EARPA Position Paper

Research Needs on Powertrains and Energy Systems (PES)

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About EARPA

Founded in 2002, EARPA is the association of automotive R&D organisations. It brings together the most prominent independent R&D providers in the automotive sector throughout Europe. At present its membership numbers 58, ranging from large and small commercial organisations to national institutes and universities.

Scope

The EARPA Foresight Group (FG) Powertrains and Energy Systems is supporting the continuous development and integration of clean and efficient electrified powertrains as well as powertrains working on alternative fuels with a holistic view on the EU energy system. For BEVs optimal energy use cannot be seen without considering thermal comfort of passengers, therefore optimal predictive and advanced thermal management plays a dedicated role in this FG. Special emphasis is put on the symbiosis between electrified transport and electrical grids. This group aims at anticipating the forthcoming research needs that cannot be addressed by industry or academia alone but that need support from future research and innovation framework programs.

Context

A clean and seamless passenger road transport system is requested to support the achievement of a future sustainable society in Europe. The main and urgent objective is to expedite the reduction of CO_2 emissions from transportation. This effort is crucial to achieve a climate-neutral transportation system by 2050, instilling confidence in realizing a global warming scenario of less than 2 °C. In order to realize sustainable mobility in Europe, tank-to-wheel CO_2 emissions of road transport should be reduced by 69% (or even 90% according to the European Green Deal) by 2050 based on 2010 emissions[1]. This objective is politically aimed to be mainly achieved by a shift of energy carriers to renewable electricity and hydrogen as renewable fuels are not yet recognized in the fleet Green house gas (GHG) reduction targets, supported by vehicle optimisations (aerodynamics, weight, etc.), powertrains electrification to support a transport system with an overall minimized energy demand.

The focus should shift from current targets to technologically driven innovations towards the identification of future societal needs in terms of mobility in order to link more efficiently the passenger transportation system to the different energy sources available. With the aim of reducing the GHG emissions and of achieving "near zero" impact on air quality, in-depth thinking is also required to identify the most appropriate energy carrier for each unique transport mission, and this will only be possible by adopting a holistic view of the energy system in Europe.

There is no single and ideal powertrain solving the demands of sustainable mobility, and addressing both the environmental impacts and the requirements of global markets and European competitiveness. Electric vehicles are identified as one part of the solution but the only reasonable

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[1] "EU Road Vehicle Energy Consumption and CO2 emissions by 2050", https://www.2zeroemission.eu/wp-content/uploads/2019/08/CO2-study.pdf, 2019

approach is to impartially support a mix of technologies and to carefully check their progress and market success in order to leverage the most sustainable, cleanest and most cost effective solutions.

All powertrains must now be assessed based on Well-to-Wheel (WtW) emissions and the overall CO_2 and resources footprints of future mobility solutions must also be evaluated through Life Cycle Analyses (LCA) of all components and systems in order to identify the truly sustainable transport solutions. It is thus essential to adopt a comprehensive approach on powertrains optimization, by considering advanced tools, methods and standards. Furthermore, meeting the expectations of both regulatory bodies and users necessitates a dual strategy. This strategy involves continuously enhancing existing solutions and developing entirely new ones. These innovations must align with environmental acceptance, total cost of ownership, and societal investments, encompassing critical aspects such as infrastructure for charging, grids, pipelines, and other essential components.

Research needs and expected impact

Several proven solutions exist to enhance the sustainability of the transportation system, e.g. fleet renewal policies. However, their implementation faces hindrances, primarily related to cost-effectiveness, insufficient energy infrastructure, and a lack of widespread user acceptance. Therefore, urgent and multifaceted action is imperative. In light of the significant challenges at hand, the EARPA Foresight Group on Powertrains and Energy Systems anticipates critical research needs in the following key areas:

1. **Holistic view on the EU energy system**
   Considering electricity grid, energy storage systems stationary and V2G or V2B, hydrogen and sector coupling but also e- and synthetic fuel production with the objective to reduce GHG emissions and the overall system and energy cost (also in a transition phase)
2. **Clean and efficient powertrains and Auxiliary Components**
   Energy Storage Systems, Electric drives and Power Electronics
3. **Powertrain Control and holistic and predictive energy management optimal energy use**
   Considering also advanced thermal management balancing thermal comfort of components, passengers and goods in a predictive and holistic way

Holistic view on the EU energy system

A critical imperative is the in-depth analysis of future energy usage scenarios across Europe, aimed at optimizing the intricate interplay between energy production, storage, distribution, and transportation systems. This analysis should encompass an evaluation of the synergy between potential energy carriers such as electricity, H_2, e-fuels, biogas, and biofuels, aligning them effectively with diverse transportation missions and other sectors like chemical industries and heating. The expected impact is an increased efficiency and use of clean energy in future powertrains, significantly reducing fossil WtW CO_2 emissions. Well-chosen synergies with other sectors and a wise usage of also imported renewable energy will be beneficial to reach emission current and future targets.

The transport sector presents valuable opportunities to stabilize the energy system. Battery capacity within vehicles and bidirectional charging offer potential for buffering excess electrical energy. Additionally, the production of hydrogen, hydrocarbons, or alcohols from recycled CO2 using renewable power serves as an alternative energy storage method, ensuring a reliable energy supply for all energy users, akin to the existing approach.

As it seems that renewable energy imports will play a major role on the way to sustainability, it is of very high importance to correct sizing the energy system in Europe, the possibilities to store temporary renewable excess energy in Europe, but also to import dedicated chemical renewable energy from outside Europe, and to also understand which mixture of energy carriers in transport make sense including bio-fuels. Transferring imported chemical energy back to power can be an option, but might be less efficient than using imported energy carriers in transport and use the European renewable electricity in heat applications or elsewhere. This discussion and a broader view on Europe's capabilities on renewable energy production is needed to avoid high efforts in electrification in areas with high additional infrastructure cost, if chemical energy carriers have to be available anyhow.

Therefore, a significant research need is to determine future energy flows in Europe and to combine the possible energy availability with drivetrain development. In line with this, Europe's development efforts in drivetrain research will match better with the potential energy sources based on the total cost for the society and the fast track to fossil free mobility.

A strong contribution towards defossilisation of road transport, e.g. also of the existing fleet, will be achieved by increasing the share of low carbon, alternative, and renewable gaseous and liquid fuels such as 2nd and 3rd generation biofuels, e-fuels, hydrogen, etc. Research needs are clearly identified to pursue the development of these future fuels with an expected impact on reduced WtW CO_2 emissions.

In 2030, these fuels should cover more than 60% of the energy demand for road transport using pure thermal powertrains, and up to 90% considering hybrid vehicles[2]. The buffering of electric energy from renewables will play a key role in a carbon-neutral future. Furthermore, renewable fuels from non-bio-based origin will be significantly required due to needed energy imports into Europe (for which bio-based fuels are critical regarding e.g. Indirect Land Use Change and much more difficult to control). Additionally, even the fleet in 2050 will contain significant amounts of cars being built from today until 2030 which will be required to operate on CO_2 neutral fuels.

Hence, further work on engine efficiency, optimization steps to maximize the potential of renewable fuels, options for fuel flexibility regarding combustion system and controls and dedicated range extender engines to match future electric vehicle platforms for enabling very long range in a weight and energy optimal way are relevant topics to be covered in future research programs.

Clean and efficient powertrains and auxiliary components

In order to provide maximum benefits to customers and society, the assessment of powertrains has to be twofold: increasing the efficiency yields the lowest energy demand from WtW. LCA can also take into account the production of vehicles and source of energy as well as potential energy imports. So Internal combustion engines (ICEs) with CO2 neutral fuels and electric powertrains can be complementary to achive a fast transistion to a fossil free Europe. Electrified vehicles, such as HEV or EV with range extenders, set specific demands for the ICE and, as a consequence, ask for dedicated engine configurations. There is thus a need for additional research and development to optimize future ICEs specifically for electrified powertrains, with a clear focus on a limited operating range of the engine but featuring very high efficiencies (>50%) thanks to high dilution rates and low carbon renewable fuels.

Losses reduction is an important topic of future research activities for ICE-powered vehicles for which a significant part of the fuel energy is not used to propel the vehicle. Electrified auxiliaries, electrified turbocharging, heat recovery systems, advanced thermal-management strategies or even innovative components based on additive manufacturing are promising opportunities to support the reduction of these losses but most of them are still not viable for cost-effective mass production.

ICE-powered vehicles will have to comply with increasingly stringent regulations for noise, for already regulated exhaust emissions, and for still non-regulated exhaust and non-exhaust emissions that must be further investigated. Careful evidence-based consideration is required for post Euro 7 / VII

[2] Future Fuels: "FVV Fuels Study IV", https://www.fvv-net.de/fileadmin/Storys/020.50_Sechs_Thesen_zur_Klimaneutralitaet_des_europaeischen_Verkehrssektors/FVV__Future_Fuels__StudyIV_The_Transformation_of_Mobility__H1269_2021-10__EN.pdf

regulations and beyond and for their impacts on vehicle requirements, test verification and on-board monitoring technologies safeguarding real-world emissions. Powertrains with a "near zero" impact on air quality must be developed in particular for vehicles (partially) operating in urban environments. Here again on-board monitoring will be needed for the aftertreatment. Clean combustion processes, combined with low carbon renewable fuels and enhanced catalytic after-treatment systems using less precious metals and electrical heating are required to achieve near zero emissions, especially for heavy duty applications. Hence, highly electrified powertrains such as range extender configurations are a great opportunity to further lower pollutant emissions with an immediate impact on GHG emissions and air quality while limiting cost and complexity. In order to reduce pollutant emissions in real driving conditions, advances are also required in model-based vehicle and fleet monitoring, and in model-based connected control strategies for real time optimisation and over the vehicle lifetime. Geofenced areas will also potentially require additional functionalities of these vehicles. Development of anti-tampering systems have to be increased as well.

The large-scale deployment of electrified powertrains calls for low cost, light-weight and highly integrated components. Advanced drivetrain concepts (wheel or axle motor concepts) will open new opportunities in vehicle design. Future research activities on modular and scalable architectures for electric drivetrains will play a key role for fully EV concepts, in terms of cost reduction and potential for mass-manufacturing, and also in terms of efficiency: 90% plug-to-wheel driving efficiency[3] over WLTC is expected, as well as a 30% efficiency improvement due to an optimized energy management and a strong reduction in parasitic losses.

The limited EVs sales so far have not yet unleashed the potential of mass production techniques applied to electric motors. In addition, powertrain modularity, scalability, and possibly standardization as well should be further enhanced. Electric motors are inherently very efficient, and it is now necessary to reduce their size and weight by targeting high power density, while limiting their environmental footprint. Therefore, motors free of rare earth materials, with easy end-of-life dismantling, and with high recyclability rate should be developed (especially magnets can be recycled and designs have to cope with this possibility). To do so, power dense high speed electric motors equipped with high voltage power electronics modules based on wide band gap (WBG) components could be a good solution to investigate. This will offer a better functional integration with other driveline components. The required power density is a critical aspect and target of optimization. Research work on high-speed transmission is necessary to operate the e-motors in their optimal efficiency. An innovative framework requires a holistic multi-physical approach to optimize the different components within the electric vehicle powertrain in a multi objective scenario, i.e., electromagnetic, thermal, mechanical, NVH, control aspects need to be fully integrated.

Power electronics modules using WBG devices have the potential to deliver a paradigm shift in the energy efficiency considering as well real-life operation in comparison with mature silicon technology. Therefore, new inverter topologies that integrate innovative concepts for high voltage modules on WBG components with low power losses and improved thermal performances need to be investigated. These systems will have to be developed for the next generation of electrified powertrains enabling high system efficiency (motor and inverter) and compactity. Future developments of power electronics modules will have to address recyclability, highly efficient fast battery charging, wireless/inductive charging, and regenerative braking, combined with predictive control strategies. R&D into higher voltage power electronics is a key enabler in a move towards next generation powertrains, which may be required to suit ultra-fast charging. Communication and protocols that are standardized throughout Europe are essential to get the e-mobility and charging system of systems working, thus a close collaboration with the foresight group connectivity automation and safety of EARPA is needed.

Fuel cells, in combination with electrification remain to offer potential where immediate access to charging is not possible, or where high energy density is required. To improve the cost of such

[3] https://www.ertrac.org/wp-content/uploads/2022/12/ERTRAC-Fuels-Powertrains-Research-Needs-Mapping-Final-Version-December2022.pdf

technologies, modular systems with high durability/lifetime are required. Likewise, strategies optimising the BoP of such systems should be developed in combination with advanced diagnostic functions and holistic energy management. Finally in such systems, it is essential that integrated thermal management and advances in hydrogen storage technologies be further developed.

Electric energy storage systems are key components of electrified powertrains, directly affecting their general performance. Overall, range, cost, weight and user-friendly smart charging options for these systems are the main factors for success. The expected impacts of research activities on electric energy storage systems needs are the extension of the driving range of EVs up to 500 km, the extension of their lifetime up to 20 years calendar life, and a cost reduction below 90 €/kWh[4].

With the support of the European Battery Alliance and taking into account the foreseen deployment of electric vehicles, there is a clear opportunity for Europe to spearhead the development and manufacturing of future battery cells.

There are various levels of maturity in energy storage systems considering the current generations of lithium ion batteries and future post-lithium cell technologies. R&D is of utmost importance and an efficient and smooth transfer of results to the industry is a must. Research into new materials and storage technologies is needed to improve energy density and durability, keeping in mind fast charging characteristics. For this purpose, an extra effort is needed in materials development, understanding degradation phenomena at the interfaces, and in multi-scale modelling which is essential for optimizing the lifetime and safety of batteries.

Further research activities should be undertaken regarding battery management systems in order to design advanced concepts for electrical and thermal control of modules and packs. The focus should be on safety and thermal management issues, especially for vehicle operation in extreme environmental conditions. The development of advanced light-weight materials at the pack level is a must to improve the structural resistance and to anticipate the second life and re-use of battery packs. Maintenance operations should also be addressed by optimizing the packaging and modularity and by developing new software-based remote strategies or by integrating additional sensors at cell, module and pack levels. Finally, research is required into higher voltage systems compatible with ultra-fast charging, including the insulation challenges that these voltages bring.

Due to the increasing number of xEVs in Europe, LCA, second life, repair, re-use and recycling issues are of high relevance from the environmental point of view and also as a business opportunity. Several options can be considered for re-using used but valuable storage systems, but it is of utmost importance to be able first to estimate the remaining life of a used battery pack. For this purpose, multi-scale modelling tools are to be developed in combination with state of health diagnosis of such batteries to ensure the long-term sustainability of the battery market. Circular economy considerations and efficient recycling of raw materials are vital to reduce Europe's material dependence on less politically stable areas and markets. This includes research on recycling processes and proposals for a supporting policy.

In general terms, the various patterns of charging and discharging create the need for normalized tests to assess the impacts on the performance and lifetime of battery packs. Fast charging and grid connected vehicles (V2G) for example will require to go along with the investigation and standardization of testing methods and simulation tools for systems and components. New charging

[4] The EU's industrial policy on batteries New strategic impetus needed: https://www.eca.europa.eu/ECAPublications/SR-2023-15/SR-2023-15_EN.pdf

concepts that allow for smaller batteries, e.g. battery swapping and ERS must also be taken into account.

Powertrain Control and holistic and predictive energy management optimal energy use

Minimizing vehicle energy demand over actual and future type approval test cycles (including real-drive conditions) is not only about optimizing the performance of sub-components, but also about the complete system through smart control. The expected impact of research activities on powertrain control and system optimization is to place European manufacturers, components and services suppliers at the leading position to increase their competitiveness.

Thermal management of the main and auxiliary powertrain components needs to be addressed as well as the various vehicle system functions with a holistic approach. The potential of shared and combined cooling circuits, the optimized use of the heat dissipated by the drivetrain, and smart energy management strategies (e.g. cabin pre-heating in cold conditions) must be exploited.

New control strategies based on continuous total optimization at a system level will be required for all types of powertrains, from hybrid powertrains using optimized ICEs with more complicated structure, (i.e. WHR, Miller timing, Advanced thermal coatings, e-turbos etc.), to electric vehicles featuring more flexibility and modularity. Adaptive control systems and associated sensors need to be developed to optimise the use of on-board energy and to control real driving emissions. Digitalisation and connectivity of future vehicles (V2X) will support these approaches and enable predictive and real time control based on the real operating state rather than on a traditional map-based approach. The introduction of techniques like Artificial Intelligence will also require investigations with respect to improvements and optimisation of powertrain implementations and their use in a connected environment. New virtualisation and testing methodologies will be required for the development, verification, and validation of these systems.

Contributions from on-board systems for reduction of energy demand using online or stored traffic and situational information have significant potential for CO_2 reduction in real life conditions. As of now, these benefits cannot be proven by the VECTO tool for CO_2 values of heavy duty vehicles. To push forward technologies that contribute to real life CO_2 reductions, additional proven CO_2 benefits should be rewarded as eco-credits even before they are formally introduced in the certification tool updates[3].

The adoption of V2X connectivity and automated driving functions will also improve customer acceptance by lowering energy demand and giving better vehicle range. Concepts for predictive control of energy management, possibly coupled with automated driving, need further emphasis to allow real-world applications and improve reliability of the prediction of range. Traffic data and big data management for transport applications will also play a role in this context.

Relation to other roadmaps or other FG

EARPA sees the requirement to identify actual research topics on a European level, in close co-operation with all relevant stakeholders and European initiatives (e.g. Hydrogen Europe and European Battery Alliance). The research needs identified here by the Foresight Group Powertrain and Energy,System within EARPA are fully aligned with parallel initiatives and analyses originating from the European Institutions[4, 5], from 2Zero[6], and from ERTRAC[7, 8, 9, 10].

Taking advantage of their expertise, EARPA members contributed to several roadmaps on a neutral basis in order to promote innovations and to maximize the impacts of research activities in the field of road transport. Strengthening the existing ties between the relevant stakeholders is a success factor for the European research and innovation area. With their research capacities and expertise, EARPA members are playing a key role in that context and contribute to raise awareness among public authorities and general public on the continuous research needs towards an affordable and sustainable road transport system.

Finally, also the relation to international programmes, e.g. those funded by the US Department of Energy or by the Japanese Cross-ministerial Strategic Innovation Promotion Program confirms the vital interest on research and innovation in the fields of Powertrain and Energy Systems.

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