European Road Transport
Research Advisory Council

European Technology Platform
on Smart Systems Integration

The Electrification Approach to Urban Mobility and Transport

Strategy Paper

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Preamble

This paper emphasizes a major topic of ERTRAC's and EPoSS' Research Frameworks aiming at the development of a smarter, greener, safer and more competitive road transport system. Recognising the growing concern about economic and energy security, climate change and air pollution, ERTRAC and EPoSS are convinced that the transition of road transport towards electric propulsion is inevitable. However, it will be a 'step change' of technologies, business models and user practice that requires strong efforts in terms of research and development. ERTRAC and EPoSS are calling Europe to take the lead and seize the unique economic opportunities of road transport based on plugin-hybrid and battery-electric vehicles and more generally the electrification of the powertrain. From the in-depth expertise and knowledge of their members, ERTRAC and EPoSS have collated the research priorities in all related fields and derived a common strategy for joint actions of the involved stakeholder from both public and private sides.

1. Introduction

The apparent volatility of fossil fuel prices, the oil dependency and the predictable shortage of crude oil are driving concerns about the future security of energy supply. At the same time, greenhouse gas (GHG) emissions are causing severe changes of the world climate that are posing a serious threat for the environment and the human health. This situation is increasingly calling for non-fossil generation and efficient use of energy.[1] Being both the major oil-consuming economic sector and the backbone of globally competitive industries in Europe, mobility and transport will thus soon undergo step changes of technologies, business models and user behaviour. Furthermore, fossil fuels will more and more be complemented by renewable, low-

[1] Intergovernmental Panel on Climate Change Assessment Report (2007).

carbon alternatives like biomass, wind and solar power as sources of energy for transport.

First automobiles running on alternative energies like biofuel blends already exist, and some other modified or completely new powertrain concepts are currently under development, e.g. traction based on high degrees of biofuels, hybrid, plugin-hybrid, and battery-electric vehicles, as well as hydrogen and fuel cell cars. There is still research needed to explore the best combination of fuel type and vehicle concept for a given condition, location and user profile. An over-all assessment has to consider factors ranging from GHG emission, air pollution and energy security to fundamental production items, as well as the availability and reuse of raw materials in well-to-wheel studies and life cycle assessments. In most cases, battery electric vehicles powered by regenerative energy are obviously the best option.[2]

In light of current activities of various high tech industry locations and regions worldwide to take the opportunities of the electrification of road transport for their economies[3] the goal of this paper is to develop a pan-European concept for the "Electrification of the Urban Mobility an Transport System". Therefore the concept of plugin-hybrid and battery-electric vehicles is outlined and opportunities and threats as well as the needs for research, development, and demonstration are highlighted. The findings on specific R&D needs and strategic recommendations are based on the broad expertise of ERTRAC stakeholders, the joint European task force on urban mobility research[4], including direct input from CLEPA, EARPA, ERTICO, EUCAR, FEHRL, POLIS, UITP, and the European Technology Platform on Smart Systems Integration, EPoSS.

2. Electrification of the Urban Mobility and Transport System

The electrification of road transport establishes yet another link between the energy and mobility sectors as well as a new domain of services in regards to the management of Electric Mobility as for the first time it brings together utilities and grid operators with the makers and users of the automobile. Electric vehicle requests to be complemented by other transportation modes and thus boosts need for intermodality (different means of transportation)/ interoperability (with infrastructures and traffic management)The full economic and environmental potential of this concept can only be exploited if novel solutions exist for the routing of electric energy and power along the path from the power generation via the grid infrastructure to the single vehicle and particularly its accumulators and drives. It also requires the integration of electric vehicles with the existing modes of transport into one system. Innovative components and novel information and communication technology (ICT)

[2] M. Jacobson, Stanford U, Review of solutions to global warming, air pollution, and energy security (2009).

[3] San Francisco Bay Area Majors, Policy Plan "Electric Vehicle (EV) Capital of the U.S." (2008); U.K. Department of Transport, Press Release "New jobs on the horizon as Britain leads green motoring revolution" (2008), German Federal Government, National Strategy Plan Electric Mobility (2009).

[4] The European joint task force on urban mobility research relies upon ERTRAC and ERRAC, whose members participates to its work, together with other stakeholders of the sector, in particular those who contributed to the definition of Eurforum Strategic Research Agenda on urban mobility.

solutions have to be found and developed at all steps of this link (see Fig. 1). Additionally, in order to improve productivity and global competitiveness of the European industry, the interfaces between the components have to be clearly defined and commonly standardised, as well as new production and procurement strategies developed especially tailored to the needs of E-components and systems . This is of particular urgency as many member states have already announced respective national initiatives. The involvement of stakeholders from all involved sectors will be crucial for a successful move towards electric mobility and transport.

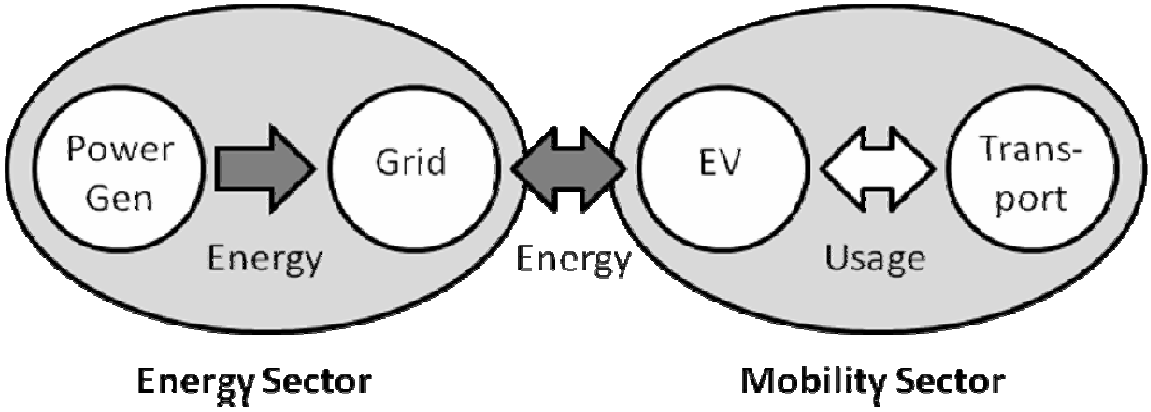

Fig.1: Electrification of road transport links the energy and mobility sectors

2.1 Power Generation and Grid

Additional users of electricity for transport like electric bikes, cars, buses, or trucks will need some extra supply of electric energy. However, even broad introduction of electrical vehicles (EV) is not limited in terms of generating capacity: assuming the energy consumption of a EV to be in the order of a hundred Wh/km (e.g. for a passenger car[5]) and taking into account on average 10.000 km travelled per year, it can be stated that one million vehicles will require about one TWh of energy which is only a minor fraction of the annual electricity output of a EU member state, e.g. for Germany it would be less than one percent.

Nonetheless, to increase the sustainability of the system this energy has to come from renewable or at least low carbon sources. To power one million electric cars just one GW of installed wind power is needed. This is little compared to the total installed wind power of more than 50 GW in Europe[6], however it poses particular challenges in terms of grid management because renewable energy generation is much more decentralised and fluctuating than today's fossil power generation and the short term local energy demand of a group of cars could be much higher than today's demand coming from households. To balance the additional supply and

[5] U.S. Department of Energy, EV America Test 1999 General Motors EV1 (1999).

[6] European Wind Energy Association, Press Release (2008).

demand in an efficient manner a smart transmission and distribution system[7] will be needed that makes use of interconnected sensors and automated controls.

2.2 Vehicle-to-Grid Connection

The purchase of power for the electrical vehicle should be as easy and convenient as today's refilling at the gas station. There should be no barriers in the usage of different facilities, providers, tariff periods or types of charging stations. For this purpose, the vehicle-to-grid concept combines smart power charging and metering capabilities and an intelligent payment system. Novel information and communication technologies making use of standard protocols like Bluetooth, W-LAN or power line are needed for the data exchange between infrastructure and storage system.

The vehicle to grid concept, however, goes well beyond charging and paying. The EVs' batteries can be integrated as a buffer for the fluctuating influx of electricity from renewable energy sources which would optimize the efficiency of the whole system. This requires the routing of energy and power to be bi-directional, from the grid to the vehicle and vice versa, and it calls for smart control devices that adapt the batteries' state of charge to both the anticipated driving range needs of the user and to the stability requirements of the grid.

2.3 The Electric Car

The Kernel of the electrification of road transport are new vehicles based on electric traction and the modules and components being part of them. Different concepts of cars, trucks and buses like plug-in-hybrids, electric vehicles with a small special internal combustion engine (ICE) as a range extender up to full electric vehicles are in the main focus of current research activities. Pure EVs, due to their zero local and potentially minor greenhouse gas emissions (if energy from renewable sources is used), are considered the cleanest option for vehicles are the mile stones towards sustainable road transport. Micro- and mild hybrid concepts as well as full hybrids are an affordable entry point to this vision as they drive the gas mileage to its maximum.

Despite all advantages EVs have not yet been introduced because they are facing several weaknesses as limited driving range, extended charging time of the battery, overall limited efficiency in electricity provision limited capacity and high cost of storage systems. Solutions for many of these aspects may be found at the level of the subsystems for energy storage (battery, super capacitors), electric drives and the smart systems for the routing of energy and power between them.[8] Furthermore, intelligent system integration will be necessary for optimising the total concept and management of the electric drive train. Nevertheless, given the fundamental restrictions of the battery it will be unavoidable to increase the energy efficiency of

[7] European Technology Platform SmartGrids, Strategic Research Agenda (2007).

[8] European Technology Platform on Smart Systems Integration (EPoSS), Strategy Paper "Smart Systems for the Full Electric Vehicle" (2008).

the EV as a whole which may require a rethinking of basic concepts of the car and the usage of it.

Although experimental EV's have been implemented many years ago, the development for a substantial critical scale requires conditions that could never be matched so far. Therefore it is important to require for the EV an integrated scheme.

2.4 Integration with the Transport System

The deployment of electric vehicles in the network will require the provision of the supporting infrastructure and systems, and their integration in the full mobility system in a wide scale. Rail public transport that uses electric energy provides sustainable mobility solutions as well and will growingly be an alternative to private vehicles in the future. Given the limitations of the electric vehicle, its intelligent integration into the existing urban transport infrastructure is essential. Intelligent ICT solutions enabling proper traffic management, managing the change between different modes of electric transport or giving travel advice will optimize the efficiency of the transport system, make it conveniently useable, and thus acceptable for the public. This contribution therefore will cover all relevant modes of possibly electric transport: individual motorized transport (cars, powered two wheelers), public transport (suburban rail systems, urban rail systems, buses, etc.), vehicles for urban delivery and logistics other vehicles, in particular public fleets of vehicles.

For charging of electric vehicles a public and private infrastructure is needed. Public parking structures or lots close to residential areas, the work place or a shopping mall as well as private garages will necessarily be equipped with charging stations, also curb side solutions must be found for charging "on the go". The deployment of electric vehicles will thus require major investments in the charging infrastructure for the electric vehicles in the city, in public and public spaces, e.g. bus depots. It is useful to differentiate between the state when there is a significant fleet of maybe 20-25 % EV/PHEV and the transition time, as the transition may offer both challenges and opportunities that are different from the established mode. This is especially true when it comes to charging infrastructure. Therefore, a phased approach in the framework of an ambitious research and demonstration programme will be needed.

3. Research Needs

The technological challenges of the electrified transport system and especially electric drive trains are very complex. The development of suitable basic technologies, modules, and components as well as the system integration will thus for at least the next decade require strong joint efforts of researchers and engineers from a multitude of disciplines and beyond the borders between industry and academia. Strengthening R&D – particularly on batteries and components - will be a prerequisite for the establishment and long retention of EV mass production in Europe.

3.1 Modules:

3.1.1 Storage systems (**battery systems and battery cells** and capacitors)

Increase of energy density and capability, increase of safety, lifetime and cycle life and robustness, fast progress towards standards of mechanical an electric and data communication interfaces as well as reduction of costs are the biggest challenges for mass production of energy storage systems and thus for the feasibility of EV's in general. For hybrid vehicles, the focus is put on high power as this is a prerequisite for storing the energy captured during regenerative breaking. For pure electric vehicles and plug-in hybrids, high energy is the priority as it determines the range of electric driving. Due to their outstanding energy and power density, Li ion batteries currently appear to be the most promising option for the next generations of battery technology both for hybrid and electric vehicles. However, due to the wide variety of possible choices for electrode and electrolyte materials other systems may be found to provide even higher performance or better matching with the user requirements in the future. As these may provide only low power densities, combinations of super capacitors and batteries are of interest, too. Thus, two major R&D paths should be followed: One for the further improvement of lithium ion based cell systems aiming at energy densities, on cell level, in the range of 200-400 Wh/kg and a second one for basic research on new open cell systems technologies for highest energy density in the range of 500 Wh/kg and beyond.

Increasing the efficiency of electric and hybrid public transport vehicles, vans and trucks (waste collection trucks, etc.), which have among other characteristics a much higher daily mileage than private cars (e.g. annual mileage of urban buses is at 80.000 km), requires research on especially robust and reliable high capacity energy storage systems (batteries, supercaps, flywheels).

Regarding lithium ion batteries, currently available battery cells are based on lithium cobalt oxide cathodes, lithium graphite anodes, organic electrolytes and a polyethylene separator. They have been optimized for use in consumer electronics, but do not match the safety and lifetime requirements for application in the automobile. Research and development should therefore focus on next generation cells using intrinsically safer cathode materials with a lower capacity loss rate like lithium iron phosphate, and on separators that prevent accelerated heating and explosions, like e.g. ceramic separators. The exploration of flexible, thin, and nanostructured separators, improved electrolytes, high-voltage cathodes, and anodes with high specific energy, e.g. based on the use of carbon nanotubes, will be the major challenge for the development of lithium ion traction batteries combining high levels of safety, lifetime and energy density.

Regarding new open cell systems, highest energy densities may be expected from e.g., lithium sulphur, metal air and manganese based systems. Research topics will be the investigation of the solid electrolyte interface, performance gains of electrodes though nanopatterning, the replacement of rare and toxic materials like nickel and cobalt, and measures that increase conductivity. General objectives are increases of energy density, safety, cycle life, lifetime and reduction of cost. Furthermore, the origins of the cell ageing processes and their complex relation to actual usage in HEVs and EVs as well as control strategies to manage these processes have to be investigated.

In light of massive international activities in the field of battery research[9], ensuring future competitiveness of the European battery industry requires immediate and strong action that strengthens the electrochemistry competence in academia and industry and the helps to rapidly turn new findings into innovative cell technologies. Given the complexity of fabrication processes, material systems and performance parameters, a central European facility for prototyping, testing and manufacturing of advanced traction batteries should be considered, shared by researchers from academia and engineers from the industry. It is important that European research efforts address the battery technology issues also outside the surface transport priority.

3.1.2 Electric motor

Regarding the electric motor, strong demands for small package volume and low weight and cost efficiency are opposed by the needed increase of power and torque. Additionally the motors need to have the ability to withstand the harsh temperature and mechanical vibration conditions in a vehicle application. The solution must be to raise the efficiency per volume meaning reduction of iron losses and copper losses and increasing efficiency in cooling. New materials for electrical sheet, permanent magnets and isolation in combination with architectural optimization or even new electric motor concepts will be required.

All these counteracting requests are even higher in hybrid applications due to the need of coexistence between electric machines and related power electronics with specifically adapted combustion engines (for instance as a range extender in the nearer future EV's).

The new motor concepts also should manage or avoid the safety problems associated to field weakening, short circuits and/or sensor failures (capability to operate in these conditions with reduced performance). Also the question of resource availability of copper and permanent magnets should be a topic of research. There is also a need for modeling transient effects in complex magnetic circuits which in the midterm may lead to architectural optimization of electric drive trains as well as to new measures for fault diagnosis.

Moreover, due to the large volumes application targets, the defined solutions have to match, both in terms of technology-layout and materials, with production processes with increased automation levels. Especially during the introduction phase of this new technology those processes have to handle small and large volumes in a low cost and high efficient way.

Also the mechanical integration between the electric motor and the mechanical transmission has to be properly addressed by finding solutions combining reduced weight, volume and costs with high efficiency and driving comfort, for instance by two or three speeds powershift transmissions. Another option is the application of an

[9] Ministry of Economy, Trade and Industry of Japan (METI) and New Energy and Industrial Technology Development Organization (NEDO), Research Program "Next Generation Batteries for the Commercialization of Plug-in HVs, FCVs, and EVs (FY2007-2011)" (2007); Argonne National Laboratory, Press Release „Alliance formed to manufacture advanced automobile batteries in the U.S." (2008).

electric motor to each of two or four wheels. If equipped with an active suspension system, unsurpassed control of the vehicle dynamics may be achieved.

3.1.3 Power electronic devices

Power electronic devices of importance for the electric vehicle include DC/DC converters, inverters for the main drive and the auxiliaries as well as battery chargers and vehicle to grid connectors. Development of these components faces challenges by the high currents and temperatures which they have to withstand. Intelligent solutions for such robustness issues are a particular property of smart systems.

Automotive power electronics may not be considered separately from the electric drivetrain system. Voltage and current ratings relate directly to chip-size and material choice and therefore to cost and space. Additionally the package volume demand results in an integration task. Thus research must be targeted on the integrated drivetrain system to minimize cost and optimize efficiency. (i.e. integrated housing and cooling solutions between electric machines and inverters able also to largely reduce the cabling and the EMI/EMC problems).

New concepts of packaging, cooling and new junction technologies need a lot of development as does the continued research into more robust reliable and cost effective semiconductor materials for high power applications.

A performance step in new and thermally more stable semiconductor materials like SiC would make possible a further shrink of power electronics in the later future.

Most important and most urgent topics of research of the power electronic component include thermal management (i.e. cooling, sensing, thermally stable materials and junction technology), packaging technology, silicon devices for high frequency switching and the development of passive components, development of alternatives to silicon or combinations of silicon and other semiconductor materials and innovative system on chip solutions for high power devices.

Investigation of new power electronics architectures is a key point to be able to:

- better fit the large DC sources voltage windows with reduced power electronics sizing
- integrate different functions (as for instance inverter with integrated battery charger function)
- make possible to cope different power levels with modular solutions (enabling an effective cost reductions)

3.1.4 Energy-efficient auxiliaries and vehicle systems

Auxiliary systems such as AC, power steering and lighting represent an increasing part of the energy demand in passenger cars. Conventionally heating uses the waste heat of the combustion process. In electric vehicles, however, all energies for any auxiliary drive are relying on the main energy storage, the battery. Any additional parasitic loss or demand is reducing the mileage of the car. Thus new electrically driven auxiliaries and a vehicle thermal management, even novel solutions for heating systems are needed. Considerable research is required to develop appropriately energy efficient solutions. Smart control units, adapting the function of the auxiliary to the needs of the passenger may play may a crucial role for enabling

the required energy efficiency. Improving the performance of electric vehicles in public transport systems requires research on the improvement of the energy efficiency of low energy consumption auxiliary components used in buses, trams, metros such as for heating, ventilation and air conditioning (HVAC). For some utility vehicles, like e.g. refuse trucks, electrification of the auxiliary systems is a promising way to reduce their GHG emissions and noise. I

This new efficiency and system smartness requirements may lead to complete new vehicle concepts and technologies. Glasses with switchable reflection or adsorptions ratios, integration of photovoltaic elements and a smart control of the thermal heat flow in the whole car are some examples. Given the need for an all-over optimization of the EV's energy efficiency, intelligent measures for reducing a vehicle's weight, drag and rolling resistance will be required, too. Therefore, electric vehicles considered for mass production will most probably be lightweight vehicles, e.g.. This implies a need for various new solutions targeted at safety and convenience aspects. Active Safety systems like adaptive pre-crash actuators, car-to-car communication devices, and driver assistance systems for collision avoidance will play a crucial role for the safety of electrified road transport.

3.2 Drive system management:

3.2.1 Systems for the management of storage systems

The integration of cells into a battery pack is an important issue particularly concerning safety, cost, manufacturability, diagnostics, maintenance, repair and recyclability. Solutions for these challenges may be found in both passive measures (e.g. packaging and thermal management) and smart systems for active electrical monitoring and adaptive control.

For the latter ones the following general research needs are considered most urgent: The development of energy management system architectures and fast active switching elements as well as the establishment of evaluation and testing standards. Furthermore, in the midterm there will be need for solving the safety issues related to the high energy content of e.g. Li-ion batteries, and for battery recycling measures.

Particularly, an advanced battery power/energy management system would integrate functionalities for the determination of the state of the battery, failure diagnosis, cell equilibration and crisis management, thus providing safety for the full life cycle of the battery including the end of life and functionality such as energy/power routing and electronic control unit (ECU) communication. Foremost research needs to be addressed at the earliest possible instance.

On the global level, this could be applied to a combination of batteries and super capacitors, on the local level it could provide a new way of extending the battery life.

Key research needs are globally the development of charge and discharge algorithms including fast charging, ageing model and measures for the protocol of aging, as well as for energy deploying circuits, and locally the application of power electronics for monitoring and switching individual cells. Important issues to reach robust and EMC/EMI compliant devices, are related to

- the effective integration of sensors (voltage, current, temperature) and protection devices (fuses) inside the cells and modules

- the investigation of wireless communication approaches between the management units on the modules and the board of the battery management system.

These topics are to be addressed as soon as possible.

3.2.2 Active control units for electric motors and wheels

Electric motors add particular performance to the vehicle, e.g. regenerative and electric braking, full torque at all vehicle speeds, and the opportunity to distribute the power between several motors if in-wheel or distributed motor architectures are used. To make use of these properties requires active and adaptive control measures taking into account the driver's intentions, the state of the road and the state of charge of the battery, i.e. the full range of functions provided by smart systems technologies.

One such smart system would be an intelligent traction control unit for vehicle dynamics. Its functionalities include good torque controllability over a wide speed operating range, high torque density, high efficiency and low cost as well as regenerative braking, anti-lock braking/traction control, and fault diagnosis and tolerance. Foremost research needs for such a smart system cover the investigation of robust traction control techniques, power quality and stability studies of the vehicle electrical systems, the analysis of safety critical failure modes and the understanding of their consequences, methods and tools for health monitoring and fault diagnosis as well as the measures for compliance with electromagnetic interference /compatibility (EMI/EMC) and power train safety standards.

3.2.3 Integration of ICE Range extenders into the Electrical Vehicle

The opportunity of long-haul driving, representing just a minor fraction of the normal drive cycle in Europe, is considered a key functionality for user acceptance of alternative drive trains. Given the range restrictions of batteries, certain electric vehicles will be equipped with an internal combustion engine (ICE) that recharges the battery if needed. Managing the efficient use of the ICE has to take into account various parameters including the state of charge of the battery, the driver's intentions, the traffic situation etc. Thus it is calling for new ICE concepts, intelligent gears and smart ICT solutions having access to predicted or real-time traffic situations along the route and specific road attributes such as slopes, road types, and speed profiles.

Regarding the ICE downsizing, high pressure supercharging, simplification and integration of the electronics are the most important and urgent topics. Innovative new concepts with integration of ICE and electrical machines should be included e.g. addressing the noise and vibration issues that are largely more critical in an EV than in a standard ICE based application. Improvement of injection systems for conventional, bio- and designer fuels should be added as well as new, high temperature – low friction materials are further important research topics.

A smart system playing a crucial role for the integration of ICE into the EV is the energy management assistant. Aiming at minimizing energy consumption in regular use it should have energy routing capabilities and should be aware of availability and limitations of power. Trip optimisation also calls for digital maps containing EV-

relevant map attributes together with key functionalities such as HMI based trip planner providing a better user controllability of the energy storage throughout their planned route adjusting efficiently for the alteration of trip plans or traffic situations. Also, thermal control of the internal combustion engine and it's after treatment device is a key aspect. Research is required particularly in the area of controller topologies, interface parameters, data management and the application of fuzzy logic. Furthermore, some research on assessment criteria New European Driving Cycle (NEDC) is needed.

3.2.4 Energy management for public transport

Urban rail systems need a holistic and systematic evaluation of energy consumption covering vehicles, infrastructure and operation and the definition of an energy consumption decision support tool. Research efforts are particularly needed to define models to better master/control overall energy consumption, and to improve energy storage (especially coming from regenerative braking) either on board the vehicles and/or in stations or wayside. Specific attention should be paid to the safety of energy storage systems.

Buses and other heavy duty vehicles running on the urban network should benefit significantly from all efforts for the development of more efficient electric vehicles and components. This includes also vans, lorries, and other light vehicles for urban delivery.Research to improve electric bikes and electric powered two wheelers is also necessary to allow for the provision of a full range of vehicles for a new mobility in the urban area.

Given the early market demand, research in these areas should start as soon as possible.

3.3 Infrastructure integration

3.3.1 Advanced vehicle to grid interfaces (V2G)

The advanced charging concept adds functionality to the basic charging and metering capabilities of a power plug by allowing the vehicle to be charged in an intelligent way, e.g. by controlling the time of the day when the vehicles will be charged. Thus, it will be possible to use the existing electricity supply network in a most efficient way. Batteries can contribute to grid stability as both consumers and providers electric power by charging during times when excess power is available or by discharging during periods of peak demand. Such a system has to anticipate and be aware of the user's charging needs and the state of the grid, and thus would be a smart system providing both new functionality and new [service] business opportunities at the interface between the car and the energy supplier.

General research needs related to V2G systems cover mainly three areas: the development of basic control algorithms and appropriate hardware, research in user acceptance, and the development of new business models at the interface of vehicle and grid including leasing concepts for batteries and life cycle cost sharing between the EV owner and the utility.

Smart systems for the Interface V2G connection are on-board and an off-board devices combining metering and charging capabilities with safe and trusty operation and simple power grid awareness. The on-board device shall also be equipped with navigation based on GPS and with wireless communication connecting the device to the computers of the grid operator. This will enable the device to identify which utility is running the nearest local power plug. Research needs are seen in charger topologies, contactless charging, increased durability and general reduction of cost, weight and size. Furthermore, public acceptance, privacy protection and smart grids in general are important research topics.

3.3.2 Deployment of the charging infrastructure

Substantial use of EVs, particularly in urban areas, will depend on ready access to the power grid. For vehicle owners without off-street storage, a system of curbside charging stations will be required, supposing strong cooperation between local authorities/cities and utility companies. A key challenge will be to implement on a sufficient scale to cause a critical mass without being cost prohibitive and causing large-scale traffic disruption due to the installation of technologies. If, for example, each 100m of a residential street requires a peak capacity of 50KW or more, substantial infrastructure works would be needed. To mitigate disruption, more research will be needed in improving underground surveying and installation technologies. Additionally, to allow the EV driver maximum independence from a particular utility, there is an obvious need for a standardization of the power plug (like in the U.S.[10]) and a billing procedure comparable to the mobile phone roaming concept.

Research should address, among other things:

- A strategy for the deployment of this infrastructure to be able to provide a dense network of charging points while taking into account the specificities of the urban environment (various type of users of the urban infrastructure and their requirements, availability of public space, etc.). This includes a careful and studied approach of the transition phase, for instance the progressive allocation of dedicated parking spaces for EV/PHEV, the challenge to keep even pace between the development of sales and the development of infrastructure, and the possible differences in requirements between EV and PHEV;
- The design and the technology of the charging stations, here again taking into account the specificities of the urban environment and the safety requirements for a large scale deployment, and the possibility to incorporate them in streets infrastructure such as lamp posts, columns, pay and display units, etc. Hence various models for the ownership and maintenance of the charging outlets need to be studied; Specific design of (fast) charging infrastructure in depots/stations for fleets (buses, public fleets, delivery fleets, etc.).
- The relative place in the future of fast-charging stations and normal charging systems, respectively, as this will be crucial for whether there is a need for many normal charging connections or if the current fuelling structure complemented with fast-charging devices or systems can fulfil most needs. The needs may

[10] SAE J1772 Electric Vehicle Conductive Charge Coupler Specification (2008).

differ widely between EV and PHEV. This is also related to the ability to impose standards for fast charging systems.
- The adaptation of the infrastructure to various types of vehicles (e-bikes, powered two wheelers) or the definition of dedicated infrastructures for some of these vehicles, and the adaptation of the infrastructure to new vehicle technology (e.g.in the case of urban rail vehicles).
- Standard for fast-charging infrastructure (voltage, plugs, etc.); security standards for the various components of the system, including the charging stations (resistance to vandalism, to extreme weather conditions, etc.); and payment standards.

4. Additional Conditions

In parallel to the R&D topics outlined above it is necessary to research and develop mobility services that can support and benefit from a large-scale deployment of electric vehicles in urban areas. Moreover, business models, user incentives, and legal foundations have to be implemented, and new ways of production and procurement need to be found.

4.1 Mobility Services

Demonstration activities relying on captive fleets can support early commercialisation of electric vehicles, and accelerate the modal shift towards more public transport, and alternative modes of transport. This should result in more sustainable mobility patterns for travellers in European cities and for more efficient and sustainable urban delivery systems. Initial large scale demonstration should include for instance:

- car sharing;
- demand responsive transport;
- public bikes and cars;
- new use of powered two wheelers;
- electric bikes
- innovative urban delivery systems with electric vehicles;

In a first stage, and together with innovative mobility services, captive fleets such as public transport fleets, fleets of public vehicles, taxis, and delivery vehicles from vans to powered two wheelers for couriers and express services etc. can trigger the implementation of the adequate infrastructure and initiate the transition towards a larger deployment of electric vehicles.

Public authorities interested in being pioneers and to take part in large demonstration activities should be enabled to include an increasing number of electric vehicles in their fleet of light and heavy vehicles, for instance for street cleaning or couriers. The deployment of electric vehicles should be supported by the development of new services, in particular for charging the vehicles and the payment of electricity bills. Citizens should have the possibility to buy the electricity from the company chosen by the customer or to get all electricity bills (charging of vehicles, home consumption) integrated in a single electricity invoice for citizens.

Services and modalities for the payment of charging services need to be studied taking into account this new function of the urban infrastructure in the mobility

system. It requires for instance to consider whether residents should be charged the same price, how long they can use the charging station, how to monitor its use, how to prevent people parking for too long etc.

Large scale research and demonstration activities of electric vehicles with these new services should also cover issues such as:

- business case models for market or PPP driven schemes to support modal shift from individual use of private car to alternatives modes of travel, as well as to support new urban delivery schemes supporting the use of electric vehicles;
- pilots to improve the infrastructures for some of these services, for instance secure parking for E-bikes and electric powered two wheelers;
- acceptance of electric mobility by different user types, related also to the choice between EV and PHEV as well as to incentives offered by electric power providers,
- application of information and communication technologies enabling the change of transport modes and giving travel advise.
- public procurement
- incentives schemes (see below)

4.2 Business Models and Incentives

The large scale use of electric vehicles will have an impact on both the energy and mobility systems. To exploit the full potential of this new technology for sustainability a strong link to regenerative power generation is required. In parallel, and in response to the same challenges as expected from demographic changes, the modal share of public transport and innovative mobility services will have to increase. Thus, research on economic scenarios for the deployment of electric vehicles and the corresponding infrastructure is needed. Given the high cost of batteries, it is likely that at even in the midterm public incentives and aids will be necessary to support this deployment. These may be linked to the obligation to purchase electric energy regenerative sources.

Furthermore, the EV has another investment/operational cost ratio than conventional vehicles, and PHEVs have yet another ratio. The consequences for the modal split, traffic, and emissions need to be analysed. This may include studies, e.g. assessing the opportunities for automakers to rather provide mobility options than single cars, or finding a package of services and advantages for commuters using electric vehicles such as, insurance, secure storing/parking, a break down service, marketing and a reward system for employer/employee. In general, to encourage the deployment of electric vehicles, incentives need to be considered and could be related to the following:

- excise duty;
- free parking or preferred parking locations;
- free on-street charging;
- reductions on tolling and any proposed infrastructure or congestion charge;
- access right to restricted areas in the urban environment;
- customer discount on electricity;

- subsidy to cover part of the cost of EV purchase if conventional car is scrapped

4.3 Production & Procurement

4.3.1 Raw Materials and Commodities

Increasing demand for raw materials and commodities for electric and electronic vehicle components and modules will expose industry to skyrocketing basic costs, in particular in cases when these materials are rare and the providers are limited. Apart from the influence on design (material-aware concepts), an effective reuse and recycling strategy is called for, which is particularly tailored to these substances and which has to be implemented to allow global sourcing and trading.

4.3.2 E-Components and Systems Production

The step towards the plug-in hybrid and the all electric car triggers a paradigm shift in manufacturing and moves the focus from mechanic/mechatronic towards electric/electronic and mechatronic components and systems. This opens the opportunity to introduce a different class of production methods to the automotive industry, which allows to break the economies of scale and addresses strongly the cost-side of future E-vehicles. The first cost of the car and its maintenance, however, will be crucial to achieve a rapid market penetration and in parallel a satisfying profit situation for industry.

4.3.3 Procurement

Since the automotive industry is of truly global character with strong and emerging market places in Europe, the USA and the BRIC countries, global concepts for manufacturing sites and their efficient interaction are essential for strengthening the European home base. This goes in line with the development and introduction of new specific logistics regulations and constraints, e.g. in the delivery of batteries, which are nowadays classified as “Dangerous Goods”, which might pose obstacles to the market introduction and service.

5. Conclusions

The move towards the electrification of the drive train will enable the future security of energy, a radical reduction of GHG emissions, local air pollution, and traffic noise. It is inevitable for maintaining the competitiveness of the European automotive industry in a rapidly changing global economy, however exploiting its full potential urgently requires intense novel research efforts as the electrified drive train requires specific solutions that are completely different to conventional the power train. The lack of cheap and secure batteries providing sufficient power and energy densities still is the biggest roadblock for the EV. Electric motors and power electronics for mobile systems are other topics of highest priority for research. New production systems and technologies for high energy density electric components are required. And, smart systems for energy management, drive train integration and drive train management need to be explored and developed as soon as possible.

The migration towards electricity is a massive change in vehicle technologies and systems that will not only substantially alter R&D priorities but even influence the decisions of OEMs and suppliers on investments, product portfolio and vehicle

concepts. Furthermore, it will bring together branches that were only little-connected before, automotive industry and utility companies. To make sure, Europe can benefit from the global trend towards the electrification of the drive train, a tight public-private partnership of stakeholders in all stages of planning, engineering, introducing and operating the required vehicles and infrastructures has to be established. Joint activities are needed to gain a common understanding on R&D road maps, cooperation schemes as well as on introduction plans, incentives, rules, business models and concepts for the integration with other transport modes. It is fundamental that any upcoming European initiative allows for an efficient coordination with existing or planned national programmes and local initiatives.

To assess more accurately the environmental impact of the mass use of electric vehicles, the various scenarios of well to wheel emissions and of electric vehicles and plug in hybrid electric vehicles should be studied in detail and life time assessment studies should be made. Nevertheless, even today it is obvious that the deployment of electric vehicles and the growth of electricity generation from renewable energy sources have to converge in order to meet the objectives of reducing GHG emissions in Europe.

6. Recommendations

a) Public Private Partnership/Major Activity “Electric Mobility for Urban Areas”

Taking into account the massive extend to which the United States and Japan are currently funding R&D in the domain of electric vehicles, the European industry and the European Commission together with the Member States should jointly take the initiative for a major action to ensure global competitiveness by leveraging technologies and innovations for the full electric urban mobility system and yield them to the public as early as possible. Europe should, like in the field of renewable energy, overtake the lead in electrifying urban mobility.

Priorities of the initiative would be to catalyse already existing or starting national and industrial initiatives to develop technologies, components and subcomponents, infrastructures, interfaces and, what is of high urgency and importance, regulations, incentives and business models, required for the mass use of electric vehicles in urban areas in Europe.

One key of this action should be demonstrations and fleet tests involving electric vehicles and their vehicle-to-grid capabilities. A larger number of cities (more than 5) in various regions of the European Union should be the test field for a fleet of (more than 1000) cars, busses and trucks. Research should focus user patterns, infrastructure needs for charge and discharge, and technical prerequisites for the connection with existing power generation and mobility systems. By such a larger activity all bottlenecks could be identified and resolved in the interfaces between the electrical power users, the infrastructure, the electrical grid and the power producers. This would also help to overcome the critical initial phase in ramping up the technology, production numbers and capacities in the industry being involved.

b) Research Priorities “Electrification of the Drive Train”

The European Commission should call for proposals on “Electrification of the Drive Train”. This call should concentrate on the medium to long term issues on electrification. In view of the input of the ERTRAC and EPoSS experts it can be stated that a call with the following content would meet both the most urgent research needs related to the electric vehicle and the plans of the major players in the automotive and supply industries:

Intelligent and smart components and systems enabling the full electric vehicle, or as first step the ICE assisted EV, by

1) providing safe, low cost and robust Electric Storage Systems by developing three axis in parallel:
    a) on the short term: optimising lithium ion cell technology and the structure of the global battery system (e.g. cooling). Assessment of cost, safety and energy/power require-ments is crucial from system up to vehicle level are crucial.
    b) on the long term: supporting the creation of a competitive European industry for battery cells by exploring cell technologies beyond lithium ion:
        i) developing innovative technologies such as new electrode materials with high energy density, cell components with lower cost or enhanced safety, special treatments to improve life
        ii) deeply understanding the safety and ageing mechanisms
    c) advanced battery management units and smart components providing ware, caring and robust means of of power and energy routing between accumulator cells, battery packs, the traction system and the grid

    Given the importance of better battery performance for the mass introduction of electric vehicles, and in light of the complexity of R&D and manufacturing challenges in this field, another key element of this action should be the establishment of a central European facility for prototyping, testing and manufacturing of advanced traction batteries, shared by researchers from academia and engineers from the industry.

2) developing electric drives (electric motor plus power electronics) and related adaptive control solutions with particular focus on:
    a) innovative electric machines maximising specific torque with increased partial load efficiency also in high speed conditions. Key issues will be: materials improvements, robust design for fault conditions usage, identification of solutions suitable for large volumes applicability (automated production processes)
    b) power electronics solutions with new architectures able to better cope application constraints, multifunction integration and modularity, e.g. for in-wheel motors. Important research issues both at device and system level (e.g. cooling).
    c) powertrain solutions able to properly integrate electric motors with mechanical transmissions and electric motors with power electronics

d) strategies able to further explore and extend the usage of adaptive controls, improved modulation techniques and mechanical sensor less solutions (also to increase the electric drive robustness)

3) Developing electric vehicles by
   a) Integration of novel electric energy storage system and electric drives
   b) Optimising and integration of novel ICE range extenders
   c) Developing, integration, and smart control of energy-efficient electrified auxiliaries
   d) Complete vehicle energy management methodologies and smart devices for the routing of energy and power to enhance the energy-efficiency of the vehicle, its use and all its loads
   e) Control methods and strategies taking into account requirements from different architectural domains
   f) Safety and robustness of communication, actuators, electronic control units and power electric converters
   g) Developing an optimal vehicle electrical architecture including new semiconductor devices for compact and cost effective solutions. This includes EMC as well as health and safety aspects.
   h) Reducing the vehicle's weight and resistance, and solving implications e.g. on road safety by smart adaptive components, driver assistance systems and cooperative driving.
   i) Life cycle aspects, including ageing of component
   j) Life cycle assessment and well-to-wheel analyses of various combinations of energy storage system, vehicle concepts and energy source.

4) Grid Integration issues: infrastructure and smart interfaces
   a) Diagnosis and communication: All relevant information of the different states like state of charge, state of health of the battery, maximum voltage and the different charge profiles have to be defined. A specification for the communication and for the system architecture (hardware and software) has to be developed to optimise the charging of the electric vehicle.
   b) High Voltage Systems Technology: This includes the specification of the HV system based on the laws, standards and codes existing to protect human beings against electric shocks. The electro-magnetic compatibility is important for the components and the complete vehicle. New methods to measure the HV-power circuit pulses and interference voltage have to be developed.
   c) On-board and off-board vehicle-to-grid connection systems for charge and discharge adapting to user needs, tariffs and the state of the grid.
   d) Charger and interconnections: This part contains the development of prototypes of chargers including connectors and cables and the built of prototypes for the integration in the vehicle. During the trial test exists a

continuous observation and analysis of the chargers and interconnections to implement improvements.

e) Standardisation of the interface between vehicle and charging infrastructure: This includes the analysis of the actual used standards (national and international) and activities of the charging infrastructure. Preparation of trial results for relevant standardisation boards will be arranged to establish a standard interface between the electric vehicle and the charging stations.

The focus shall be on technologies representing a breakthrough in efficiency, simplicity and cost reduction. There is clear potential for IPs in each of these areas. Therefore, ERTRAC suggests including the abovementioned research needs a single call within the RTD Work Programme 2009/10 on “Electrification of the Drive Train”. In this call, the requirements of all types of vehicles, including for public transport, should be addressed.

5) Production technolgies and logistics isues:

Aiming at:

a) availability of raw materials

b) regulations for transport of batteries (today, they are considered “dangerous goods”

c) “break the economies of scale”, ie. Best cost at low volumes to secure the transition to EV

d) global planning of manufacturing sites given the fact that EV market will emerge in Europe, US and Asia.

c) Coordinated and Support Action (CSA) “Enabling Technologies for the EV”

ERTRAC and EPoSS experts made obvious that there is a tremendous need of coordination between the different players involved in the move towards electric vehicles. Therefore, ambitious Coordinated and Support Actions (CSA) aiming at identifying the needs in terms of research, components, system integration, standardisation, assessment of energy efficiency, GHG emission and life cycle impact, infrastructure and regulations enabling and leveraging the technologies for full electric vehicles and their convergence with regenerative energy sources are urgently needed. It should bring together automakers, suppliers, independent research and development capacities, standardisation bodies, utilities, national and local authorities, public transport operators and user organizations, European Technology Platforms and the European Commission. Its tasks should include editing and regularly updating of a European EV roadmap, the organization of expert hearings and networking events, and the intense cooperation with EV-related activities at the member states’ and global levels. ERTRAC and EPoSS recommend calling for such CSAs at the earliest possible instance.