A3PS

Rethinking Propulsion.

AUSTRIAN POSITIONS FOR ADVANCED PROPULSION TECHNOLOGIES

A3PS Position Paper R&D Demand 2024+

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Content

A Introduction

The present A3PS position paper **"R&D Challenges 2024+"** summarizes envisaged developments and trends, as well as priorities of the industrial and scientific A3PS members. It provides an overview on the R&D challenges in the coming years and the necessary R&D activities to strengthen Austria as a business location.

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

1) **Support of mobility and powertrain technologies & innovations** in Austria, taking a holistic view of the value creation process, based on the **LCA (Life Cycle Assessment)** method ("from cradle to grave") to meet the 2030 targets and to enable mission 2050 targets in full.
2) **Establishment of a legal framework**, norms, standards and a strategy 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.

A3PS considers primarily R&D topics in this position paper. A3PS is convinced that investing in and therefore funding research is the most effective way for the achievement of more sustainable, more efficient and cost-effective technologies.

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 2024-2026 (download at https://www.a3ps.at/a3ps-position-papers.

A more extensive list of research requirements including **mid-term** (2025-2030) 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.

All sustainable technologies are 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]

A.1 Circular Economy

Circular economy must be considered in all technology sectors. This increases the research demand since, besides functional efficiency, additionally safety, security, durability, recyclability and

[1] FVV (2022), "Future Fuels: FVV Fuel Study IVb: Transformation of European Mobility to the GHG-neutral Post-fossil Age", https://www.researchgate.net/publication/366974074_FVV_Fuel_Study_IVb_-_Transformation_of_European_mobility_to_the_GHG-neutral_post-fossil_age_-_FVV_H1313_2022, retrieved 8 May 2024

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]

A.2 A3PS – Austrian Association for Advanced Propulsion Systems

A3PS and its members from industry and research institutions discussed, phrased and prioritized the contents of this position paper in early 2024. Founded in 2006 as an initiative of the Austrian Ministry of Technology, 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 to keep Austria competitive. All R&D topics presented in the A3PS area – such as this position 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 2024

[3] https://ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview, retrieved 8 May 2024

[4] https://medium.com/topangasupply/defining-circularity-is-sustainable-a-dirty-word-a47bb5ce5ef9, retrieved 10 May 2024

[5] https://www.topanga.io/post/how-the-9r-framework-can-change-our-economy, retrieved 10 May 2024

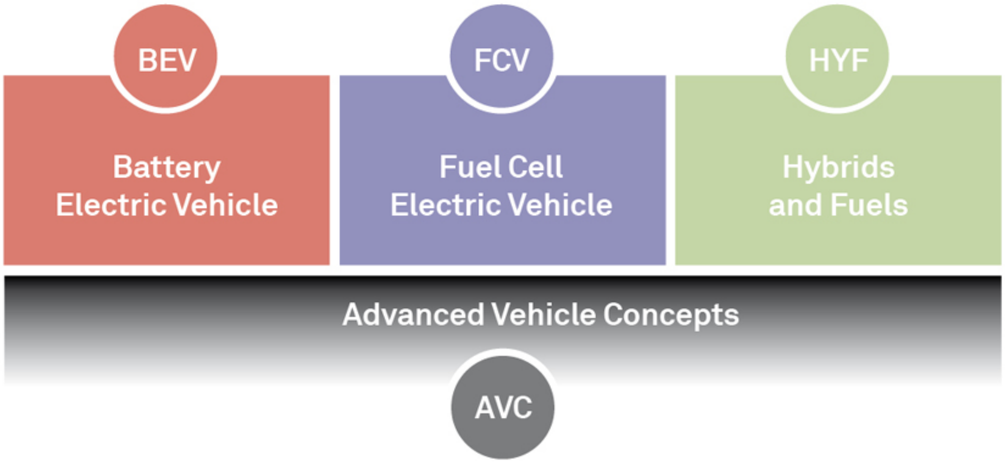

Fig. 1: 4 A3PS thematic expert groups

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. The wide range of different technologies in expert group AVC is addressed in two chapters within this position paper:

- Advanced Vehicle Concepts, including automatization, digitalization, connectivity – the vehicle as part of the "system of systems."
- Innovative Materials and Vehicle Production Technologies

B R&D Challenges: Battery Electric Vehicle 2024+

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 2024+:

- Energy Storages
  - (Structural) Battery Integration from cell to pack to battery system
  - Advanced Lithium-Ion Batteries 3rd and 4th generation as well as advanced Battery Technologies
- Electric Components
  - Electric Motor and matching inverter technology and manufacturing for high voltages and supply chain independence warranty (Heavy Rare Earth Free designs)
  - Vehicle-, Motion-, Drive- or Powertrain-Control components & systems (Software & Hardware)
  - Converter, inverter and Power Electronics with new architecture for higher integration levels and lower costs
  - New design guidelines to guarantee disassembling and remanufacturing to fulfill sustainability regulations.
- Charging Technologies
  - Ultra-fast charging technology
- Thermal Management and Energy Management on BEV Level
  - More efficient Technologies and system integration

B.1 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.

Although this position paper focuses on the automotive sector with on- and off-road vehicles including non-road mobile machinery, other mobility sectors such as aviation and inland/maritime shipping will also benefit from the research addressed in this section.

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 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 to bring advanced products onto the market safely, cost efficient and sustainably.

B.2 Requirements on Technology Development and Research Demand

B.2.1 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

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

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).

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 needs to enable fast charging capability to achieve charging times comparable to ICE refueling, in the range 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.

B.2.2 Electric Components

B.2.2.1 (High) Voltage Level BEV System

High-voltage systems with voltage levels post 800 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).

B.2.2.2 E-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), sustainability and cycle efficiency requirements. An important aspect is the **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 (e.g. separately excited synchronous motor, HRE (heavy rare earth) free PSM, in-wheel motor or axial flux machine). The development of directly cooled (high-speed) machines with a particularly high power-to-volume ratio is crucial. All conflicting aspects of cost, cycle efficiency, power density, sustainability and supply chain resilience (e.g. HRE free design) must be addressed to gain an economy of scale effect for a successful BEV implementation.

The R&D efforts include not only the optimization of the E-Motor but also of the inverter and -control and communication. To assure a defined reduction from the future very high-speed E-Motor designs the Gear Box must incorporate novel technologies for sealings, bearings, NVH cover, and gear flank run off geometries. Manufacturing and assembling excellence is necessary to hit the cost target and guarantee together with smart design future sustainability regulations (re-use, re-manufacturing, second live).

Other tasks in the area of transmission belong to smooth actuation (with several gear ratios), loss minimization, torque vectoring and single cooling circuit (of the rotor and stator shared with the gearing). 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 alternative semiconductor materials** such 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** with an overall cost benefit. 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 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.

Last but not least, R&I efforts must cover necessary functional safety and system (cyber) security aspects too.

B.2.3 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 (>> 50 kW) is transferred via a suitable interface using direct current (DC voltage). 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.

B.2.4 Thermal Management and Energy Management

Thermal consideration is highly essential both for the battery electric propulsion system and for the overall vehicle management. The latter aspects can be found in Chapter E R&D Challenges: Advanced Vehicle Concepts 2024+.

Batteries, power electronics, and E-Motors for require complex thermal management to perform in cold and hot conditions (e.g. during fast charging) without damage (reduced service life, early shutdown etc.). There is an increasing demand from customers and OEMs for fast charging. This requires new ideas for efficient cooling using innovative heat exchangers and new manufacturing processes. In addition, new safety regulations must be met, which call for new component solutions. Waste heat can be used via suitable technical processes (e.g. heat pumps). Heat storage concepts must be developed (especially using new chemical latent heat storage devices that reduce heat losses). 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 control issues. It is essential to include all relevant components: In addition to the energy storage and drive system, these include air conditioning, cooling, and the related operating strategies. The formerly independent subsystem controls must either be integrated to form a central control unit or have to be increasingly communicating with one another.

Predictive models must be used to anticipate thermal events and react in advance.

In addition to intelligent heating and cooling concepts, also modular thermal architectures at the system and component level have to be developed, which meet different e.g. country-specific, performance, or comfort requirements. To enable effective thermal system design, there is a high need for R&D in scalable thermal models for all relevant components of an electrified powertrain (E-Motor, inverter, battery, and cables).

With increasing EV numbers, real-life fleet data must be used to enable an update of battery performance and degradation models, typically used for the remaining useful life (RUL) prediction. Specifically, ageing prediction models parameterized with lab data can be improved significantly. A cloud-based digital twin of the battery can help to mitigate degradation, predict/prevent failure and extend battery life.

B.3 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 because 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. Based on the new EU Battery Regulation[7] the supplement documents (Delegated Acts), which describe the technical requirements for circular economy tasks, must be developed in cooperative joint research (lead: EC JRC). Thus, must be supported by industrial actors with deep technical knowledge reg. EV and HVB (High Voltage Battery) business together with the downstream Waste Management & Recycling Tech companies to have at the end a practical 9R'[8] process to be established on the European markets. In this context the consequences of this regulation for integrating a HVB into a vehicle and the efficient implementation of the technical details for the battery passport shall be addressed.

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

B.4 Life Cycle Assessment and Circular Economy

Global differences in production technologies, energy supply, and waste treatment stress the necessity to consider country specific aspects when applying a Life Cycle Assessment (LCA) and required Product Carbon Footprint reporting. Regarding the fulfilment of diverse legal and taxonomy reporting requirements for Product Carbon Footprints, supply chain engagement, education and involvement for LCA, e.g. data collection, is of importance. LCA of BEVs, ideally 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 (to estimate emissions a robust model for electricity generation and change of its carbon intensity in the future is needed (e.g. based on IEA STEP[9] or EU RED[10] prognoses)
- energy supply for battery manufacturing (share of renewable energy sources vs. fossil or nuclear energy sources)
- cell chemistry and related extraction and refining of critical raw materials (e.g. Nickel, Cobalt, Lithium), including the increasing demand for secondary 'recycled' cell material (high quality black mass refined to recycled CAM precursors and cell material)
- production of materials for battery casing (e.g. Aluminum)
- E-Motor (e.g. rare earth metals).
- Electronics (PCBs, semi-conductor, Si-wafers and precious metals)

Also end-of-life (EoL) treatment of BEV (e.g. a better mandatory recovery of dismantling parts, like EV batteries or electric drive units) influences their life cycle performance. Especially in Europe, complete vehicle and battery recycling is an important element to (partly) close "critical" material cycles (EU CEAP, e.g. incl. ELV Regulation proposal, Critical Minerals Regulation, Battery Regulation). However, challenges such as (global) used-battery collection, the diversity of cell chemistries as well as metallurgical material recovery rates remain to be solved. A crucial topic is to characterize quality of EV waste streams before any other end-of-life treatment following the 9R' principles. Innovative solutions for repurpose, remanufacture or higher automated dismantling must be found. 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. Such new developed technologies and

[7] Regulation (EU) 2023/1542, https://eur-lex.europa.eu/eli/reg/2023/1542/oj, retrieved 10 March 2024

[8] Categorisation System for the Circular Economy; The 9 R's are: They are Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle and Recover, https://circulareconomy.europa.eu/platform/sites/default/files/categorisation_system_for_the_ce.pdf, retrieved 10 March 2024

[9] IEA Stated Policies Scenario (STEPS), https://www.iea.org/reports/global-energy-and-climate-model/stated-policies-scenario-steps, retrieved 22 March 2024

[10] Renewable Energy Directive, https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-directive_en, retrieved 22 March 2024

solutions for EoL treatment of EV must be covered in automotive LCA. Activities and environmental impact for new repurpose applications or recycling technologies is currently rarely investigated in Europe.

B.5 Research Requirements

The research requirements listed below are expected to be most relevant within a short-term perspective (2024-2026).

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).

B.5.1 Energy Storages

B.5.1.1 (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

B.5.1.2 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 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

B.5.2 Electric Components

B.5.2.1 E-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[11] 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

[11] IIoT: Industrial Internet of Things

B.5.2.2 Inverter, Power Electronics

- Advanced materials (e.g. printed circuit boards, housings, capacitors) and advanced manufacturing technologies
  - Material and component design for reusability and recyclability
  - Joining 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)
- Passive components required for optimum utilization of new inverter design (e.g. SiC or GaN based inverters)

B.5.3 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

B.5.4 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) complemented by using environmental data (traffic, weather, etc.)
- Optimal Cooling Concept with SiC inverters
- 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

B.5.5 Requested National Funding Instruments for “Battery Electric Vehicles”

- Low TRL research
- Co-operative industrial research and experimental development
- Flagship projects
- High TRL research (close to serial production) with focus on vehicle test fleet operations to drive market introduction of innovative and sustainable vehicles

B.5.6 Estimated National R&D Project Volume for “Battery Electric Vehicle”

Starting in 2023, an annual[12] volume of 80 M€ is estimated for R&D projects on BEV. The list below is an assessment of project types needed to cover all topics from basic to applied research, demonstration and R&D infrastructure:

- 12 M€ for low TRL research: 8 projects of 1 M€ each
- 20 M€ for applied & cooperative research: 11 projects of x 2 M€ each
- 28 M€ for flagship projects or a cluster of flagship projects: 2 projects of 10-20 M€ each
- 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: 1/10
4. Thermal Management and Energy Management 3/10

[12] for projects granted within one year – project/funding volume for the whole project duration

C R&D Challenges: Fuel Cell Electric Vehicle and H_2 2024+

This Position paper's focus is on R&D requirements of fuel cell technology for electric vehicles and renewable H_2. Regarding H_2, production from non-fossil sources as well as distribution, storage and H_2 refueling stations (HRS) are addressed here. H_2 combustion can be found in chapter D R&D Challenges: Hybrids and Sustainable Fuels 2024+.

C.1 Requirements on Technology Development and Research Demand

H_2 and fuel cell technology in Austria offers the opportunity to implement the energy transition faster and more efficiently, to expand and use the country's own renewable resources in addition to the import of renewable H_2 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. Although this position paper focuses on the automotive sector with on- and off-road vehicles including non-road mobile machinery, other mobility sectors such as aviation and inland/maritime shipping will also benefit from the research addressed in this section.

To harness these advantages of fuel cell and H_2 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 2026:

- Strengthening Austria as a location by building up H_2 and fuel cell industry
- Increase of research funding for H_2 and fuel cell technologies and create a specialized funding instrument with a separate budget focused on R&D of all types of electrolyzers, H_2 on-board storage and fuel cells
- Accelerated expansion of renewable electricity generation for H_2 production
- Certification system for green H_2 - as H_2 generated by renewable energies
- Decentralized / regional approach to enable use, grid system release and balancing
- Simplified and standardized approval procedures for H_2 refueling stations and facilities
- Expansion of the H_2 refueling infrastructure for cars, buses and trucks
- The weight potential of fuel cell trucks compared to BEV trucks should be promoted in view of the increasing overall traffic.
- 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 H_2 Strategy should strengthen the role of mobility in R&D and in the roll-out of H_2 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 H_2 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

C.2 Position

Green H_2 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 H_2 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. **H_2 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. H_2 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, H_2 will also play a growing role in integration and storage of renewable electricity. H_2 allows to store and transport renewable energy efficiently over extended periods of time and is therefore a key enabler of the transition to renewable energies. Hence, it will also be available in enormous quantities **for mobility**. Fuel cell electric vehicles in combination with H_2 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 H_2 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 crucial importance for electromobility for heavy/long-distance transport, electromobility with **Fuel Cell Electric Vehicles (FCEVs)** offers the drive concept of choice. H_2 fuel cell vehicles are **locally emission-free** electric vehicles. In particular, **electric vehicles with PEM** (polymer electrolyte membrane) **fuel cells** in combination with **green H_2** 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).[13,14] Moreover, fuel cell vehicles feature potential to achieve competitive costs at high production volumes[15,16] 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 run with H_2 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, H_2 enables nationwide coverage. **H_2** is safely stored at the refueling station and, as with fossil fuels, high refueling capacities are possible. For a nationwide supply of **H_2** there are **significantly lower infrastructure investments** than for battery electromobility, which require a higher number of charging stations.[17]

Power-to-X: PEM-electrolyzers, powered by renewable energy sources, allow the production of enormous amounts of green H_2, 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[18] of H_2O or co-electrolysis of CO_2 and H_2O with suitable processes allow the production of 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 H_2. Solid oxide electrolysis cells (SOECs, PCECs) need new oxygen and proton-conducting

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

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

[15] 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.

[16] 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.

[17] 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*

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

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 H_2 and other energy carriers by electrolysis will significantly contribute to supply H_2 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 H_2 technologies. Now, developments must be continued, accelerated and results need to be transferred to the market. Overall, the H_2 fuel cell is the appropriate zero-emission technology for Europe and especially for Austria, because the existing expertise, 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 best training in this field and to support research.

Specific **research demand** for 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, H_2 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 needed.

C.3 Life Cycle Assessment and Circular Economy

Life Cycle Assessment (LCA) of FCEVs involves a range of influencing factors, such as H_2 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 H_2 production and use in the fuel cell, the manufacturing of the FCEV propulsion system and related extraction and refining 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 essential 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 must be developed for FCEVs.

C.4 Research Requirements

The H_2 and fuel cell technologies are now in a process of accelerated development, showing 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 (2024-2026) 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 H_2 storage technologies and their BoP (balance of plant) components
  - Simulation tools and development methods
- Electrolysis (all types) - cell, stack, system and systems powered with renewable energies
  - Efficient production technologies for PEM electrolyzers for efficient production of green H_2 powered by electricity from renewable sources

    - Energy efficient, low cost and ageing-resistant catalysts for the efficient conversion of green H_2 and CO_2 to e-fuels
    - Ageing resistant and low-cost oxygen and proton conducting ceramic materials with reduced amount of critical elements for solid oxide electrolysis of H_2O or co-electrolysis of H_2O and CO_2 for the efficient production of e-fuels
    - Process management and control
    - Inexpensive and efficient auxiliary units (BoP components)
    - H_2 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)
    - Improving the tolerance of future fuel cell systems to H_2 quality, as this can eliminate the requirements for refueling with H_2 and the sometimes-complex cleaning, for example when connecting H_2 filling stations to an H_2 pipeline network.
- 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 drivetrain (battery, power electronics etc.)
    - Evaluation of crash situations (Emergency Response Management)
    - LCA, Recycling Concepts, Life cycle optimization
    - Impact of new Eco-design Regulation
    - Establishment of an independent legal regulation for the periodic technical monitoring of H_2 vehicles and their H_2-specific components.
- 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
- H_2 refueling infrastructures for all vehicle categories
    - Process management
    - Safety-related communication between HRS (Hydrogen Refueling Stations) H_2 powered vehicles
    - Logistics (distribution and storage of H_2)
    - More reliable and efficient components and systems
    - Rapid H_2 refueling ("dynamic-data" H_2 fueling) and the associated upgrade of components and controls
    - Focus on the development of cost optimized H_2 tank system components
    - Studies on the creation of uniform approval guidelines and requirements for HRS in Austria
- H_2 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 H_2 systems and components with focus on supplier industry

C.4.1 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 expertise and ability, 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 and implementation of large fleets
- Funding for participation: creation of an EU-wide legislative framework as well as directives and standards
- High TRL research – market launch and fleet testing

While there is no question that H_2 -powered vehicles in near future need to run exclusively on H_2 from sustainable production, this requirement is often a hurdle for R&D projects, as green H_2 is not yet available everywhere. It would therefore make sense not to see this regulation as a basic requirement for funding R&D projects if H_2 from renewable sources is not available.

C.4.2 Estimated National R&D Project Volume for "Fuel Cell Electric Vehicle and H_2"

Starting in 2023, an annual[19] volume of 65 M€ is estimated for R&D projects on fuel cell electric vehicles and H_2. 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 of 1 M€ each
- 15 M€ for cooperative R&D projects, experimental development and industrial research: 5 projects of 2 M€ each
- 30 M€ for Flagship Projects: 3 projects of 10 M€ each
- 10 M€ for R&D infrastructure (support of laboratory 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 %.
Additionally, to the necessary funding volume for R&D projects we suggest about a
40-60 M€ budget for the implementation of fleets and infrastructure.

[19] for projects granted within one year – project/funding volume for the whole project duration

D R&D Challenges: Hybrids and Sustainable Fuels 2024+

This Position paper summarizes the R&D requirements of hybrid powertrains incl. hydrogen combustion engine (H_2 ICE) fueled with sustainable liquid and gaseous fuels, i.e. incl. “green” H_2. H_2production from non-fossil sources as well as distribution, storage and hydrogen refueling stations (HRS) are addressed in chapter C **Fehler! Verweisquelle konnte nicht gefunden werden.**.

D.1 Trends on Technology Development and Research Demand

Although this position paper focuses on the automotive sector with on- and off-road vehicles including non-road mobile machinery, 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.** H_2– i.e. biofuels and so-called RFNBOs (renewable fuels of non-biological origin)[20] – 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 H_2) 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 H_2in internal combustion engines (ICE) (as well as turbines) – in pure ICE and hybrid powertrains can help to increase the demand for H_2 as a transport fuel in the near future. This could make a H_2network and H_2refueling stations economically viable much sooner.

Fuel-side measures have a high potential for reducing GHG emissions. Firstly, 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. H_2 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 2024+:

1) Efficiency improvement of the powertrain system by all kinds of hybridization including range extender architectures with ICEs along with intelligent operating strategies for matching current and future emission standards, optimal and predictive thermal and energy management, waste heat utilization (e.g. on-board fuel reforming from waste heat recovery) and loss reduction through electrification of auxiliary units.

[20] https://energy.ec.europa.eu/publications/delegated-regulation-union-methodology-rfnbos_en, retrieved 8 May 2024

2) Continuous development of sustainable fuels - including the efficient production of H_2 from renewable electricity sources and CO_2, or from synthesis gas e.g. by co-electrolysis of H_2O and CO_2.
3) Upgrade of biogas to fully convert biogenic carbon to biofuels.
4) Continuous research on energy efficient, low cost and aging resistant catalysts
5) Technology research and development on hybrid transmissions to achieve highest powertrain operation efficiency.
6) Overall efficiency improvement of ICE in combination with sustainable liquid and gaseous fuels, particularly H_2.

D.2 Essential Legal Framework

To facilitate the deployment of sustainable fuels and hybrid powertrains, policymakers are encouraged to:

- Create an EU-wide legislative framework and directives for rapid implementation of an efficient and climate neutral mobility, enabling the 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 investments, even if very expensive, but these can only be made on a sound basis.

D.3 Life Cycle Assessment and Circular Economy

A key factor for Life Cycle Assessment (LCA) of hybrid vehicles is the energy demand and efficiency throughout the vehicle's entire lifetime - from production via operation to recycling. While research focuses on increasing system efficiency, LCA must consider a "bigger picture", e.g. considering 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, H_2production, 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.

D.4 Research Requirements

The research requirements listed below are expected to be most relevant within a short-term perspective (2024-2026).

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).

D.4.1 Hybrid System

- New hybrid topologies
  - Increase of efficiency and thus reduce GHG emissions
  - Development of 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 lifetime 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")

D.4.2 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)
    - Efficient production processes of liquid and gaseous energy carriers (e.g. biofuels and RFNBOs), produced from H_2 from renewable electricity sources and CO_2 in view of cost-per-unit impact
  - Low cost and ageing resistant oxygen and proton conducting ceramic materials for solid oxide co-electrolysis of H_2O and CO_2 for the efficient production of RFNBOs, in view of cost-per-unit impact
  - Economic processes for capturing CO_2 from exhaust gases, flue gases, or other sources (no economic solutions exist so far on the medium scale capture)

  - Gasification technologies and other thermal processes to produce biofuels (e.g. gasification of biomass followed by synthesis to liquid or gaseous fuels etc.)
  - Upgrade of biogas to fully convert biogenic carbon sources to e.g. synthesis gas
  - 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
  - Energy efficient, low cost and aging resistant catalysts
  - Adaptation of powertrain systems for the application of higher blends of sustainable fuels
  - Safe on-board storage of sustainable gaseous and liquid energy carriers with high energy density and low specific costs
  - 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)
  - Rapid and efficient H_2 refueling ("dynamic data" H_2 fueling) and the associated upgrade of components and controls

D.4.3 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
  - Components and systems for range extender architectures

D.4.4 Thermodynamics of the ICE including Exhaust Gas Treatment

- Combustion technologies for sustainable fuels incl. H_2in compliance with future legal requirements
  - Low-pressure port/direct injection H_2 engine (H_2-injector, tank/gas pressure for PFI/DI ignition system, combustion stability, avoidance of backfiring/anomalies, safety of H_2 engines)
  - High-pressure direct injection H_2 engine (tank/gas pressure, H_2-DI-injector, combustion stability/anomalies, safety of H_2 DI engines)
  - Optimization of H_2engines in terms of torque and power density, transient operation, efficiency and costs
  - 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 % "plus" 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
- Special measures to reduce cold start emissions

- Material technology for engine (and transmission) 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

D.4.5 Requested National Funding Instruments for "Hybrids and Sustainable Fuels"

- Low TRL research also including support for RTD work of start-ups and spin-offs
- 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
- High TRL experimental development with focus on vehicle test fleet operations to prepare for industrialization

D.4.6 Estimated National R&D Project Volume for "Hybrids and Sustainable Fuels"

Starting in 2023, an annual[21] volume of 75 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, fleet testing, field tests and R&D infrastructure:

- 8 M€ low TRL research: 8 projects of 1 M€ each
- 12 M€ for applied & cooperative research: 6 projects of 2 M€ each
- 30 M€ for flagship projects / cluster of flagship projects: 2 projects of 10-20 M€ each
- 10 M€ for high TRL experimental development: 1-2 projects of 5-10 M€ each
- 15 M€ per year for R&D infrastructure

This **total R&D project volume of 75 M€** should be supported with a **funding volume of about 37,5 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

[21] for projects granted within one year – project/funding volume for the whole project duration

E R&D Challenges: Advanced Vehicle Concepts 2024+

E.1 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 drivetrain (see "**Fehler! Verweisquelle konnte nicht gefunden werden.**" and "**Fehler! Verweisquelle konnte nicht gefunden werden.**") - 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, must 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

E.1.1 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. In the future, these systems will interact both with each other and with infrastructure. 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 must 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.

An overarching system of systems engineering approach enables the analysis and optimization of complex systems composed of multiple subsystems. 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 needs to be developed.

For this system of systems approach it is 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

E.1.2 Optimal Control and Offboard Functionality

E.1.2.1 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, 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.

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.

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, 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 during development as well as during manufacturing final testing before delivery. 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 demands of vehicle and vehicle powertrains.

E.1.2.2 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 for single components but additional complexity for the combined integrated system

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

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.

E.1.3 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.

E.1.3.1 Energy Management and Energy Efficiency:

Thermal consideration is highly essential both for the overall vehicle management and the battery electric propulsion system in particular. The latter aspects can be found in chapter B The present A3PS position paper **"R&D Challenges 2024+"** summarizes envisaged developments and trends, as well as priorities of the industrial and scientific A3PS members. It provides an overview on the R&D challenges in the coming years and the necessary R&D activities to strengthen Austria as a business location.

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

4) **Support of mobility and powertrain technologies & innovations** in Austria, taking a holistic view of the value creation process, based on the **LCA (Life Cycle Assessment)** method ("from cradle to grave") to meet the 2030 targets and to enable mission 2050 targets in full.
5) **Establishment of a legal framework**, norms, standards and a strategy for R&D activities, the rapid implementation of R&D results and for regular operation (street / off-road / rail).

6) **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.

A3PS considers primarily R&D topics in this position paper. A3PS is convinced that investing in and therefore funding research is the most effective way for the achievement of more sustainable, more efficient and cost-effective technologies.

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 2024-2026 (download at https://www.a3ps.at/a3ps-position-papers.

A more extensive list of research requirements including **mid-term** (2025-2030) 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.

All sustainable technologies are 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.

E.2 Circular Economy

Circular economy must be considered in all technology sectors. This increases the research demand since, besides functional efficiency, additionally safety, security, durability, 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”. 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.

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, 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.*

E.3 A3PS – Austrian Association for Advanced Propulsion Systems

A3PS and its members from industry and research institutions discussed, phrased and prioritized the contents of this position paper in early 2024. Founded in 2006 as an initiative of the Austrian Ministry of Technology, 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 to keep Austria competitive. All R&D topics presented in the A3PS area – such as this position paper – comprise only CO_2-neutral solutions, global oriented.

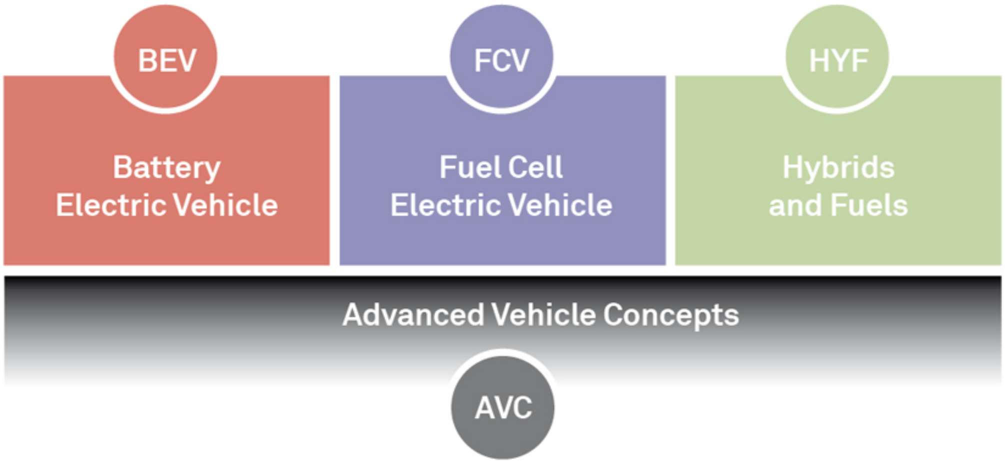

Fig. 1: 4 A3PS thematic expert groups

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. The wide range of different technologies in expert group AVC is addressed in two chapters within this position paper:

- Advanced Vehicle Concepts, including automatization, digitalization, connectivity – the vehicle as part of the "system of systems."
- Innovative Materials and Vehicle Production Technologies

R&D Challenges: Battery Electric Vehicle 2024+.

Trustworthiness for range prediction and charging of electrified vehicles must 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 considering time-dependent available power at charging stations. This requires the knowledge of the demand of other drivers, a decent information and control system and 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 this 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 one key aspect for reliable range prediction (especially in winter). For all kind of HV-battery (integration) concepts highly efficient thermal conditioning to reach highly thermal uniformity must be ensured.

The formerly independent subsystem controls must either be integrated to form a central control unit or must be increasingly communicating with one another.

E.3.1.1 Vehicle Safety

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

Vehicle technology: Developing new technologies that assist drivers and enhance safety is a key research area. This includes systems such as collision avoidance, lane departure warning, and adaptive cruise control that require to be integrated on complete vehicle level.

Human-machine interaction: As vehicles become more automated, studying how drivers interact with these systems and ensuring they are intuitive and user-friendly is important.

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 2024+" 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 2024 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 must 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 must 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 must 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.

E.3.1.2 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 vehicle operating strategy from complete vehicle level down to system behavior, the development of new materials for tires and brake pads that generate fewer and less toxic particles or even capture those, the implementation of measures to reduce road surface abrasion, and the use of dust suppression technologies at construction sites.

E.3.2 Life Cycle Assessment and Circular Economy

Meaningful Life Cycle Assessment (LCA) of vehicles must cover the entire life cycle including material origin, 2nd 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 eco-driving can decrease energy demand. Supply chain engagement, education and involvement for LCA, i.e. data collection, needed for diverse legal and taxonomy reporting requirements regarding Product Carbon Footprint and the necessity to consider a wide range of global differences in the method applied for automotive LCA and required Product Carbon Footprint reporting) must also be considered.

E.3.3 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).

E.4 Research Requirements

The research requirements listed below are expected to be most relevant within a short-term perspective (2024-2026).

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).

E.4.1 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)[22], as well as manufacturing end of line testing.

- (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), as well as manufacturing final testing.
- Development of test and approval procedures for HAD + HIL, in particular early clarification of the scope of requirements or AI (artificial intelligence), as well as manufacturing final testing.
- Implementation of urban test scenarios with test options both on dedicated test fields and in field tests in public spaces
- Development of vehicle concepts with a focus on the overall vehicle safety concept and homologation, especially for vehicle categories for which the guidelines from the automotive sector can only be applied to a limited extent. Examples of this include self-propelled work machines and special vehicles such as tractors and agricultural machinery, construction machinery, forestry, and municipal technology.
- Studies and equivalence considerations for the normative anchoring of at least excerpts from the guidelines for electric and H2 drives tailored to cars and trucks as a basis for conformity and approval for self-propelled work machines and special vehicles.

> 4 Projects of 3 Mio Euro each

E.4.2 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
- 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)
- 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

> 3 Flagship Projects of 5 Mio Euro each

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

E.4.2.1 Sensors and xCU

- Sensor fusion and virtual sensors (including quantification of uncertainty)
- Sensor modelling and digital twinning
- Real time health monitoring methods and data management of components and EDUs for reuse applications
- Enlarged use of AI methodology and digital twins for predictive and model-based control functions and component maintenance
- New testing and validation methodologies und systems (e.g. continuous testing, SIL) for development phase, as well as manufacturing final testing
- 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 of 2 Mio Euro each

E.4.3 Specific Requirements for Energy Efficiency, Safety and Non-Exhaust Particle Emissions

E.4.3.1 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 systems considering environmental conditions (weather, traffic etc.)

> 3 Projects of 1 Mio Euro each

E.4.3.2 Vehicle Safety

- 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)
- Driver behavior and cognition
- Developing new technologies that can assist drivers and improve safety
- HMI concepts that consider driver states and methods to validate HMI-concepts in early concept phases of complete vehicle development
- Acceptability and trust
- 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) in particular 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 of 2 Mio Euro each

E.4.3.3 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 of 2 Mio Euro each

E.4.4 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 of 5 Mio Euro each

E.4.5 Estimated National R&D Project Volume for “Advanced Vehicle Concepts”

Starting in 2023, an annual[23] 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 M€ low TRL research: 3 projects of 1 M€ each
  - 6 M€ low TRL research: 3 projects of 2 M€ each
  - 16 M€ for applied & cooperative research: 8 projects of 2 M€ each
  - 12 M€ for applied & cooperative research: 4 projects of 3 M€ each
- 25 M€ for flagship projects: 5 projects of 5 M€ each

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 %.

[23] for projects granted within one year – project/funding volume for the whole project duration

F R&D Challenges: Innovative Materials and Vehicle Production Technologies 2024+

F.1 Position

F.1.1 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.

F.1.2 Development Processes

The seamless introduction of networked development backbones, which provide the information across the different technology areas and lifecycle levels, 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. Equally important is to efficiently incorporate the production requirements to the product from manufacturing into development to ensure efficient manufacturability in general but especially for new technologies.

F.1.3 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 enable this, the materials must be further optimized for this purpose, the processes (e.g. energy parameters) must be optimized and must be even faster, cheaper and with higher throughput, for which great efforts must 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.

F.1.4 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, planning and execution, 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.

F.1.4.1 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.

F.2 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 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 GHG-optimized design and GHG-optimized operation of a vehicle.

F.3 Research Requirements

The research requirements listed below are expected to be most relevant within a short-term perspective (2024-2026).

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).

F.3.1 Innovative Material Design

F.3.1.1 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

F.3.1.2 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

F.3.2 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)

F.3.3 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

F.3.4 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
- Development of generative and self-learning production planning tools
- 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

F.3.5 Estimated National R&D Project Volume

Starting in 2023, an annual[24] volume of 50 M€ is estimated for R&D projects 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 of 1 M€ each
- 10 M€ for cooperative R&D projects, experimental development and industrial research: 5 projects of 2 M€ each
- 20 M€ for flagship projects: 2 projects of 10 M€ each
- 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

[24] for projects granted within one year – project/funding volume for the whole project duration

G 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
HVB	High Voltage Battery
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 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 Electrolyzer 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

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