EARPA Position Paper

'Research and Innovation on ELECTRIC VEHICLE SYSTEMS AND COMPONENTS - through Horizon2020 & towards FP9'

5th April, 2018

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.

Introduction

In recent years, significant R&D efforts were made to drive electric vehicles and electric mobility forward. Today, the electromobility concept has proven its feasibility and benefits, with several commercial products from various EU and non-EU manufacturers and vehicles of all sizes on the market. Thus, focus is shifting towards research efforts 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, the next phase of the innovation cycle has to pursue enhancing **customer acceptance**, which is essential for success. The keys to achieve *customer acceptance* are:

- Range improvement;
- Cost reduction;
- Charging speed and procedures;
- Added value;
- Mobility options;
- Safety aspects (crash safety and fire protection);
- Battery life cycle and working life.

With this in mind, a working group was established in early 2016, with significant contribution from EARPA EVSC members, to update the ERTRAC-EPOSS-SMARTGRIDS European Electrification Roadmap for Road Transport. That update reflects the framework evolution in the electromobility sector from being technologically driven to focusing on customer acceptance issues.

At this time, Europe has a great opportunity to position itself as a world player in the battery supply chain and, more specifically, at the cell level, however today (2018), Europe lacks the appropriate manufacturing critical mass in order to supply the automotive industry. In this regard, the new initiative of the European Battery Alliance has been established to grasp the opportunity: this will undoubtedly include a substantial research effort.

Scope of this document

The EARPA Electric Vehicle Systems and Components Task Force (TF EVSC) aims to not only give support but also anticipate the forthcoming needs of the transport electrification challenges. Hence, TF EVSC is organized into a technologically driven structure, focusing around three technical categories, namely **Energy Storage Systems**, **Drivetrain Technologies**, and **Electric Vehicle Integration**.

EARPA partners have identified high priority research topics, addressing technical challenges while bearing in mind their impact on key user acceptance issues. These topics should be implemented in the short-term, in the final period of Horizon 2020 and also in the early stages of FP9. This calls for substantial and strategic research and development of all electric vehicle systems and components, as a necessary effort to facilitate the general deployment of electric vehicles.

1. Energy Storage Systems

Electric energy storage systems are a 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 on novel battery chemistries and materials, is needed to improve electric vehicles' performance and their range of application. Furthermore, it is necessary to address the manufacturing issues of any new material or battery technology. It is also necessary to develop battery options which have 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 in time.

Research challenges and topics identified:

- **Cell materials for enhanced lifetime, energy density, power density, safety, and reliability; post-lithium cell technologies; understanding battery cell degradation.**

In view of the deployment of electric vehicles foreseen by most manufacturers, there is a clear opportunity for Europe to position itself in the supply chain as a whole, and specifically regarding battery cell manufacturing. From this perspective, advanced lithium ion technologies are considered technologies that will have more impact in the market in the next few years, with other technologies, mainly solid state electrolyte-focused coming afterwards.

There are various levels of maturity in energy storage systems, where R&D is of utmost importance, and where 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: all of them key factors to satisfy the customer expectations. For this purpose, an extra effort is needed in materials development, understanding degradation phenomena at the interphases, and modelling. Further progress in multiscale modelling tools is crucial for establishing a credible mechanistically based modelling chain considering cell materials, cell characteristics, duty cycles, cell performance, side reactions and degradation phenomena. Such a modelling chain is essential for optimizing the lifetime and safety of batteries, whereas it will also provide valuable inputs for development of enhanced cell materials and cell designs, as well as of battery management systems.

- **Prototyping, scaling-up and manufacturing of new battery technologies.**

In order to bridge the gap between research and industrial application, it is necessary to introduce scaling-up at pilot plant levels for the early stages of materials research. This enables a promising concept to be proven, and fine tuning of the process conditions in later stages. This will allow making progress synergistically through the cell level TRL and MRL[1] scales. The deliverable of this phase would be 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 transfer to the industry and ultimately to the market. The experience acquired in processing and fine-tuning of materials for current lithium ion cells is of high value, serving also as a benchmark for the progress to date.

[1] *TRL: Technology Readiness Level; MRL: Manufacturing Readiness Level*

- **Optimized battery packs: battery management systems including cell and module sensorisation and thermal management.**

Advanced concepts for electrical and thermal design plus control of modules and packs are needed to assure the best possible performance and lifecycle for a range of applied cell types at lowest costs. Regarding battery management systems, further research activities relating to hardware and inter-cell/module/package communication should be undertaken. As a concept, a holistic approach should be applied to maximize the performance of the final product, rather than the individual optimization at cell, module and pack levels.

For research on integrating batteries into the vehicle structure, the focus should be on safety and thermal management issues, especially for operation in extreme environmental conditions (e.g. intense and prolonged solar radiation). The need to use advanced, light-weight materials for structural parts at the pack level is a must. Aspects of second life, re-use and maintenance operations should be further addressed, 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 within the Battery Management System should be developed to facilitate remote maintenance and troubleshooting, software uploading and other functions. Further, the integration of additional sensors at cell, module and pack levels should be investigated.

Finally, research is required into higher voltage systems compatible with ultra-fast charging,. including the insulation challenges that these voltages bring.

- **Lifecycle issues, assessment availability of raw materials, recycling processes for Li Batteries, re-use and second life concepts for batteries.**

LCA, second life, re-use and recycling issues are of relevance due to the increasing number of xEVs on European streets, and the consequential increase of used, valuable storage systems with their base raw materials. There are several options to explore for using used batteries, which still retain a significant storage capacity. These options include use in stationary applications, operation in the original field of application but as an aftermarket replacement or to just end their life in a sustainable way.

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

Finally, circular economy considerations and efficient recycling of the full amount of raw materials are a must, to reduce Europe’s material dependence on less politically stable areas and markets. This includes research on recycling processes as well as standardization, and proposals for policy supporting the circular economy in an efficient way.

- **Research into testing and modelling methods: towards European guidelines for lifetime and range, batteries and V2G.**

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 a specific issue, there is the imminent need to standardize the testing of the impact of fast charging procedures in the battery, both at the cell and at the pack level. The same can be said of grid connected vehicles through V2G concepts, with an uncertain impact on battery life, as seen by the car owner. In more general terms, the various patterns of charging and discharging will create the need for normalized tests to assess the patterns’ impact on the performance and lifetime of battery packs. This needs to go along with the investigation and standardization of testing methods and simulation tools for systems and components.

2. Drivetrain Technologies

The large-scale deployment of electric vehicles calls for low cost, light-weight and highly integrated components (motors and power electronics). New and optimized drivetrain concepts, e.g. wheel motors, axle motor concepts or multi-motor topologies, will open new opportunities in vehicle design. Modular and scalable architectures for electric drivetrains will play a key role for fully electric vehicle concepts, in terms of cost reduction and the potential for mass-manufacturing. Hence it is important to use components for various functions, exploiting a systems' structural and electrical synergies.

Research on the electrical part of pure electric, fuel cell and hybrid drivetrain architectures needs to focus on the different subsystems or components, prior to system integration, and optimal energy management. Electrical integration of these systems will entail topological analysis as well as studying the degree to which components can be integrated, with a multi-disciplinary, multi-physics approach.

Research challenges and topics identified:

- **Next generation of electric motor for Hybrid and Battery Electric Vehicles, new concepts, materials for electrical machines, low-cost & light-weight.**

Electric machines are still in their early stages of automotive applications. The limited number of sales so far has not yet unleashed the potential of mass production techniques applied to electric motors. In addition to this, aspects related to powertrain modularity and scalability have not been fully explored. Concerning powertrain performance, although electric motors are inherently very efficient, it is necessary to reduce the space occupied by the powertrain within the vehicle. Miniaturization and weight reduction of electric motors offer a competitive advantage, a clear trend being increasing electric motor speeds. Where suitable, functional integration with other driveline components should serve improved modularity.

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

- **Highly efficient, high voltage, high temperature electrical power systems, which are compact and robust.**

Currently power electronics modules are mostly based on silicon devices, with the inverter a bulky element that needs significant space allocation on the vehicle. Silicon technologies have significant limitations in terms of operational temperature as well as losses associated with increasing switching frequencies. It is clear that a migration to wideband gap materials has to be carried out with the next generation of electric vehicles. These wideband gap technologies offer a significant potential to reduce losses in and the volume of the future e-drive solutions, also enabling the switching frequencies needed for high speed machines. However, the maturity of such solutions needs to be developed, requiring a significant effort at different levels within the supply chain to enable robust and affordable solutions.

Highly efficient fast battery charging, i.e. plug-in recharging, wireless/inductive charging and regenerative braking, combined with predictive control strategies must also be addressed by power electronics developments (with solutions for both light and heavy duty applications needed). R&D into higher voltage power electronics is a key enabler in a move towards higher voltage systems, which may be required to suit ultra-fast charging. New semiconductor materials, such as SiC or GaN are needed, requiring research to increase the capabilities at a device level, including higher voltage, cost reduction and manufacturing capabilities for mass market demand.

- **Energy efficiency and recovery concepts, thermal control systems, high integration of sub-/systems.**

New concepts need to be developed to minimize the overall driving energy consumption, new energy recuperation, waste heat usage (from cabin, battery, electric motors and batteries) and energy harvesting. Various technologies should be investigated to identify the potential for improving overall system efficiencies. Research in optimizing integrated vehicle electric drivetrain 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 or Al-C-batteries) for heavy-duty applications. The charging process management presents challenges both for the local grid and the vehicle, as power levels increase (particularly for heavy-duty). The energetic drivetrain concept needs to allow a daily use, comparable to state-of-the-art vehicle technologies with combustion engines, when considering possible mileages and driving comfort. All-wheel-drive opportunities and torque-vectoring capabilities, for increased safety, need to be taken into account. In addition, actuators and sensors suitable for automation need to be considered.

For overall vehicle optimization, the thermo-mechanical integration of the electrified powertrain components, in particular the electric energy storage system, motor/generator and power electronics in combination with the vehicle thermal control system including air conditioning and thermal energy storage, have to be investigated. In addition, a higher level of integration of the electric drivetrain would lead to new design opportunities and demands. The necessity of auxiliary power units over the medium to longer term should be reviewed, as electrical energy storage solutions increase both in gravimetric and volumetric energy and power density whilst simultaneously reducing in cost.

3. Electric Vehicle Integration

The electric vehicle integration concept covers a wide spectrum of activities, ranging from implementation of means to reduce the high energy consumption of accessories in current EV, to new vehicle architectures taking up design opportunities enabled by electrification. The continuous rethinking of packaging and systems integration, independently of newly developed components and subsystems, is a must.

Research challenges and topics:

- **System integration & modular architecture, modularisation of subsystems and standardisation of component features and interfaces, in hard- & software**

Enhancing packaging and the integration of devices requires a systems approach, with emphasis on experimental activities (mock-ups, demo-vehicles, pilot applications etc). 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 be combined with appropriate control systems, e.g. "new" optimized control architectures. In particular, inverter/charger concepts will play an important role in future plug-in hybrid and electric vehicles. In addition, modular approaches need to be developed, enabling the design of novel vehicle/powertrain architectures, the identification of new modular systems and components, as well as the investigation of flexible/adaptable architectures by means of exchangeable components/modules, is needed.

- **Control strategies for electric components & vehicle energy management.**

System optimisation should simultaneously aim to achieve the highest possible overall efficiency over actual and future type approval test cycles (including real-drive conditions), enabling the derivation of customized solutions for providing the end-user with the best value, and the best LCA performance through the optimum use of raw materials. This will lead to enhanced solutions for future low carbon passenger and freight vehicles. Furthermore, system optimization will require developments in advanced control architectures and energy management functions, including the optimal control for hybrid and electric powertrains, and enhanced vehicle driveability and durability. The adoption of new technologies, particularly V2X connectivity and automated driving functions, topologies and control schemes for loss reduction on component level (power electronics, electric motor, low-to-mid voltage systems, battery etc.), will improve customer acceptance by lowering energy consumption and thus giving better vehicle range.

Concepts for predictive control of energy management (climbing, downhill, traffic prediction and more real-drive conditions, charging events and zero emission zoning etc.), possibly coupled with autonomous 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. In addition, safety aspects need to be carefully considered, identifying trade-offs between maximum energy harvesting and vehicle stability. Considerations derived from functional safety requirements (ISO 26262) could lead to new requirements and concepts.

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

Efficient solutions for cabin heating, ventilation and cooling under various environmental conditions require a holistic approach for the thermal management of electric vehicles. Thermal management of the main and auxiliary powertrain components needs to be addressed as well as the various vehicle system functions, such as windscreen de-frosting, 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 drivetrain must be exploited, with particular attention for the reduction of cabin noise and the improvement of passenger comfort. The energy load of the auxiliaries must be assessed, accounting for range reduction effects and smart energy management strategies (e.g. cabin pre-heating in cold climate conditions). The electric vehicle should benefit particularly from the enhanced integration into a transport system as a whole via connectivity and automated drive functions.

- **EV architectures for different situations – from small to commercial vehicle applications; flexible vehicle platforms.**

The overall electrified drivetrain architecture, the component integration and the vehicle integration within the energy distribution grid are core aspects 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 the further growth of the electrified vehicles market. The full functional integration of components, the efficient use of raw materials, vehicle cost reduction and public acceptance must be addressed as priorities. In the case of commercial vehicles (particularly heavy-duty) optimization of the complete system should lead to compelling reductions in the Total Cost of Ownership.

The final themes that should be investigated include dedicated simulation and development tools for fuel cell and hybrid configurations, and the interdisciplinary development & production environment for EV global commodity management.

Expected impact

Considering the R&D activities and assuming the achievement and industrialization of the objectives in a timeframe of 2020-2030, the following impacts on the transport sector are expected:

Expected Impacts

1. **Energy storage systems:**
   a. Extension of average driving range up to real 500 km through increased energy density;
   b. Extension of lifetime up to 1000-5000 cycles (calendar life 15-20 years);
   c. Cost reduction below 90 €/kW.h;
   d. Enhanced safety.

2. **Drivetrain 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 through advanced V2X technology and communication (500 km);
   c. Increase of real life range by optimized energy management and more efficient cabin conditioning/thermal management concepts.

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 EGVIA are major instruments bringing together all relevant stakeholders. EARPA expects the EGVIA to continue this role and is committed to represent the automotive researchers' voice and perspectives in the stakeholder processes. The strategy here is aligned with the ERTRAC Electrification of Road Transport European Roadmap released in 2017, following active involvement from EARPA partners.

Furthermore, the spirit and targets of EARPA and TF EVSC are fully aligned with the recent revision of the SET PLAN (2015/2016), Core Priority 4: "Diversify and strengthen 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 emphasizes the importance of continuous RTD effort to develop the next generation electric vehicle technologies and deploy existing ones. With their research capacities and expertise, EARPA members are playing a key role in this. Strengthening the existing ties along the entire value chain is seen as a success factor for the European Research & Innovation Area.

For further information, please contact the Task Force EVSC:

Contact

TF EVSC Chairman
Oscar Miguel
E: omiguel@cidetec.es
T: 00 34 943 309 022

TF EVSC Secretary
Andreea Balau
E: andreea.balau@tno.nl
T: 0031 6 5924 6353

More information at our website: www.earpa.eu