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, 2^{nd} 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