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 "R&D Challenges: Battery Electric Vehicle 2024+" and "R&D Challenges: Fuel Cell Electric Vehicle and H_2 2024+") - 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 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.1.3.2 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.1.3.3 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.1.4 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.1.5 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.2 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.2.1 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.

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

- 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.2.2 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

E.2.2.1 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.2.3 Specific Requirements for Energy Efficiency, Safety and Non-Exhaust Particle Emissions

E.2.3.1 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.2.3.2 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.2.3.3 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.2.4 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.2.5 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