EARPA Position Paper

RESEARCH AND INNOVATION ON HYBRID & ELECTRIC COMPONENTS & SYSTEMS TOWARDS HORIZON 2020

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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 51, ranging from large and small commercial organisations to national institutes and universities.

Research, Development And Innovation on Hybrid & Electric Vehicles & Systems

High efforts on research and development have been made in the last years to push electric and hybrid vehicles and electric mobility forward. Today the electromobility concept has already proven its feasibility and benefits, with several commercial products –either hybrid or pure electric vehicles of all sizes-, already in the market from various EU and non-EU manufacturers. Then, it is time to focus research efforts towards supporting the roll out and market penetration of electric vehicles. With the ultimate target to ensure Europe's competitiveness and technological leadership in the electric mobility arena, next phase of the innovation cycle has to pursue enhancing **customer acceptance**, which is key for success. The concept of *customer acceptance* can be translated into five categories:

- Range improvement
- Cost reduction
- Charging speed and procedures
- Added value
- Mobility options

In this line, a working group was stablished early 2016 –with significant contribution form HESC TF members- to update the ERTRAC-EPOSS-SMARTGRIDS European Electrification Roadmap for Road Transport, the former versions dating from 2011/2012. This update basically reflects the framework evolution in the electromobility sector from technologically driven to customer acceptance issues. Nevertheless, the structure and targets of the HESC TF reflects the more technologically driven structure from the original Electrification and Hybridization roadmaps from 2011/2012, focusing around three of the technical cathegories included therein, namely **Energy Storage Systems**, **Drive Train Technologies**, and **Vehicle Integration**.

Within this context, EARPA partners identified high priority research topics, addressing technical challenges while bearing in mind their impact in user acceptance as key issue, and which should be implemented in the short-term in the final period of Horizon 2020. This calls for substantial and strategic research and development of all electric vehicle systems and components with these targets in mind, as a necessary effort to facilitate a general deployment of electric vehicles.

1. Energy Storage Systems

Electric energy storage systems are the key component of an electric vehicle, directly affecting its range, cost, safety and general performance. Research on the improvement of existing systems as well as of novel battery chemistries and materials is key to improve electric vehicles performance and their range of application. Furthermore, it is necessary to address manufacturing issues of any new material or battery technology. It is also necessary to develop battery options with fast charging characteristics. Overall, range, cost and user friendly charging options for the energy storage systems are the main factors for success at this point.

Research challenges and topics according to ERTRAC roadmaps:

- **Cell Materials towards Lifetime, Energy Density, Safety; Post-Lithium Cell Technologies; Battery Cell Degradation; Prototyping and scaling up of new battery technologies**

Next generation battery technologies and their manufacturing:

There is a clear opportunity for Europe in the next generation of battery technologies, a concept broadly comprising advanced Lithium ion, the so-called Post-Lithium ion, and even other lithium free technologies. These are areas of medium to low maturity, where R+D is of utmost importance, and where an efficient and smooth transference of results to the industry is a must. Research in new materials and storage technologies is needed to improve energy density and durability, keeping in mind fast charge characteristics, all of them key factors to satisfy customer expectations. For this purpose an extra effort is needed in materials development, understanding of degradation phenomena at the interphases, and modelling.

Also, in order to facilitate to bridge the gap between research and industry, it is necessary to introduce scaling up at pilot plant level since relatively early stages of materials research –fine tuning of processing conditions may be done at later stages-, as soon as a promising concept has been proven. This will allow making progress synergistically though the cell level TRL and MRL scales. The deliverable of this phase is the validation of the new materials and technologies at the electrode and cell pilot plant level, in a format close to the final product, hence facilitating transference to the industry and ultimately to the market. For this purpose, the experience accumulated in processing and fine tuning of materials for current lithium ion is of high value, serving also as a benchmark for the progress done.

- **Optimized Battery Packs: Battery Management Systems; Thermal Management; Light Weight Materials; Integration of Batteries into Vehicle Structure; V2G functionalities**

Module and pack engineering:

Advanced concepts for electrical and thermal design and control of modules and packs are needed to assure the best performance and cycle life possible out of a certain cell at the lower cost. On the subject of battery management systems, further research activities related to hardware and inter cell/module/package communication should be undertaken. As a concept, an holistic approach should be applied in order to maximize the performance of the final product, rather than the individual optimization at cell, module and pack levels.

Regarding research on integrating batteries into the vehicle structure, focus should be on safety and thermal management issues, especially under operation in extreme environmental conditions (e.g. intense and prolonged solar radiation). The need of using advanced, light-weight materials for structural parts at the pack level is a must. Aspects of second life, reuse and even maintenance operations should be further addressed already in the design of the energy storage system for first life application by improving the packaging, integration and the modularity of battery systems. Advanced functionalities at the Battery Management System should be developed in order to facilitate remote maintenance and troubleshooting, software uploading and other functionalities.

- **Life Cycle issues: Assessment Availability of Raw Materials; Recycling Processes for Li Batteries; Reuse and Second Life Concepts for Batteries**

LCA, Second Life and business model development:

LCA, second life, reuse and recycling issues are of increasing relevance taking into account the increasing number of xEVs in the European streets, and the consequent increase of used, valuable storage systems. There are several options to explore and develop for such used batteries, still retaining a significant storage capacity: jumping into stationary applications due to the end of their duty life, operating in the original field of application as aftermarket replacement, or just end their life in a sustainable, environmentally friendly way.

Second life and reuse of such preowned batteries is highly desirable from the environmental point of view, but also a source of business opportunities. In this sense, it is of utmost importance to be able to estimate the remaining life of a used battery pack. For this purpose multiphysics and other modelling tools are to be developed in combination with state of health diagnosis of such batteries, either at cell, module and pack level. This will be a valuable input to develop sound business models for the implementation of second life applications and in order to ensure the long-term sustainability of the battery market.

- **Research Testing Methods; Towards European Guidelines for Lifetime and Range; Batteries and V2G**

Testing and Standardisation:

Having in place a set of European guidelines (e.g. for range and lifetime) is considered an essential tool for RTD, even more where research is oriented to near market, high TRL activities. As an specific issue, the need to standardize the quantification of the impact of fast charging procedures in the battery both at the cell and at the pack level is of particular relevance. In more general terms, the various patterns of charging and discharging profiles will create the need of normalized tests to assess their impact in the performance and lifetime of battery packs. This needs to go along with the investigation and standardization of testing methodologies and simulation tools for systems and components. Further aspects, such life-cycle analysis and second battery life, must be also considered.

2. Drive Train Technologies

Research regarding diverse electric/hybrid drive train architectures needs to focus on the different subsystems or components as well as on the system integration and optimal energy management.

- **Next generation of electric motor for Mild Hybrids; Electric in-wheel motor to allow new vehicle architecture. New concepts, materials for electrical machines, low- cost & light-weight**

'Rare-earth free', high-rotational speed, efficient motors should be targeted in this context, equipped with wide-bandgap (e.g. SiC, GaN) power electronics modules to support increased operating temperature, higher voltages and adequate high speed switching frequency.

- **High efficient-, high voltage-, high temperature electrical power systems, compact & robust**

The large-scale deployment of hybrid and electric vehicles calls for low cost, light weight and highly integrated components (motors and power electronics). New and optimised drive train concepts, e.g. series/parallel, mild and full hybrids with a diverse degree of hybridisation will open new opportunities in vehicle design. Modular, scalable architectures for electric drivetrains will play a key role for both hybrid and fully electric vehicle concepts in terms of cost reduction and the potential for mass-manufacturing. Hence it is important, if possible, to use components for various functionalities, exploiting systems' structural and electrical synergies.

Highly efficient battery charging, i.e. plug-in recharging, wireless/inductive charging and regenerative braking, must be addressed by power electronics developments.

- **Integration of hybrid-electric transmission architectures and concepts**

To minimize the overall driving energy consumption, new energy recuperation, waste heat usage and energy harvesting concepts need to be considered. Various technologies should be investigated to identify the potential for improving overall system efficiency. Research in optimizing whole vehicle hybrid systems (rather than just components) would be advantageous. Kinetic energy recuperation systems for various applications need to be investigated, together with fast-charge/fast-discharge solutions (e.g. super-capacitors) for heavy duty applications.

- **Hybrid suitable combustion engines; High efficiency optimisation of downsizing**

Synergies between the cooling systems of the internal combustion engine and electric motor should be exploited in hybrid configurations, where possible. In the short to medium term, in order to satisfy near-future emissions regulations, the impact of 48V electrified drivetrains should be considered and research is required focusing on the increasing integration of 48V vehicle systems, e.g. mild hybrids, e-axles, B/ISG, compressors, anti-roll systems.

- **Range extender modules / generator sets, high integration of sub-/systems**

Auxilliary power units (incl. range extenders) are seen as a potential technology to further the deployment of electrified mobility. Either optimized, downsized combustion engines or fuel cell systems may be required to alleviate range concerns with an emphasis on cost and weight reduction, real-world emissions (including driving, cold-start and evaporative emissions), or multi-fuel use. Research is needed to further improve the ICE conversion efficiency towards a narrow operation point and customize downsized solutions for hybrid applications. In the case of fuel cells, the systems have to be improved in terms of power density, thermal performance, durability and cost. For overall vehicle optimisation, the thermo-mechanical integration of the electrified powertrain components, in particular the electric energy storage system, motor/generator and power electronics has to be investigated. In addition a higher level of integration of the electric motor and the ICE would lead to new design opportunities and demands. The necessity of auxiliary power units should be reviewed over the medium to longer term as electrical energy storage solutions increase both in gravimetric and volumetric energy and power density, whilst simultaneously reducing in cost.

3. Vehicle Integration

Vehicle integration tasks cover a wide spectrum of activities ranging from reducing the high energy consumption of accessories in current EV and new vehicle architectures taking up design opportunities due to electrifications up to the continuous rethinking of packaging and systems integration in dependence of newly developed components and subsystems.

- **System Integration & Modular Hybrid Architecture; On-demand auxiliaries and vehicle functions; Modularisation of subsystems and standardisation of component features and interfaces, in hard- & software**

Integrated devices with combining functionalities:

Enhancing packaging & integration of devices requires a systems approach, with emphasis on experimental activities (mock-ups, demo-vehicles, pilot applications). The main objective of future system integration is the delivery of high performance components with high power/energy density, manufactured with lightweight materials and reduced cost solutions. As an enabling technology to advance system integration, simulation tools for thermo-electric-mechanical systems should be further improved by accounting for proper electromagnetic shielding of high-voltage components. New packaging concepts have to go along with appropriate control systems, e.g. „new" optimized control architectures. Particularly inverter/charger concepts will play an important role in future hybrid and electric vehicles. In addition modular approaches need to be developed, enabling the design of novel vehicle/power train architectures, the identification of new modular systems and components as well as the investigation of flexible/adaptable architectures by means of exchangeable components/modules.

- **Increased system efficiency with existing components; Control strategies for electric components & vehicle energy management**

System Optimization:

Research and innovation activities regarding system efficiency are seen as important and continuous tasks for the next years to ensure the integration of newly available (at-time-existing) components into optimized systems. System optimization should simultaneously aim to achieve highest possible overall efficiency over actual and future type approval test cycles (including real-drive conditions), enabling to derive customized solutions for providing the end-user with the best value and the best LCA performance by the optimum use of raw materials, proving enhanced solution for future passengers and freight low carbon vehicles. Furthermore, system optimization will require developments in advanced control architectures and energy management functions, including the optimal control for hybrid and electric powertrain, and enhanced vehicle drivability and durability. The adoption of new technologies – particularly V2X connectivity and automated drive functions, topologies and control schemes for loss reduction on component level (power electronics, electric motor, low-to-mid voltage systems, battery, ICE) will enable to meet the target of future type approval regulations.

Concepts for predictive control of energy management (climbing, downhill, traffic prediction and more in general real-drive conditions), possibly coupled with autonomous driving, need further emphasis to allow real-world applications and improve reliability of the range prediction. Traffic data and big data management for transport applications will also play a role in this context. In addition, safety aspects need to be carefully considered to identify the trade-off between maximum energy harvesting and vehicle stability. Considerations derived from functional safety requirements (ISO 26262), e.g. standard classification of most common components and Security out of Context (SooC) approaches, could lead to new requirements and concepts. The impact of increasing levels of autonomous driving over the medium to long term should be considered from a component development perspective as requirements for durability, maintenance, robustness, remote monitoring may increase leading to different technology choices, e.g. motor type selection.

- **Thermal systems & technologies for advanced power electronics and electric machines, for heating, venting, cooling**

Holistic thermal management:

Enabling efficient solutions for cabin heating, ventilation and cooling under various environmental conditions requires a holistic approach for the thermal management of the electric vehicle. The thermal management of the main and auxiliary power train components needs to be addressed as well as the various vehicle system functions such as wind shield defrosting, which may raise new safety issues. In this context the potential of combined cooling circuits as well as the smart use of the heat dissipated by the drive train must be exploited, with a particular attention for the reduction of cabin noise and improvement of passengers' comfort. The energy load of the auxiliaries must be assessed, accounting for range drop effects and smart energy management strategies (e.g. cabin pre-heating in cold climate conditions). Hybrid and electric vehicle should particularly benefit from enhanced integration of the vehicles in a transport system as a whole via connectivity and automated drive functions.

- **HEV architectures for smaller vehicle classes for wider market penetration; Flexible vehicle architecture for sales fluctuations between conventional ICE or hybrid vehicles; HEV design for commercial vehicle application**

EV-Architecture:

The overall electrified drive train architecture, the components integration and the vehicles integration within the energy distribution grid are the core aspects to be developed to enhance an effective co-operation between OEMs, suppliers and market operators. The standardization of internal and external interfaces, the interoperability and development of adequate communication protocols and components supported by an adequate ICT backbone for smart charging (including fast and wireless charging, Vehicle-to-Grid interface) and automated driving still constitute a major task to enable further spin-off of the electrified vehicles market. In this context, the full functional integration of the components, the efficient use of raw materials and the vehicle cost reduction and public acceptance must be addressed as priorities.

Expected impact

Considering the R&D activities and assuming the achievement and industrialization of the objectives in a time-frame 2020-2030, following impact on the transport sector is assessed:

1. **Energy storage systems:**
    a. Extension of average driving range up to 500 km
    b. Extension of lifetime up to 1000-5000 cycles (calendar life 15-20 years)
    c. Cost reduction below 90 €/kwh

2. **Drive Train Technologies:**
    a. 90% driving efficiency (plug-to-wheel) on the duty cycle (WLTC)
    b. Efficiency improvement due to reduction of parasitic losses: halving losses with respect to the 2016 benchmark
    c. Efficiency improvement due to optimized used of energy and optimized energy management + 30%

3. **Vehicle Integration:**
    a. Purchase cost comparable to an equivalent segment ICE-powered vehicle. Total cost of ownership cut down according to the business model implemented due to better integration in vehicles
    b. Extension of average driving range due to advanced V2X technology and communication (500 km)

Relation to other roadmaps

EARPA sees the requirement to identify actual research topics on a European level in close co-operation with all relevant stakeholders. In particular ERTRAC as well as the EGVI are major instruments bringing together all relevant stakeholders. EARPA expects the EGVIA to continue this path also in Horizon 2020 and is committed to represent the automotive researchers' voice and perspectives in those stakeholder processes. Also, the spirit and targets of EARPA and HESC TF are fully alligned with the recent revision of the SET PLAN (2015/2016), Core priority 4: "Diversify and strenghten energy options for sustainable transport" and related Action 7: "Become competitive in the global battery sector to drive e-mobility forward". Taking advantage of their expertise, EARPA members can offer support to those processes on a neutral basis.

Besides this strategic role, EARPA wants to emphasise the importance of continuous RTD effort to develop next generation electric vehicle technologies and deploy existing ones. With their research capacities and expertise, EARPA members are playing a key role in that context. Strengthening the existing ties along the entire value chain is seen as a success factor for the European Research & Innovation Area.

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