with specific computing tasks) will be essential for reliable and complex computing in future architectures.

Advanced **control methods** for vehicle powertrains (e.g. fuel cell hybrids) that both **minimize component degradation** and **maximize efficiency** are crucial. For example, predictive control schemes that consider forecasts on e.g. route, traffic, weather, etc. are necessary. State-of-health monitoring systems (**virtual sensors**) as well as adequate new sensors to measure the operating conditions (e.g. in batteries or fuel cells) and parameters (e.g. $H_2$/$O_2$ concentration, temperature, pressure, etc.) during development and operation, in order to avoid negative effects on lifetime and performance are required. Future vehicles will continuously provide their operational data (e.g. battery health parameters) to a central unit over the air. This enables new opportunities to evaluate the performance of a whole vehicle fleet in real-time. Adjustments to battery degradation models and associated operation strategies can be fed back to the vehicle fleet. Thus, adaptive control strategies could be implemented on the fleet level, optimizing component lifetimes, emissions and efficiency on the go, without the need for maintenance downtime.

An increasing number of sensors in vehicles to cope with new challenges, like environmental perception, measurement of components and system states for control functions and the future use of trustworthy digital twins require the efficient use of sensing equipment on board.

**Virtual sensors** will on the one hand enable cheaper sensors to be used in the vehicle and on the other hand enable measurement of „not directly measurable“ quantities like, congestion warning or state of health of components, which are of uttermost importance.

**Automated driving functions** of SAE Levels 3 to 5 will enable the driver to hand over the driving task to the vehicle to increase **safety**, **comfort** as well as **efficiency** of traffic and transport and finally shared mobility concepts without the need for a driver at all. However, a prerequisite for this progress is that the driving functions are objectively verified to an unprecedented extent. Currently, there is no complete method that allows to perform the associated verification process at a reasonable cost to the industry. In scientific literature, there are approaches available that propose incredible real driving testing distances, but such efforts are not feasible in industrial projects. Therefore, new innovative smart approaches consisting of virtual methods, real-world testing and combination of both must be investigated that allow a holistic verification of the automated driving functions on complete vehicle level. For the use of such new approaches in industrial vehicle development it is important that these new methods can be performed with the available resources to ensure safe and comfort orientated operation of automated vehicles, whether they are developed for public traffic or for special applications on restricted areas.

**Optimized operation strategies** can **increase efficiency** and **reduce pollutant emissions**. Predictive operating strategies play an important role, as well as the consideration of a combined controller, for both passenger cars and commercial vehicles. Predictive maintenance is becoming increasingly important when **fail-safe operation** of relevant drivetrain components is considered but also degradation effects that can affect efficiency of the entire system.

For future control strategies and systems AI technologies need to be considered and developed towards the particular demands of vehicle and vehicle powertrains.

**Offboard Functions and Hardware abstraction layer**

Future automotive **electrical and electronic** (E/E) **architectures** will become more centralized and consolidated. Cross-domain vehicle computers will centralize functionality, which in today’s systems runs on different electronic control units (ECUs). However, it is important that the hardware is to a large extend independent from the Software – with a hardware abstraction layer, so that upgrades of both layers (HW and SW) are possible, without having the need to redesign both layers completely at the same time.
Also, for most domains, horizontal technology stacks will replace classical vertically integrated, embedded systems to reduce complexity, simplify update processes, and increase reuse of software components.

This future automotive-software architectures will, in general, consist of horizontally interlinked technology stacks. These stacks will feature IT components and processes like those proven in today’s consumer-electronics applications (such as smartphones) or cloud applications with managed and stable abstractions and APIs (Application Programming Interfaces) between layers.

This new technology stack will still include classical “onboard” layers like:

- Sensors and actuators
- Dedicated embedded control units
- Data and power distribution
- Computing platforms
    - such as DCUs, cross-domain central computers, and zone computers

Additionally, this technology stack will have a stronger focus on “offboard” layers like:

- *offboard infrastructure*, such as public, private, or hybrid clouds
- back-end platforms on top of the offboard infrastructure that provide basic enablers and services for connected-car back-end services
- *connected-car back-end services* running on offboard infrastructure — for example, real-time traffic monitors, road-hazard warnings, remote control, or predictive maintenance
- *edge devices*, including connected hardware that can extend the scope of the connected vehicle to road infrastructure such as charge points, parking meters, traffic control devices and infrastructure based sensors

Out of this change in the overall architecture the question rises, which functions shall be hosted “onboard” (i.e. running on a vehicle computing platform) and which shall be hosted “offboard” (i.e. running finally on a cloud infrastructure).
Typically, offboard software will be used for functions in software without hard real-time requirements and which are not safety critical. Those functions usually have high computation requirements or data-exchange needs or are location-based functions.
Possible functions could be:

- complex algorithms: e.g. energy / range optimization functions, route planning algorithms, map data & processing, speech recognition etc.
- data centric features: e.g. digital twins, offboard diagnosis, predictive maintenance etc.
- infrastructure based features: e.g. virtual / infrastructure based sensors, infrastructure based autonomous driving (e.g. Automated Valet Parking)

Advantages of offboard functions:

- reduced energy consumption on vehicle level, due to less computing power needed in vehicle
- overall energy optimization possible as central power supply might be more efficient
- reduced vehicle requirements in terms of integration, cooling and updateability of computing units
- shared usage of sensor infrastructure is a possibility for resource optimization (not every vehicle needs to be equipped with a given sensor set)
- more efficient scaling of computing power in IT-infrastructure possible (e.g. costs per performance power, maintenance)
- usage of offboard data and sensor information possible (e.g. traffic data, digital twins, etc.) to enable new functions

- easier homologation of safety critical functions by decomposition of features between vehicle and infrastructure (like in infrastructure based autonomous driving)

The usage of offboard functions needs a reliable, high-bandwidth / low-latency communication path from the vehicle to the offboard infrastructure.

In order to support the development of such architectures, development tools are necessary that support automated testing, continuous integration and continuous deployment of software functions and make sure that the safety and security of the entire vehicle is guaranteed, and validation and homologation requirements are fully considered and met.

### Specific Challenges for Energy Efficiency, Safety and Non-Exhaust Particle Emissions

The **technology progress** for all kinds of road vehicles in the past decades has significantly improved **safety**, **energy efficiency** and **emissions** as well as the **comfort** of today's vehicles. But still, the number of fatalities and injured persons in road traffic is too high and therefore extended effort is needed to bring these figures down – finally to zero.

**Energy Management and Energy Efficiency:**

Trustworthiness for range prediction and charging of electrified vehicles have to be increased. Retrieving relevant **vehicle information** – such as **state of charge**, and **state of health** of the battery and **information concerning the trip** are crucial to plan charging with the power needed to complete the trips in the desired time, while taking into account time-dependent available power at charging stations. This requires the knowledge of the demand of other drivers, a decent information and control system and also information about the actual state of the distribution grid. Power losses (i.e. heat) that occur during the charging process shall be transferred to other systems, where these heat can be used effectively. Prediction of the behavior and predictive control of components is crucial for increasing energy efficiency on system level. While the predictive control has been demonstrated in several applications, digital twins of components and retrieving information on traffic and road conditions for the upcoming kilometers offer a high potential to increase energy efficiency. Predicting the thermal comfort of passengers in battery electric vehicles is key for reliable range prediction (especially in winter). For new battery concepts thermal conditioning like Cell-to-Pack and Cell-to-Chassis design with highly efficient and highly thermal uniformity concepts like dielectric fluid immersion cooling with focus on long-term stability has to be ensured.

**Vehicle Safety**

**Driver behavior and cognition:** Understanding how drivers behave and make decisions on the road is crucial for developing effective safety systems. This requires studying human factors such as attention, perception, reaction time, and decision-making.

**Vehicle technology:** Developing new technologies that can assist drivers and improve safety is also a key area of research. This includes systems such as collision avoidance, lane departure warning, and adaptive cruise control.

**Human-machine interaction:** As vehicles become more automated, it is important to study how drivers interact with these systems and how they can be designed to be intuitive and easy to use.

**Data analysis and modeling:** Collecting and analyzing data from real-world driving situations can provide valuable insights into the causes of accidents and the effectiveness of safety systems. Developing accurate models of driver behavior and vehicle dynamics is also important for designing effective safety systems.

**Battery Safety** is addressed in „R&D Challenges: Battery Electric Vehicle 2023+" and not part of this chapter. However, there is still an open point to be considered about the evaluation of the context of an accident, since the battery must not be disconnected after a not-severe crash, where the car then would be an unnecessary obstacle for other vehicles.

**Braking:** Brakes are an essential safety feature that rely on the energy provided by the powertrain to function. The powertrain must provide enough power to the brakes to stop the vehicle quickly and safely. Additionally, the powertrain must work in tandem with other safety systems, such as anti-lock brakes (ABS), electronic stability control (ESC), and traction control, to ensure that the vehicle remains stable and safe during emergency maneuvers.

**Crash avoidance:** Advanced safety systems like automatic emergency braking (AEB), lane departure warning (LDW), and blind spot detection rely on sensors and cameras that are often integrated with the powertrain. These systems use data from the powertrain to make decisions about when to engage and how much force to apply.

**EMC (Electromagnetic Compatibility) research:** is essential in electric vehicles because these vehicles rely on a complex network of electronic systems and components that generate electromagnetic fields. These electromagnetic fields can interfere with the proper functioning of other electronic devices and systems, including communication systems, navigation systems, and medical equipment.

In addition, electric vehicles generate high voltage, high frequency and high power electrical signals that can potentially cause electromagnetic interference (EMI) and radio frequency interference (RFI). This interference can affect the safety and reliability of the vehicle, as well as the safety of the driver and passengers.

EMC research is therefore needed to ensure that electric vehicles meet the relevant safety and regulatory standards for electromagnetic compatibility. This includes testing the vehicles for EMI and RFI, developing methods to reduce interference, and ensuring that the vehicle's electronic systems are designed and constructed to minimize electromagnetic emissions. Where test equipment is not available or feasible to fulfill this task today (e.g. in-vehicle testing, certain accuracies for high-frequency testing, test labs without measurement interferences, etc.), this must also be researched and developed.

Overall, EMC research is critical to ensure the safe and reliable operation of electric vehicles, and to enable the widespread adoption of this important technology.

**EMC Simulation**: Advanced Vehicles in 2023 and beyond will contain more advanced electronic systems with high performance computing (HPC), enhanced connectivity for ADAS, automated driving and power electronics. Accordingly, meeting of Electromagnetic Compatibility (EMC), Power Integrity (PI) and Signal Integrity (SI) requirements will be even more challenging. Although there are known solutions and methods from non-automotive applications, these are mostly not fitting to automotive applications. For example, a personal computer can be shielded simply compared to a zone control device with connectors to harnesses with multiple cables. Also, a vehicle contains high power electronics, sensitive sensors or communication interfaces in closer vicinity than in most other applications, so that electromagnetic susceptibility is more an issue.

Simulation and EDA (electronic design automation) methods have to be applied and further enhanced to enable to meet the requirements efficiently and consistently. For instance, the emission from ICEs has been modeled by application of integrated circuit emission models (ICEM), but these are often not readily available with the necessary accuracy, especially for new ICEs. Measurement based component models are an approach to enable a quick and accurate model-based design, but modeling methods have to be enhanced compared to the current state.

Full EMC simulation of complex automotive electronics is not feasible yet and if for selected cases, this is time consuming, not allowing in depth multiple parameter sensitivity analysis. Therefore, a smart modelling has to reveal main EMC effects and concentrates on the design parameters, with influence on EMC, PI, SI. Another well-known issue is the emission from power electronics, where costly, bulky and heavy filters are currently used to meet EMC requirements. Here new solutions with altered filter design, active filtering and new filter components (modelled more accurately to consider magnetics), could lead to significant weight and cost reduction.

**Non-Exhaust Particle Emission reduction**

Non-exhaust particle emissions refer to the release of small particles into the air from sources other than vehicles' exhaust, such as brake wear, tire wear, road surface abrasion, and construction activities. These particles can have adverse effects on both human health and the environment. Therefore, there is a need for research on non-exhaust particle emissions to better understand their sources, composition, distribution, and potential impacts, and to develop effective mitigation strategies.

One of the main research needs for non-exhaust particle emissions is to improve our understanding of the contribution of different sources to overall particle emissions. This requires the development and application of reliable methods and devices for measuring and quantifying non-exhaust particle emissions, as well as the use of advanced modeling techniques to simulate the dispersion and transformation of particles in the atmosphere.

Another research need is to investigate the health effects of non-exhaust particle emissions. These particles are typically smaller in size than exhaust particles and can penetrate deeper into the respiratory system, potentially causing respiratory and cardiovascular diseases. Therefore, there is a need for epidemiological studies to assess the health risks associated with exposure to non-exhaust particles.

Furthermore, research is needed to identify effective mitigation strategies for reducing non-exhaust particle emissions. This may include the development of new materials for tires and brake pads that generate fewer particles, the implementation of measures to reduce road surface abrasion, and the use of dust suppression technologies at construction sites.

## Life Cycle Assessment and Circular Economy

Meaningful Life Cycle Assessment (LCA) of vehicles must cover the entire life cycle including material origin, 2$^{nd}$ life use, and recycling for a circular economy approach. These aspects need to be quantified and considered in simulation and optimization of the product in parallel to efficiency, weight, and performance. This holistic view shall equally cover the GHG emissions of production processes and will promote regional European solutions and competitiveness, rather than delegating material consumption and emissions to other global regions.

Key factors in LCA of autonomously driving passenger cars compared to non-autonomous vehicles are the changes in energy demand and efficiency during operation. Additional weight for the specific components, increased number of trips due to rebound effects and empty miles can increase energy demand, whereas increased productivity, increased driving efficiency due to shared mobility, vehicle platooning and ecodriving can decrease energy demand.

## Essential Legal Framework

A legal framework for type approval and operation of driverless vehicle functions of SAE L3 and L4 needs to be established (e.g. HighwayPilot, AVP (automated valet parking) - already in series (in Germany) - and shuttles), especially the driverless operation in conjunction with the elimination of the need of persons nearby, applicable in a mixed traffic environment. Here, primarily *conduct law* adaptions are required (driving and operation) since those changes for type approval regulation are expected to be developed on EU level.

The AVP use case could be a good starting point for gaining experience with a L4 system because of its reduced scope. As a parking function in dual-use vehicles it has reduced complexity and risk because of the defined controllable driving area (ODD) and functional scope (parking in garage, slow speed).

## Research Requirements

The research requirements listed below are expected to be most relevant within a short-term perspective (2023-2025).

A more extensive list of research requirements including mid-term (2025-2030) and long-term (2030+) topics can be found in the A3PS Roadmap "Austrian Roadmap for Sustainable Mobility – a long-term perspective, Version 2022 (https://www.a3ps.at/a3ps-roadmaps).

### 1. Research Requirements for Digitalization, Automation and Connectivity

- Methods, tools and test systems for the development and optimization of conditionally, highly and fully (SAE Level 3-5) automated driving functions or sensors, including verifying & validating them on the road, on the test site or under laboratory conditions (MIL, SIL, HIL)[15]
- (Highly) automated driving (HAD): Development of methods and tools for efficient verification and validation (V&V) of HAD in different test environments (from simulation in MIL/SIL/ HIL to road tests)
- Development of test and approval procedures for HAD + HIL, in particular early clarification of the scope of requirements or AI (artificial intelligence)
- Implementation of urban test scenarios with test options both on dedicated test fields and in field tests in public spaces

> 4 Projects à 3 Mio Euro

### 2. Research Requirements for Optimal Control and Offboard Functionality

- Development of controls and testing of innovative sensors including object and environment recognition for automated driving functions
- Development of decision and control algorithms with appropriate software and middleware for highly and fully automated / autonomous driving with or without artificial intelligence and their integration into Domain-Domain computer architecture structures

[15] Software in the Loop (SIL), Model in the Loop (MIL), Hardware in the Loop (HIL)

- Evaluation methods and tools for large amounts of measurement data from, for example, fleet tests or driving tests with comprehensive or high-resolution sensors. In particular, the automatic generation of scenarios, auto-tagging (object description), automatic measurement data evaluation and correlation to ground truth data
- Standardization of communication paths between vehicle and infrastructure protocols, first approaches exist (e.g. W3C) but optimization is needed for broad adoption and usage
- Security and Privacy requirements:
    - Certified Sender/Receiver in real Time (Latency < 10ms).
    - Robustness against attacks of any form (hacking, physical destruction, local signal jamming, etc.)
    - Guarantee privacy of the driver
- Development of open standards and standards for data exchange between different partners in the mobility ecosystem (e.g. Catena-X, COVESA)
- Further development of IT security methods (encryption techniques, penetration tests, etc.) and definition of design and testing methods and tools and specifications for ensuring IT security and data protection (also for over-the-air updates of automation functions)

> 3 Flagship Projects à 5 Mio Euro

**Sensors and xCU**

- Sensor fusion and virtual sensors (including quantification of uncertainty)
- Sensor modelling and digital twinning
- Virtual xCU: virtual validation (incl. model validation and generation of digital twins), enhancement of FMI/FMU
- V2X capable on-board units (road-side units) – validation in traffic management
- Modular software functions
- Self-X of zone-CUs

> 5 Projects à 2 Mio Euro

## 3. Specific Requirements for Energy Efficiency, Safety and Non-Exhaust Particle Emissions

**Energy Efficiency**

- Trustworthiness of range prediction (considering thermal comfort of passengers)
- Smart charging: optimization of benefits of ALL stakeholders of the value chain (i.e. from end user over charge point operator to distribution grid and transmission grid operators)
- Predictive energy management and predictive control of components taking into account environmental conditions (weather, traffic etc.)

> 3 Projects à 1 Mio Euro

**Vehicle Safety**

- Driver behavior and cognition
- Developing new technologies that can assist drivers and improve safety
- HMI concepts that take into account driver states
- Battery safety in the context of an accident
- Braking: traction control, to ensure that the vehicle remains stable and safe during emergency maneuvers.
- Improvement of advanced safety systems in terms of human-centric-approaches increasing trust and acceptance
- EMC research to ensure that electric vehicles meet the relevant safety and regulatory standards for electromagnetic compatibility
- Early development of innovative room concepts (alternative seat configurations, ergonomics, operating concept, adapted air conditioning, and adapted occupant protection) for vehicles that have automated driving functions at level 4 and level 5. (Note: Especially the scope of occupant protection requires a very long lead time and must therefore be developed in advance of level 4 and 5.)

> 3 Projects à 2 Mio Euro

**Non-exhaust-particle emissions:**

- Particle Emissions: Checking the suitability of available measurement methods and subsequent development of new measurement methods and tools.
- Development of suitable test bench infrastructure and “real life” measurement procedures.
- Development of technical solutions and operating strategies to reduce particle emissions, especially in real operation.
- Research on zero-emission concepts for the fundamental new components and systems that offer the same range of functions and the same functional safety.

> 3 Projects à 2 Mio Euro

## 4. Life Cycle Assessment

- Lack of standardized and comparable data
- Harmonized methods and tools for affordable (in terms of cost and time) and easy-to-handle LCA
- Strategies and definitions for consistent circular economy approaches
- Knowledge and skills for LCA and circular economy

> 2 Flagship Projects à 5 Mio Euro

## Estimated National R&D Project Volume for "Advanced Vehicle Concepts"

Starting in 2023, an annual volume of 62 M€ is estimated for R&D projects on advanced vehicle concepts. The list below is an assessment of project types needed to cover all topics from basic to applied research, demonstration and R&D infrastructure:

- 37 M€ for applied and cooperative research: 3 projects à 1 M€, 11 projects à 2 M€, 4 projects à 3 M€
  - 3 M€ low TRL research: 3 projects à 1 M€
  - 6 M€ low TRL research: 3 projects à 2 M€
  - 16 M€ for applied & cooperative research: 8 projects à 2 M€
  - 12 M€ for applied & cooperative research: 4 projects à 3 M€
- 25 M€ for flagship projects: 5 projects à 5 M€

This **total R&D project volume of 62 M€** should be supported with a **funding volume of about 31 M€** considering an average funding rate of about 50 %.

# R&D Challenges: Innovative Materials and Vehicle Production Technologies 2023+

## Position

### Innovative Materials – Trends and Developments

The energy balance of future “climate neutral vehicles” will strongly depend on effective weight reduction and consequently on lightweight construction. The demanding requirements regarding $CO_2$/GHG emissions and safety make integrative vehicle concepts a major driver of innovation, in which **functional**, **material engineering** and **joining technology** lightweight construction are systematically linked. The use of fiber-reinforced plastics as well as new types of aluminum and magnesium alloys, hybrid lightweight construction and mixed construction (composites) will become increasingly important. But innovative materials are more than “only” lightweight, since with the target to transform towards a circular economy the opportunity of recyclability, reuse, refurbishment, etc. is an essential criterion for the selection of suitable materials.

Lightweight construction will be essential for the further development of electromobility in order to compensate for the challenge that new electric cars are between 10 and 30 percent heavier than conventional vehicles due to the additional battery weight.

So far, the design and the modular building block systems as well as the materials of the vehicles are still based on the conventional series, as higher quantities result in lower costs. Therefore, cost-effective solutions are essential for a complete switch to lightweight construction concepts.

### Development Processes

The seamless introduction of networked development backbones, which provide the information across the different technology areas and lifecycle levels, in order to be able to develop the increasingly complex vehicles in always shorter times, is necessary to remain successful in the global market. A particular challenge is the seamless integration of information from field tests into development and production processes. The closed loop of engineering data to manufacturing during development process as well as while lifecycle change management is mandatory but steady raising required relevant data types are to reflect – Geometry and parts list of the past have not been sufficient for a long time.

### Production Technologies

Regarding the increasing emergence of e-mobility with a large variety of models and still relatively small quantities, the manufacturing industry is confronted with small and zero series (prototyping) for new vehicle concepts and their innovative components (e.g. smart components, smart materials). At the same time, it is important to create individualized products with "high volume" processes (mass customization). Material production processes are energy intensive thus the decarbonization of industrial processes needs to be accelerated by e.g. switching to carbon neutral energy sources, reducing processing steps, avoiding yield losses by predictive operation and maintenance but especially by increasing recycling and reuse.

Function oriented process control of parts can help to achieve zero defect manufacturing. The trustworthy simulation of parts and their production processes are key to predict their behavior in operation and help to predictively maintain tools in the process.

Especially for production and logistics we are well advised to develop an automated closed loop for gathering data from engineering and the manufacturing processes, processing those to the relevant information and provide the relevant decision bases easy understandable to our employee, or to an AI for knowledge-based decision making with automated execution of measures in a closed loop.

Additive manufacturing has great potential, especially in lightweight construction, energy efficiency (creating complex flow channels, cooling in the parts) and functional integration. To do this, the materials have to be further optimized for this purpose, the processes (e.g. energy parameters) have to be optimized and have to work even faster, cheaper and with higher throughput, for which great efforts have to be made in research. For individual manufacturing and small series, it must be ensured that the "additive processes" used for the first test components also allow conclusions to be drawn about the later large-series solution.

Likewise, the optimization of the "classic" technologies with a high degree of maturity (pressure die casting, metal forming, machining, joining, etc.) should not be forgotten. When optimizing well known processes in conjunction with further material optimization, energy intensive steps (e.g. heat treatments) can be skipped. An important task to do so is the digitalization and the data collection of our (traditional) processes in our brownfield factories.

## Digitalization of the Development and Production Processes

Due to the possibilities offered by new data processing and communication technologies in competition, companies are required not only to increase the efficiency of classic production technology, but also to **improve and convert business processes**, to **link them with data processing** and to **integrate** them appropriately.

This applies in particular to digitalization from development to production to the service area and its networking along the value chain as well as the integration of digital technologies in all areas of the company (e.g. use of online elements in design and development as well as in the entire procurement and logistics and distribution system). The digitalization of security mechanisms, test and approval procedures and the use of simulation, artificial intelligence and machine learning in production will determine competitiveness.

Artificial intelligence (AI) and machine learning algorithms offer enormous potential to increase efficiency in production processes and to master the complexities that come with greater individualization. Automated systems in verification and validation and in production must work together with people with the highest level of security.

New methods and visualization e.g. xR tools are required to train people new tasks of work and guide employees through their processes. This speeds up their qualification and allows employee to handle the raising complexity by unification of human skills with digital support.

### *Digital Twins in Development and Production Technology*

Digitalization and digital twinning are key to enable predictive control and bringing components and systems close to their limits, without having to consider production tolerance-based safety margins.

Product design benefits from virtual twins because production variations can be tested more quickly and easily. Physical tests are often no longer necessary since the digital images reproduce the living environment true to the original. This saves resources and manufacturing tolerances and speeds up the design process noticeably. Digital twinning concerns both production as well as development technology.

The data that flows from the real to the virtual object/process is also referred to as a digital shadow and may serve as an enabler to find the best possible use of an object such as repair, reuse, refurbishment or recycling by providing essential information about this object.

## Life Cycle Assessment and Circular Economy

Meaningful Life Cycle Assessment (LCA) of vehicles must cover the entire life cycle including material origin, 2nd life, and recycling for a circular economy approach. These aspects need to be quantified and considered in simulation and optimization of the product in parallel to efficiency, weight, and performance. This holistic view shall equally cover the carbon output of production processes and will promote regional European solutions and competitiveness, rather than delegating material consumption and emissions to other global regions.

For a circular economy approach, recyclability is not enough, and reuse, refurbishment and repair are preferable. This requires considering these aspects already in the design process and to provide required data. Design for recycling aims to support the recovery of packaging materials for further use. In addition to other environmental benefits such as saving fossil resources, this significantly contributes to reducing the emission of greenhouse gases responsible for climate change. This requires simulation and development methods for the design process to ensure $CO_2$-optimized design and $CO_2$-optimized operation of a vehicle.

## Research Requirements

The research requirements listed below are expected to be most relevant within a short-term perspective (2023-2025).

A more extensive list of research requirements including mid-term (2025-2030) and long-term (2030+) topics can be found in the A3PS Roadmap "Austrian Roadmap for Sustainable Mobility – a long-term perspective, Version 2022 (https://www.a3ps.at/a3ps-roadmaps).

### 1. Innovative Material Design

*CONSTRUCTION BASED LIGHTWEIGHT DESIGN*

- Function integration
- Weight management concepts for electric vehicles
- Multi-material design
- Crash management systems with functional integration made of die-cast Al
- Novel shape optimization approaches especially for flow-through components (pumps, paddle wheels, pipes, heating systems, energy exchangers, ...) for energy efficiency optimization and the resulting material savings in components (such as numeric/bionic optimizations)
- Lightweight design using multi-scale, multi-physical numerical model approaches (use model approaches with and without nets)
- Design for reuse (and Methodology) on component and part-level
- Zonal architecture – impact on full vehicle weight
- E/E components

*MATERIAL BASED LIGHTWEIGHT DESIGN*

- High performance lightweight materials incl. *one-alloy/material fits all* approach
- Application of fiber-reinforced plastics, light metals (Al, Mg, Ti) and light metal alloys with mechanically and thermally optimized properties (e.g. fire-resistant magnesium alloys)
- Use of high-tensile steels (TRIP, multi-phase steels)
- Hybrid use of light metal / steel / glass fiber / carbon fiber
- Hard coatings & technologies enabling for a lifetime expansion
- Increase in recycling rations of polymers metals and light metals
- Sustainable materials and processing technologies for batteries with high energy and power density (e.g. based on Li-Air or Mg-Air)
- Suitability for repair / reuse / recycling / circular economy of materials
- Design for recyclability

## 1. Innovative Development Processes

- Development of modular, scalable production lines (in terms of size and production volume) that can also be combined across companies to increase profitability
- Development of Industry 4.0 compatible control systems for the "networked, island-based factory", including suitable technologies and strategies for securing against unauthorized access to factory data systems and cloud-based communication systems, as well as techniques to support safety & security-based systems in edge computing area
- Development of magnesium extrusion technologies for applications in EVs
- Consistent "cradle to cradle" approach (re-use, recycling) in product design and production planning (e.g. for battery systems)

## 2. Innovative Production Technologies

- Additive manufacturing (AM)
    - Additive manufacturing techniques with order outputs greater than 10-15 kg / h
    - Wire-based additive manufacturing processes for variation of cast components
    - Faster development processes by using additive manufacturing technologies in combination with special materials
    - Functional integration by additive manufacturing using more than one material
- Novel casting and forming processes (e.g. vacuum-assisted casting, semi-solid-casting, cryoforming, electroforming) for optimized material utilization (e.g. uniform thinning) or for increased mechanical properties
- Manufacturing of smart products (intelligent components, smart materials) with integrated sensor functionality in parts, components and materials
- Research program for pilot line of large-scale production of fuel cells
- Manufacturing processes (e.g. electric metal stacks, winding assemblies) for the automotive industry

    - High quality automation process for power modules and E-Motor subsystem assembling
    - Solid vs. dismantle jointing concept
    - Automated recyclability dismantling concepts for near net zero waste based on adequate designs
    - Assembling and disassembling concepts to close material loop use, reuse components or secondary material grade
    - In line process/closed loop control motor assembling processes
    - Low-cost manufacturing processes regarding winding assemblies e.g. welding-process in hairpin technology, welding/joining stator winding, impregnation-process development (if resin needed) or trickling process (if resin is needed)
    - Low-cost manufacturing processes for sheet stacks and sheet stamping of electrical steel (e.g. stamp rolling)
- New joining technologies (electron beam welding, gluing, hybrid joining technologies, aluminum laser, spot-weld application, etc.)
- Development of new welding consumables and solders for special metal mixing combinations
- Development of resources for efficient manufacturing processes for hybrid materials
- Development of joining processes for high-strength and low-ductile lightweight materials or mixed connections made of metal-plastic fiber composites

## 3. Digitalization of Processes

- Development of valid simulation models and algorithms for production processes, "virtual product development"
- Simulation-supported life cycle assessments for technology scouting and decision-making processes
- Development and application of digital twins (for system optimization, variant handling, etc.)
- Methods for "Big Data" - use in technology and product development
- Combination of production technologies, process data, big data mining, material data and material data for numerical simulations
- Deviations in production and its influence on EMC
- Use of artificial intelligence and machine learning in the entire supply chain: self-optimizing production and machines, quality assurance (e.g. visual inspection), preventive maintenance, autonomous (intra-) logistics
- Wireless data transmission in harsh environments
- Digital Twins in Production Technologies (for saving resources)
- Digital shadows during lifetime (for optimized after-life)
- EMV test and release

## Estimated National R&D Project Volume

Starting in 2023, an annual volume of 50 M€ is estimated for R&D projects on on innovative material design, development and production as well as digitalization of the process. The list below is an assessment of project types needed to cover all topics from basic to applied research, demonstration and R&D infrastructure:

- 10 M€ for cooperative projects of oriented basic research: 10 projects à 1 M€
- 10 M€ for cooperative R&D projects, experimental development and industrial research: 5 projects à 2 M€
- 20 M€ for flagship projects: 2 projects à 10 M€
- 10 M€ for R&D infrastructure (support of laboratory infrastructure)

This **total R&D project volume of 50 M€** should be supported with a **funding volume of about 25 M€** considering an average funding rate of about 50 %.

Suggested allocation of projects/funding volume to the research areas in this chapter:

| | |
|---|---|
| 1. Innovative Material Design | 1/5 |
| 2. Innovative Development Processes | 1/5 |
| 3. Innovative Production Technologies | 2/5 |
| 4. Digitalization of Processes | 1/5 |

## List of Abbreviations

| | |
|---|---|
| ABS | Anti-Lock-Brakes |
| AC | Alternating Current |
| AD | Autonomous/Automated Driving |
| AEB | Automatic Emergency Braking |
| Ah | Ampere hours |
| AI | Artificial Intelligence / Alcohol Interlock |
| AM | Additive Manufacturing |
| API | Application Programming Interfaces |
| AUTOSAR | Automotive Open System Architecture (global partnership of automotive and software industry) |
| AVP | Automated Valet Parking |
| BEV | Battery Electric Vehicle |
| BMK | Federal Ministry Republic of Austria for Climate Action, Environment, Energy, Mobility, Innovation and Technology |
| BoP | Balance of Plant |
| C2C | Cell-to-Chassis |
| C2P | Cell-to-Pack |
| C2S | Cell-to-Structure |
| Ca | Calcium |
| CCAM | Cooperative, Connected Automated Mobility |
| CD-Lab | Christian Doppler Laboratory |
| CF | Carbon Fiber |
| CO | Carbon monoxide |
| $CO_2$ | Carbon dioxide |
| COMET | Competence Centers for Excellent Technologies |
| COVESA | Connected Vehicle Systems Alliance |
| CU | Control Unit |
| DC | Direct Current |
| DCU | Domain Control Unit |
| E/E | Electrical and Electronic |
| ECU | Electronic Control Unit |
| EDA | Electronic Design Automation |
| EDU | Electric Drive Unit |
| EMC | Electro-Magnetic Compatibility |
| ESC | Electronic Stability Control |
| EV | Electric Vehicle |
| FAME | Fatty Acid Methyl Ester (biodiesel derived by esterification of fats such as vegetable oil with methanol) |
| FC | Fuel Cell |
| FCV/FCEV | Fuel Cell (Electric) Vehicle |
| FEM | Finite Element Method |
| FMI | Functional Mock-up Interface |
| FMU | Functional Mock-up Unit |
| GaN | Gallium Nitride |
| GHG | Greenhouse Gas |
| $H_2$ | Hydrogen |
| HAD | Highly Automated Driving |
| HF-PWM | High-Frequency-pulse-width-modulation |
| HIL | Hardware in the Loop |
| HPC | High Power Charging |
| HPC | High Performance Computing |
| HREE | Heavy Rare Earth Element |
| HRS | Hydrogen Refueling Station |
| HV | High Voltage / Heavy Vehicles |
| HVAC | Heating, Ventilation and Air Conditioning |
| HW | Hardware |

| | |
|---|---|
| ICE | Internal Combustion Engine |
| ICEM | Integrated Circuit Emission Model |
| IGBT | Insulated-Gate Bipolar Transistor |
| IIoT | Industrial Internet of Things |
| IPCEI | Important Projects of Common European Interest |
| KPI | Key Performance Indicators |
| kW | kilo Watt |
| LCA | Life Cycle Assessment |
| LDW | Lane Departure Warning |
| LFP | Lithium Ferro phosphate |
| Li | Lithium |
| LOHC | Liquid Organic Hydrogen Carrier |
| LTO | Lithium Titanate Oxide |
| Mg | Magnesium |
| MIL | Model in the Loop |
| MW | Megawatt |
| Na | Sodium |
| NMC | Nickel Manganese Cobalt |
| NVH | Noise, Vibration and Harshness |
| ODD | Operating Design Domains |
| OEM | Original Equipment Manufacturer |
| OPEX | Operational Expenditures |
| PCB | Printed Circuit Board |
| PCEC | Protonic Ceramic Electrolysis Cell |
| PCFC | Protonic Ceramic Fuel Cell |
| PEM | Polymer Electrolyte Membrane |
| PI | Power Integrity |
| PnC | Plug-and-Charge |
| R&D | Research and Development |
| RDE | Real Driving Emissions |
| RFI | Radio Frequency Interference |
| RFNBOs | Renewable Fuels of Non-Biological Origin |
| RUL | Remaining Useful Life |
| SAE | Society of Automotive Engineers; SAE international’s J3016 provides a common taxonomy and definitions for automated driving in order to simplify communication and facilitate collaboration within technical and policy domains. The report’s six levels of driving automation span from no automation to full automation. |
| SAF | Sustainable Aviation Fuels |
| SI | Signal Integrity |
| SiC | Silicon Carbide |
| SIL | Software In the Loop |
| SNG | Synthetic Natural Gas |
| SOEC | Solid Oxide Electrolyser Cell |
| SOFC | Solid Oxide Fuel Cell |
| SW | Software |
| TCO | Total Cost of Ownership |
| Ti | Titanium |
| TRIP | Transformation Induced Plasticity |
| TRL | Technology Readiness Level |
| V&V | Verification and Validation |
| V2G | Vehicle-to-Grid |
| V2L | Vehicle-to-Load |
| V2X | Communication from vehicle to X (e.g. Vehicle, Infrastructure, Grid, Load) |
| VCU | Vehicle Control Unit |
| W3C | World Wide Web Consortium |
| xCU | Any Control Unit |
| XIL | Model, Software or Hardware in the Loop |
| xR | extended Reality |

A3PS – Austrian Association for Advanced Propulsion Systems

Otto Bauer Gasse 6, Top 9 | 1060 Wien

www.a3ps.at

Autors: M. Nöst, B. Brandstätter, R. Ratzi, P. Prenninger, A. Trattner, A. Wolfbeisser

With contributions from A3PS and community members