



European Roadmap Electrification of Road Transport 2nd Edition



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European Roadmap

Electrification of Road Transport

2nd Edition



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1 Introduction

Within the last years electrified mobility has been given first priority in the US, Japan, China, Korea and EU. Dedicated national programmes are legion, similarly there is a proliferation of qualitative position papers and reports, while several automotive company executives have contributed to raise the general expectations through announcing the imminent mass production of electric vehicles (EV). The move from conventional combustion based mobility to more electric or full electric mobility poses many questions with answers depending on a multitude of interdependent parameters. The matter is quite complex and because of that, when treated only in qualitative terms, gives rise to controversy that may slow down the decisional processes. The aim of this roadmap is to help quantifying the differences between conventional and new technologies in terms of the much cited aspects of energy and resource security, climate change, public health, freedom of mobility, and economic growth, and to suggest actions that will create an impact on these. Therefore, in the first instance the EV is assessed in comparison with the internal combustion engine (ICE) taking into account:

- Primary energy savings
- Security of energy supply
- Cut of GHG emissions
- Reduction of noxious emissions
- Range and speed
- Cost of technology and constraints on raw materials

Furthermore, based on surveys among major European companies from the automotive and energy value chains, milestones for implementation of the new technologies are set and required actions are indicated in terms of content and timing.

This roadmap builds on the European roadmap “Electrification of Road Transport” as published in October 2009 by the European Technology Platforms ERTRAC, EPoSS and Smart Grids. This roadmap was the result of a Task Force Electrification, which was established at the beginning of 2009 to support the Public Private Partnership (PPP) European Green Cars Initiative. A detailed breakdown of steps towards milestones were formulated in order to assess what benefits electric vehicles bring by when and what actions are required to master the different challenges of deploying electrified mobility on a large scale. A 1st milestone was set in 2012 representing the first step in the implementation of electrified mobility.

With the first milestone being reached in 2012, the time is right for a review of the goals and objectives of the first electrification roadmap. In this updated roadmap the 1st milestone defined as “the introduction phase” is reviewed by mapping current European Green Cars Initiative projects against the defined actions. Furthermore, a new 4th milestone is introduced looking further into the future, extending the timeframe of the roadmap to 2025.

Roadmap scope

Electrification of road transport generally can refer to vehicles of many kinds including bikes, scooters, passenger cars, delivery vans and vehicles for public transport. In this roadmap however the focus is put on passenger cars, and the term electric vehicle (EV) means all kinds of vehicles that provide at least 50km of pure battery-electric range such as pure electric vehicles, electric vehicles equipped with a range extender, and plug-in hybrids, which may provide potential beyond the transition phase, e.g. when combined with biofuels. It shall be pointed out, however, that Light Electric Vehicles (LEV) like e-bikes, motorbikes and

small cars are expected to have a rapidly rising market share and may facilitate the market entry of electric mobility in its entirety. This roadmap is only dealing with vehicles which can be charged with electricity from the electricity grid (Plug in EVs or PLEVs). Thus, this roadmap does not include fuel cell electric vehicles (FCEV). FCEVs are dealt with in other documents, like those generated by the Fuel Cells and Hydrogen Joint Technology Initiative (FCH-JTI) or EUCAR.

This electrification roadmap is part of the long term strategic visions formulated in the Strategic Research Agenda (SRA) of the involved European Technology Platforms, with ERTRAC e.g. presenting the research priorities to tackle the societal challenges of Road Transport, and EPoSS being focussed on ICT and smart systems as key enabling technologies. To implement this vision, implementation roadmaps are developed on key issues. These are concerned with passenger as well as goods transport and the future mobility system as a whole. Some of these roadmaps address topics relevant for electrification, e.g. roadmaps for the future European bus system, light duty freight transport (i.e. modes of transport being responsible for high levels of noise, CO₂ and noxious emissions), and hybrids (which have an enabling role for electrified mobility), heavy duty freight transport (where efficiency gains are rather expected from smart logistics than from electrification) as well as for infrastructures, integration into urban mobility system and European technology and production concepts. These roadmaps complement each other and ensure all aspects of the electrification efforts are covered.

This roadmap aims to serve as one basis for the electrification of passenger cars. It presents the framework for additional more detailed roadmaps on a few topics regarded as horizontal or essential issues for reaching the electrification goals. Identified topics deserving a more in-depth and detailed analysis are simulation, EV manufacturing, grid infrastructure and Information and Communication Technologies (ICT). In a next step detailed roadmaps for these topics will be developed, identifying the steps to be taken in the different areas to reach the common milestones.

EV roadmap purpose and process

This roadmap has been prepared by the members of the European Technology Platforms ERTRAC, EPoSS, and SmartGrids and led by the chairman of ERTRAC. The targeted portfolio of R&D topics in this roadmap is the result of an efficient and fast stakeholder consultation process developed in the PPP European Green Cars Initiative (Fig. 1). Decision makers from major European companies dealing with automotive, energy or mobility topics have gathered in an Industrial Advisory Group, representing the European Technology Platforms ERTRAC, EPoSS and SmartGrids. They entered into a continuous and cooperative dialogue with the involved Directorates General of the European Commission. Their advice and recommendations are based on a continuous process of strategic stakeholder consultations taking place mainly in dedicated workshops. There, the expertise of the members of the platforms can be channelled into the development of this multi annual implementation plan.

The commitment of the involved industries is reflected in collaborative research projects jointly funded with the EC. The approaches and results of ongoing research activities are regularly monitored and matched with the milestones of the roadmaps, in order to gain feedback which is continuously used for the improvement of the advice. Thus, this report is a vital document that is constantly being updated in a broad consultation process. The current update is coordinated and facilitated conjointly by the Coordination and Support Actions CAPIRE and ICT4FEV funded within the 7th Framework Programme.

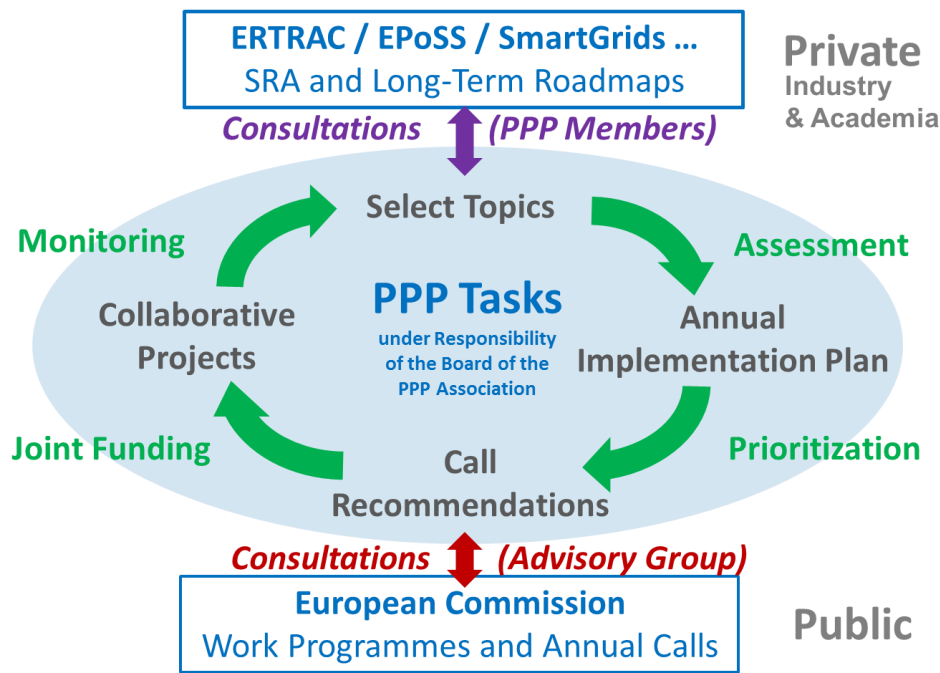


Figure 1: Stakeholder Consultation Process of the PPP European Green Cars Initiative

The mentioned first edition of this report contained recommendations regarding the European 7th Framework Programme. So far, three rounds of calls have been launched and projects are running or starting. The first call published in summer 2009 focused mainly on components and architectures of the electric powertrain, electrochemical storage applications and demonstration of electric mobility. The second, launched in summer 2010, called for projects targeting energy management, stability and safety issues and manufacturing of batteries. Moreover, a joint call of public authorities at Member States and regional level within the framework of ERA-Net Plus was launched. The third call published in summer 2011 addressed electrochemical storage, lightweight material, modelling and simulation, range extenders, smart infrastructure and integration of EVs into transport infrastructure, electric drive and components as well as functional safety. The authors expect that the European Commission and the Member States will continue to refer to this report as a common industry position when setting priorities and timing of actions towards the electrification of mobility and transport as a system. With the current update including the extension to a 4th milestone scheduled in 2025, the basis is provided for recommendations concerning Horizon 2020.

2 Benefits and Challenges of the Electric Vehicle

2.1 Primary energy savings (aiming at energy security)

A growing world population and a growth in GDP will lead to a growth in future primary energy demand. According to IEA the world energy consumption will increase in 2025 with 50%, compared to the level of 2005, 15 billion tons of oil equivalents. This growth will mainly come from non-OECD economies. Oil will remain a long time the basis for fulfilling the world primary energy demand, but gas and renewable energy will gain share by 2030 ⁽¹⁾.

Due to the EU's growing dependency on primary energy sources this parameter is very likely the most motivating one. In the EU, 73% of all oil (and about 30% of all primary energy) is consumed by the transport sector ⁽²⁾. Today, internal combustion engines (ICE) depend heavily on fossil fuel usage, creating depletion of the finite reserve of non-renewable energy sources and creating economic and geopolitical concerns. Biofuels and natural gas are playing a role in securing fuel supply for ICEs, however just for a small fraction. On the other hand, electricity can be produced from many different energy sources including renewable energy sources like hydro, wind solar and biomass.

To quantify the technological evolution that makes electric mobility appealing we take as a reference an ideal vehicle whose energy consumption depends only on mass, aerodynamic drag (frontal area and C_x ¹) and tyre/road rolling resistance. In reality, the amount of energy consumed strongly depends on the typology of the powertrain, the chosen cycle, and the energy need for cooling or heating. To compare the electric vehicle and the ICE we take as a reference a mid-size vehicle (1300kg) with aerodynamic factor of 0.7m^2 , conventional rolling resistance tyres, and an ideal powertrain with 100% efficiency, thus consuming 120 Wh/km ⁽³⁾ at the wheels over the New European Driving Cycle (NEDC).

Combustion engines made in Europe are among the most economical ones in the world. Their efficiencies can reach up to 0.45, however varying with speed and load. The extracted oil can be refined into diesel or gasoline with an efficiency of 0.88-0.92. Taking into account real driving cycles and a typical transmission efficiency of the order of 0.9 the overall well-to-wheel (WTW) efficiency of modern powertrains can be set in the range of 0.16 to 0.23 ⁽⁴⁾ (5). These values already include the most advanced innovations in fuel and transmission controls. Hence, in reality the consumption of primary energy is between 520 and 750 Wh/km.

The peak efficiency of an electrical motor can achieve 0.95 at defined power and torque values ⁽⁶⁾. It may drop to below 0.6 in extreme cases, but for a large range of power and torque the average efficiency can be kept at above 0.9, thus the electric powertrain can be designed intrinsically less sensitive to the characteristics of the driving cycle, particularly when using more than one motor. The overall combined efficiency of power switches, DC/DC and AC/DC inverters can reach 0.9 whilst that of motors and gears depends on the chosen driving cycle with typical values ranging from 0.8 in case of large excursions of power and torque to 0.86 for smoother cycles. In conclusion from the battery via power electronics to the wheel, the modern electrical powertrain can assure efficiencies in the range of 0.72 to 0.77. For the electric car, the assessment of the well-to-wheel efficiency has to include on the well-to-socket side the efficiency of the generation and the load losses at distribution of electricity. In most EU member states the average efficiency of power plants is at 0.45 (7) ⁽⁸⁾

¹ C_x – aerodynamical drag coefficient

,while that of the power grid can reach up to 0.93. Thus considering the whole chain of current conversion efficiencies (power plants, electrical grid, AC/DC inverter, energy-power storage systems in slow charge/discharge modes, power electronics, electrical motors), the well-to-wheel efficiency of the electrical powertrain can be stated to be 0.24 to 0.26 i.e. the consumption of primary energy for the reference vehicle is in between 457 to 492 Wh/km (**Table 1**).

Year	Power Plant Efficiency	Grid Efficiency	Inverter AC/DC Efficiency	Battery Efficiency (Slow Charge)	Power Electr Efficiency (DC/DC, DC-AC)	Motor to Wheel Efficiency (NEDC)	Energy Consumption Ideal mid size car Wh/km #	Total Consumption of Primary Energy Wh/km*
1998 Range 20km°	0.39	0.88	0.85	0.70	0.85	0.65-0.70	120	987-1064 -7% Reg. Braking
2008 Range 150km	0.45	0.93	0.90	0.90	0.90	0.80-0.86	120	457-492 -15% Reg. Braking
2008 Range 150km	Renewable Energy only	0.93	0.95	0.90	0.90	0.80-0.86	120	205-221 -15% Reg. Braking
2008 Range 600km	WTW Powertrain Efficiency of a Conventional Internal Combustion Engine car in reality: 0.16 - 0.23						120	522-750 -10% micro-mild hybrid

Table 1: Evolution of primary energy consumption of electric vehicles, and comparison to the conventional power train. #Energy needed to move an ideal mid-sized vehicle in the NEDC (New European Driving Cycle). °Reduced battery weight. *Cars smaller than the reference vehicle may have less energy consumption.

A comparison with the situation ten years ago shows that in the last decade the technological evolutions have radically changed the impact of the electric vehicle on primary energy consumption: from about 30% higher primary energy consumption as compared to the ICE in 1998 to about 25% energy savings in 2008. These figures do not yet take into account the potential for energy harvesting e.g. by modern low cost on-board photovoltaic technology. The growing fraction of renewable energy in the EU electricity mix will increasingly enable the convergence of CO₂-neutral primary energy sources with electrical mobility.

The well-to-wheel assessments also show that introduction of EVs is less advantageous in countries having power plants and grids with efficiencies below average or when used in the fast charge mode with maximum efficiencies reaching no more than 0.8 at a low state of charge of the battery (**Table 2**). In those cases priority should be given to modernising the sectors of energy production and distribution. Moreover, for both primary energy savings and longer battery lifetime, slow charge should be suggested as best practice until next generation batteries can assure high efficiency under accelerated charging conditions.

Year	Power Plant Efficiency	Grid Efficiency	Inverter AC/DC Efficiency	Battery Efficiency (Fast Charge)	Power Electr. Efficiency (DC/DC DC-AC)	Motor to Wheel Efficiency (NEDC)	Energy Consumption Ideal mid-size car Wh/km #	Total Consumption of Primary Energy Wh/km
2008 Range 150km	0.42	0.80	0.90	0.80	0.90	0.80-0.86	120	641-689 -15% Reg. Braking
2008 Range 150km	Renewable Energy only	0.93	0.90	0.80	0.90	0.80-0.86	120	235-219 -15% Reg. Braking
2008 Range 600km	WTW Powertrain Efficiency of a Conventional Internal Combustion Engine car in reality: 0.16 - 0.23						120	750-522 -10% micro-mild hybrids

Table 2: Primary energy consumption with reduced power plant and grid efficiencies as well as fast charge mode. # Energy needed to move an ideal mid-sized vehicle in NEDC (New European Driving Cycle).

Clearly the convergence of renewable energies (RE) and electrified mobility appears the most appealing for reducing the anthropogenic impacts on the environment as well as reducing the oil dependency. One of the most interesting aspects of the electric vehicle is the freedom to produce electricity from many different energy resources. As a result of the 2007 EU 20/20/20 Energy & Climate strategy ⁽⁹⁾, a binding goal of 20% of EU energy demand to be gained from renewable resources was set by the renewable energy directive in 2009 ⁽¹⁰⁾. Following this, 62% of energy generation investments in 2009 ⁽¹¹⁾ have been dedicated to renewable energies. Member States projections foresee much higher growth rates in the coming years than in the past, which would add up to a share of renewable energies in 2020 that exceeds the targeted 20%. Hence, even if the plans may not be fully met, the way for the provision of renewable energies is paved.

On high-speed highways, full hybrids have higher consumption at full-throttle-operation than conventional ICEs due to their higher weight. But the hybridisation of conventional (mainly) large and mid-sized ICEs can be considered a first step towards energy efficiency through electrification since it allows energy savings up to 25-35% in urban cycles ⁽¹²⁾ compared to the corresponding conventional powertrain. Its implementation on a large scale will thus help to comply with the CO₂ emission targets for cars of the EC for 2012/2015. Thus, in the next 5 years a number of hybrid systems from micro to full hybrids will emerge. At the same time, lighter and smaller full electric cars will be developed requiring even significantly less energy from the battery to the wheel on the NEDC than the reference car considered here.

Well-to-Wheel analysis considers the life cycle of the energy vectors used by the vehicle, but does not consider the whole life cycle of the vehicle. A vehicle's life cycle can be divided into four stages; vehicle production from extraction of raw materials to delivery of the complete product, production of the fuel and/or electricity used by the vehicle during its life, the impact of vehicle use, and finally vehicle disposal at the end of its life. For the purpose of evaluating various powertrain types in terms of environmental impact and primary energy consumption over their entire life time, life cycle assessment (LCA) is a very useful and powerful tool. The general principles for LCA are explained in ISO 14040:2006 and a guide for

practitioners is provided in ISO 14044:2006. ISO 14025 defines Environmental Product Declarations (EPDs). Many vehicle manufacturers are already using LCA to produce EPDs of their vehicles. However there is inconsistency between manufacturers on how the results are presented, and a lack of information provided on input assumptions. This can make it difficult to compare LCA results of vehicles from different manufacturers. Further work is required to achieve commonality in LCA results across the automotive industry and to enable consumers to consider life cycle environmental impacts when making purchasing decisions. EPDs tend to be compiled at the end of the development process as the vehicle goes into production. At this point it is too late to make changes that will significantly impact the vehicle's life cycle environmental impact. Therefore, adoption of a Life Cycle Philosophy from the earliest stages of automotive research and development is required to ensure the appropriate selection of technology for lower environmental impacts. The connection between the purpose of an LCA study and the vital parameters of the goal and scope definition has been explored by Tillman (2000) ⁽¹³⁾. The goal and scope definition of an LCA study is heavily dependent on the intended use of the study and the questions it has been setup to answer. This makes different LCA studies which are not formatted for comparison very difficult to compare indeed, even for seemingly similar product case studies. In order to overcome these difficulties and make full use of LCA as a powerful tool for evaluation of new vehicle technologies, there is a need for increased methodological LCA research, both for general studies as for vehicles studies in particular. An important issue to cover is the selection of a functional unit. The functional unit is the backbone of every LCA as it enables a comparison of different products based on the same provided service. For vehicle LCA the effect of hybridization on different vehicle types and the service they provide should be taken into account when exploring functional units, like in Matheys (2007) ⁽¹⁴⁾. A wide range of vehicle technologies exist. The question is how to treat electric vehicles (with different ranges and batteries), plug-in hybrids, range extenders, strong hybrid vehicles, mild hybrid vehicles and hybrids with various energy sources (thermal engines, solar panel, fuel cell ...). Close to these methodological issues it should be made clear how to perform a sensitivity and uncertainty check in vehicle LCA. Often the environmental impact of a vehicle calculated with life cycle assessment is shown as one single value. This approach approximates the environmental impact of a vehicle, but fails to provide decision-makers with a wide view on the possible effects of their decisions. The complexity, uncertainty and variability of the system are not well approximated with one single value. Uncertainties are an inherent part of LCA and should not be avoided but embraced and made explicit in the result. Identifying and integrating uncertainties in the end result should provide decision makers with a more robust interpretation of the results. An example of a range based vehicle LCA can be found in Van Mierlo (2009) ⁽¹⁵⁾. LCA data is shared on a European level through the Joint Research Center of the European Commission within the European Reference Life Cycle Database (ELCD) and globally within the International Reference Life Cycle Data System (ILCD). The most effective way for LCA researchers investigating electrification of road vehicles to improve data quality will be to use and supply data within these existing networks. Projects directed to data gathering should focus on making production data more specific and detailed on component level instead of aggregated as now. This should also be applied on impact assessment by for instance including geographic information on the emissions of vehicle with a GIS based LCA. When developing new technologies such as electric vehicles, the influence on sustainability parameters should be taken into account. A framework based on case studies on Life Cycle Sustainability should be

worked out. A typical Life Cycle Sustainability Assessment would combine E(nvironmental)-LCA, S(ocial)-LCA and Life Cycle Cost (LCC) aspects in one multi-criteria assessment (MCA).

2.2 Cut of GHG emissions (preventing climate change)

Vehicle emissions are contributing to the increased concentration of gases that lead to climate change. In order of significance, the principal greenhouse gases (GHG) associated with road transport are carbon dioxide (CO₂) and methane (CH₄). In the EU the transport sector causes 26% of all GHG emissions due to human activities ⁽²⁾ ⁽¹⁶⁾. Although these are only 4% of the total GHG emissions they accumulate in the atmosphere because the ecosystem is unable to compensate for them at the same rate as human activities have changed in the last one hundred years. Furthermore, the transport sector is the fastest growing source of greenhouse gases, and of the total from transport, over 85% are due to CO₂ emissions from road vehicles. Therefore, they are considered a major sector to attack for a limitation of GHG emissions ⁽¹⁶⁾.

The differences between conventional mobility based on internal combustion engines (ICE) and BEV in terms of CO₂ emissions are summarised in Table 3. Especially considering the expected development of the European electricity production mix towards renewables, it is evident that EVs may lead to a considerable reduction of CO₂ emissions.

CO _{2eq} in g/km			
	Well to Tank (Batteries)	Tank (Batteries) to Wheels	Total CO _{2eq} Emissions
Conventional ICE Car *	23	120	143
Biofuels	17 - 28	97 - 135	114 - 163
Battery Electric Vehicle 27% Nuclear 20% Renewable 53% Fossils (EU-27 mix 2010)	67 - 84	0	67 - 84
Battery Electric Vehicle (Coal)	126 - 155	0	126 - 155
Battery Electric Vehicle 50% Wind 50% Photo Voltaic (Renewables)	0 – 4**	0	0 – 4*

Table 3: Comparison of WTW CO₂ emissions for conventional gasoline ICE vehicles, biofuels conventional ICE and EVs in relation to the electricity mix. EU-27 Electricity mix derived from Eurostat. Emissions from ⁽⁴⁾. * Definition of conventional ICE car from ⁽⁴⁾. **Emissions for Photovoltaics from EPIA, Wind from EWEA.

Again the impact would not be the same everywhere; for instance in a country where most of electricity is produced by burning coal there would be only minor GHG emission benefit from the EV introduction. The largest reduction is associated with the use of renewable

energies with the lowest values for EVs achieved e.g. in the emerging “carbon free communities”, where the electricity is entirely produced by wind, water, photovoltaic, geothermal energy, biomass or animal waste. However, in a vision where most of new power installations will be renewable technologies, the EV is considered a way towards a radical reduction of greenhouse gas emissions. Deployment of electric vehicles may even help to extend the use of renewable energy if it is targeted at captive fleets in areas close to an abundant supply of stochastic renewable electricity. With the mass deployment of EVs the securing of marginal energy production from sources with low GHG emissions will become important for the GHG balance of EVs.

In order to assess thoroughly the environmental impact of vehicles, a full life cycle assessment has to be carried out, taking into account variability and uncertainty. BEVs powered with wind power, hydropower or nuclear power appear to have very low greenhouse effect, since there are no conversion emissions related to electricity production. They are followed by the scenarios of the European electricity mix and natural gas electricity production, which also have very low greenhouse effect in comparison to diesel and petrol vehicles. In extreme scenarios, in which BEVs are for 100% powered with oil or coal based electricity, the LCA results shows that BEV have climate impacts which are comparable to the ones of diesel cars. As fuel saving technologies are reducing the total life cycle carbon emissions mostly by lowering the WTW carbon emissions, the balance of the carbon footprint between life cycle stages is relatively changing towards the production of the components. In absolute terms, the WTW stage still remains the most important life phase. When a BEV is only powered with renewable energy or nuclear energy, the embedded carbon of the vehicles’ components becomes the majority of the impact on climate change, since there are no tailpipe emissions neither conversion emissions related to electricity production. Different data sources for the carbon footprint of batteries can lead to different interpretations of carbon footprint of electric vehicles. ^{(15) (17)}

2.3 Reduction of noxious emissions (raising public health)

Road transport remains the main source of many local noxious emissions including benzene, 1,3-butadiene, carbon monoxide (CO), nitrogen oxides (NO_x) and particulate matter (PM). Within urban areas, the percentage of contributions due to road transport is particularly high. There is a growing body of evidence linking vehicle pollutants to severe health effects such as respiratory and cardio-pulmonary diseases and lung cancer. In general according to the World Health Organisation the emissions from car exhausts are responsible for more deaths than road accidents. It should be pointed out however, that major improvements in urban air quality have occurred in the past decades, due to improvements in emissions performance from conventional vehicles. This improvement has frequently been estimated to be better than about 95% compared to about 20 years ago. Looking out to 2025, and given the EV penetration shown in Figure 2 in this roadmap, advanced ICE vehicles will still represent more than 90% of the on-road fleet in 2025. So, further improvements in urban air quality to a large extent will have to come from emissions improvements in advanced ICE vehicles. The growing penetration of EVs in the longer term will contribute to the elimination of the side effects, which are due to hydrocarbon combustion in conventional vehicles, provided that they don’t occur during power generation. Some emissions, e.g. due to

tyre/road abrasion however remain and studies will be needed to ensure that they are not worsened because of the different traction characteristics of EVs.

Road traffic is known to be the most important contributor to urban noise levels, which usually exceed the WHO-guidelines and cause major health problems. The noise of electrical vehicles is limited to rolling resistance and air drag. First steps are currently taken to understand the NVH (Noise Vibration Harshness) properties of electrified vehicles, but the road is still long before a similar level of expertise and dedicated numerical and experimental tools are available as for ICE vehicles. Exterior noise at different speeds needs to be studied, for example the effects on road safety caused by low-speed noise levels have rarely been studied so far and need to be further investigated.

2.4 Range and speed (freedom on mobility and the need of fuels)

A mid-sized BEV in use for urban mobility will be designed such that it can be operated for most of the day by a single charge. In contrast, with long distance highway driving and/or at with sustained high speeds, battery capacity may not be sufficient to complete a journey or a full day's driving with a single charge. As a consequence, due to the limitations imposed by affordable costs, acceptable extra weight and by the timing of recharge, the use of a fuel based range extender will remain necessary until the next generation of much more advanced battery technology becomes available. To cover the full spectrum of mobility needs, whether the vehicle is a full, mild, or micro hybrid powertrain, the use of high energy density liquid or gaseous fuels will remain necessary without alternatives in the midterm horizon⁽³⁾. At the same time, micro hybridisation of conventional mid and large size vehicles will continue and expand on a broad scale.

A need for research is hence foreseen in the direction of integration of compact and efficient ICEs and electrical motors, as well as in advanced fuel cells as a range extender. Higher consumption of fossil fuels in emerging economies is likely to hamper biofuels output at the global level. The search of new routes to new fuels is therefore of paramount importance in view of the ever increasing gap between demand and supply of oil. Further achievements should be encouraged towards novel biofuels derived from algae grown with biowaste nutrients and novel synthetic fuels assigning a priority to solutions that minimise the use of land and freshwater. In the longer term, charge while driving as a solution may remove the need for ICE as range extenders and create full freedom of mobility in a long term perspective. Several techniques and system solutions are now being pursued and developed in the world, and the prognosis of these technologies are that they will be up and running in the period of 2025-2030.

It is however worthwhile to note that about 90 % of the mobility needs in European cities can be satisfied by pure mid-sized EVs as the average mileage is almost always below 100 km per day at low speed. Range and speed are not a strong limiting factor when speaking about urban traffic. Furthermore, since an average vehicle is parked for 20-22 hours of the day, the possibility of low power charging (2-6 kW charging power) and thus the opportunity to satisfy an even higher percentage of Europe's inhabitants driving needs is obvious. But real-world driver experience shows that "range anxiety" is real (especially when considering the range impact of different driving styles and in particular outside temperature) and that thus many drivers do not dare to use the battery capacity fully. In this context more research regarding range anxiety and EV driving behaviour as well as the interrelation with the

availability of infrastructure is needed. Furthermore, innovative ITS services and tools will support the driver with the benefit to enhance his confidence in EVs and their integration with the infrastructure. Another important issue is research on typical driving cycles for specific regions since the battery and hence the range will be influenced by the different regional conditions as e.g. landscape and weather.

2.5 Cost of technology and constraints on raw materials (EU security)

The cost and supply constraints of the battery pack are acknowledged to be the most limiting factors for the wide scale introduction of battery electric vehicles. Making a detailed analysis of the raw materials used in the current state of the art Li-ion technology their selling price may be expected to reach affordable values at below 200€/kWh on cell level in the mid term (18) (19). This is a very challenging target and can only be achieved when learning effects due to large scale productions and further optimisation of the cell structure are achieved. This would very likely lead to the desired price levels in a few years, but the user of the automobile is asking for much more than just lower costs. Progress has been dynamic in terms of design of lightweight chassis, powerful and efficient drive trains, aerodynamic shapes, and sophisticated computer controllers.

Substantial reservations persist about the long-term performance of Li-ion batteries under the extreme heat, cold, humidity and vibration conditions that automobiles have to endure on a daily basis (if not compensated for by appropriate protection measures). For instance the lifetime of a battery is halved every 10 deg of average temperature increase, which requires complex and expensive temperature conditioning including either expensive liquid or forced air cooling of the overall battery compartment.

Still a couple years ago, analysis showed that battery production and especially European battery production will not be sufficient to cover the expected demand by the automotive industry. OEMs reacted and accelerated their efforts to build up their own battery production facilities or build Joint Ventures to secure their battery supply. Presently, the number of production facilities and their announced capacity starts to raise concerns of over supply starting in 2015. These predictions however, are very dependent on the expected market development of EVs. Hence, a stronger take-up of EVs on the market may easily lead to an under supply again. Furthermore, the strengthening of the European production ability should be watched closely.

The second large source of uncertainty is related to the availability of reliable and diversified supply of raw materials, e.g. copper and rare earths for permanent magnets that are necessary to assure high efficiency and high power density, that is compact, electrical motors. While at a research level several solutions are pursued, it seems there is no viable industrial alternative to NdFeB for at least another decade when considering Permanent Magnet synchronous motor designs. The move from few and critical sources of oil to a likely even more critical single source of rare earths magnets should urgently address the development of both new high efficiency motors using a limited amount of permanent magnets and completely new motor designs, as e.g. induction motors. Like for the batteries the production of low cost, efficient and compact motors using permanent magnet technology will not be available in adequate volumes and will be subjected to supply constraints for several years. The issue of rare materials is also important for other parts and components as e.g. power electronics. The Raw Materials Initiative of the European Commission DG Industry and Enterprise has developed a strategy for rare materials supply

⁽²⁰⁾. Automotive specific aspects related to R&D will be considered in detail in the Materials Roadmap described as transversal function in chapter 7.

The issues of batteries, motors, and the scarcity of crucial materials severely threaten the large scale introduction of electrified vehicles as they are pushing back the enormous and crucial economic and environmental benefits that EVs can provide.

3 General expectations

Public perception of the move towards the electrification of road transport is affected by a multitude of motivations like e.g. climate protection, primary energy savings, and public health. Government incentives are also expected to play a major role in accelerating the move towards lower emission vehicles. Governments across the world are providing different economic stimuli to push the development of new technologies. On the other hand regulations on vehicle emissions, force OEM's to pursue CO₂ reducing technologies. The stringent European emission regulations coupled with the high fuel prices provide an additional incentive to develop new and cost efficient technologies. These factors can be an important driver for the European automotive industry to develop the right solutions for the future and secure exports to megacities abroad. At the same time however, there are concerns about high investment costs and scarcity of raw materials. Nevertheless, there is a growing awareness that the underlying technology has gained a sufficient level of maturity which is pushing towards a quick change.

From one side the users are asking for EVs well beyond what the OEMs can deliver, on the other side the spread of unsafe vehicles, bad practices and inefficient infrastructures should be avoided. The number of people living in urban areas has recently overcome the rest of the world population and everywhere the tendency is to avoid the urbanisation of new lands while remodelling the urban area by introducing new concepts of mobility.

To understand the potential current driving factors for the future market of EVs we consider the following EU data ⁽²¹⁾:

- 68% of the EU population including associated states live in urban areas
 - 6 cities have more than 3 million inhabitants (Berlin, Madrid, Paris, London, Ankara, Istanbul)
 - another 20 cities have between 1 and 3 million inhabitants
 - considerably more cities have between 0.5 and 1 million inhabitants
 - 80 cities have between 250.000 – 500.000 inhabitants
- from 7% to 10% of all Europeans live in areas or aggregations of houses that can potentially be transformed into smart communities efficiently using renewable energies.
- 17% of vehicles are purchased by public administrations in the EU

As pointed out previously, urban transport will be the major application for the battery electric vehicle, at least within the short and medium term. However, the challenge of the BEV goes beyond this, and intercity and cross-border driving should be kept within the focus of R&D. In several cities, the experimental use of BEVs has started in public fleets and demonstration and deployment projects. Some of those are connecting infrastructure through whole regions or set the stage for a country wide EV use within the near future. Below some selected examples are given, but many more projects were and are being conducted.

In Germany and Austria within the model regions, infrastructure was installed. EV use schemes and business cases for public transport were set up as well as car sharing schemes. Also, private EV use with their combination depending on the specific regional conditions and requirements were set up. Broader programs were also started in Portugal and Spain.

Within the MOBI.E project several Portuguese municipalities are involved promoting EVs by incentives and the renewal of public fleets. Furthermore, the related infrastructure is installed also along main highways. Similarly, the Spanish project MOVELE aims to promote the countrywide use of EVs with purchase incentives and supports funding the required infrastructure. Another example is France, where a broad EV car sharing project is launched in the urban area of Paris. AutoLib (Automobile Liberty) started with 250 EVs on 250 Stations (180 among them in Paris downtown) and plans to reach 3000 EVs by the end of 2012 which will be shared between 1200 Stations in Paris and 46 cities in the Paris Region (Ile-de-France). Coordination and synchronization of these regional EV deployment initiatives is aimed for at the European level. In the Netherlands, as of March 2012 E-laad.nl and eight other EV infrastructure operators have installed about 1700 charging stations across the country at public places. It is planned to reach 4000 stations at the end of this year. This EV infrastructure can be used with one authentication card within a payment roaming system. Furthermore, the Amsterdam Car2Go EV car sharing fleet operates 200 EVs.

In the frame of CIP-ICT-PSP (22), first deployment projects started January 2012 like smartCEM⁽²³⁾ piloting EV services in Newcastle, Turin, Barcelona, San Sebastian and Gipuzkoa region with the aim to demonstrate the potential for EVs in urban and interurban contexts and to encourage their uptake through advanced and heterogeneous mobility services (EV navigation, EV efficient driving, EV trip management, EV charging station management, EV sharing management). Besides the smartCEM project, 3 other CIP-ICT-PSP deployment projects are conducted in European cities and countries: Molecules⁽²⁴⁾ (Barcelona, Berlin and Turin), ICT 4 EVEU⁽²⁵⁾ (Bristol, Vitoria-Pamplona, Ljubljana-Maribor) and MOBI.Europe⁽²⁶⁾ (Portugal, Ireland, Galicia-ES, Amsterdam).

The European project Green eMotion⁽²⁷⁾ draws together the results and experiences of regional deployment projects in order to develop a European electric mobility concept. This work incorporates harmonization of technology, standards, policies and regulations, solutions for recharging infrastructure and the integration of electric mobility services and ICT solutions.

So far the demand for EVs has been generated especially by public funding programs. It can be expected that this demand will constantly rise as more and more cities and regions take up the promotion of EV usage and the installation of infrastructure. Furthermore, the European Commission promotes public procurement of clean vehicles. These demonstration and test projects will form the bridge towards the broader market launch of the EV. Improved public procurement practices can help foster market uptake of innovative products and services, such as EVs, whilst raising the quality of public services in markets where the public sector is a significant purchaser. Mobilizing public authorities to act as 'launching customers' by promoting the use of innovation-friendly procurement practices is therefore an important measure in action plans, taking into account risks and regulatory limitations. In December 2011, the publication of the EC proposal: "Horizon 2020 - The Framework Programme for Research and Innovation (2014-2020)"⁽²⁸⁾ confirmed procurement of innovation, with both Pre-Commercial Procurement & Public Procurement of Innovation, as a new policy tool to support smart, sustainable and inclusive growth and to foster the business competitiveness in the European Union. State and municipal procurements processes often are designed to follow old paths and thus risk to hinder innovations that would be better suited to meet the needs of society, create jobs and provide new export opportunities for Europe.

4 Timing for development and implementation

In response to the abovementioned public expectations, the involved industries have combined their knowledge and experience in order to assess what benefits of the electric vehicle can be achieved by when, and what actions will be required to master the challenges of electrified mobility at large scale. The setting of milestones refers to passenger cars and considers six major technology fields being:

- Energy Storage Systems
- Drive Train Technologies
- Vehicle System Integration
- Grid Integration
- Integration into the Transport System
- Safety

In all these technology fields, further research and development is needed prior and in parallel to the first phase of market introduction. Besides R&D within the abovementioned technology fields the electrification of the passenger vehicle requires a coherent development and horizontal coordination across the various domains. There is e.g. a need for at least Europe-wide standards to ensure interoperability. Especially in the area of charging the sooner standards are available the quicker the market for EVs can develop, e.g. inductive charging. Furthermore, other areas as manufacturing, challenges regarding rare materials and the development of new materials, implementation of new value chains, education and training as well as studies of customer expectation and the development of new business models have to be considered. Many of these areas are complex and require a high level of coordination and coherence with other fields. Testing, Modelling & Simulations, Information & Communication Technologies, Grid Infrastructure and Materials will therefore be detailed in separate roadmaps. They are within this document introduced as transversal functions (chapter 7). The specific roadmaps will become annexes to this document. Other aspects are roadmapped within the European Technology Platforms⁽²⁹⁾.

Example: Grid Integration

The need for a coherence of R&D activities, business development and regulatory measures across various disciplines and sectors can exemplarily be described for the topic of grid integration of the electric vehicle: For EVs no expensive infrastructures like what would be needed to deliver and store hydrogen are required, however even for the most simple case, that is the conventional home plug, controlled unidirectional charging is desirable, and to take advantage of the full potential of an EV, a smart bidirectional energy flow (Vehicle-to-Grid, V2G) capability may be aimed at the longer term. This will be based on an appropriate interface allowing the exchange of both electricity and data between the vehicle and the grid. Furthermore, the interaction of the EV with the grid is a deal involving the car owner, energy providers and grid operators, public authorities (state, regional and city levels) and utilities, all calling for a positive business case.

A large scale implementation of grid integration requires the definition of safety standards at the charge station as well as regulations to avoid undesired effects when connected to the grid⁽³⁰⁾. The bidirectional energy flow between the vehicle and the grid or V2G will rather be a second step as the timing to get the infrastructure ready will critically depend on the speed the standards and the regulations enter into force, as on the availability of the required

smart grids technology and the necessary investments. In this sense the field operational tests with large fleets appears necessary so that enough data and experience on best practices could be collected prior to implementation.

With the electrification of road transport we are facing a disruptive technology objective that will be backed by massive investments all over the world. Thus major European companies agreed to jointly discuss their strategies and expectations for the largest and most demanding application, i.e. urban mobility, from which other applications will follow. They developed dedicated road maps describing the milestones as well as the actions that have to be taken in order to turn the move towards electrification into opportunities for Europe.

5 Milestones

By setting milestones dedicated objectives and the overall timeframe of the roadmap are identified. Thus milestones define the basis of the roadmap. Within this report, the way towards these milestones is detailed in the next chapter where topical roadmaps specify the individual goals and tasks necessary to reach the milestone targets. Both, milestones and roadmaps are the outcome of a broad consultation process involving the stakeholders from the automotive and related sectors within the European Green Cars Initiative PPP as described in the introduction.

As a kernel for the roadmaps up to the foreseen mass production in 2018-20, a scenario for passenger cars based on two technology paths was considered which can be expected to develop at comparable pace:

- The plug-in hybrid car providing 50km pure electric range, having an energy consumption of about 120-100 Wh/km as well as same comfort and same safety as a conventional car. Studies indicate that customer acceptance can be expected to develop within the next years towards the acceptance of a price of an additional 2000 Euros per unit ^{(31) (32) (33) (34)}.
- The electric car providing 200km pure electric range, seating four passengers, having an energy consumption of 120-100 Wh/km, smart (and on the long run: V2G) charging capabilities, same comfort and same safety. The total cost of ownership will be comparable to the ICE vehicle although the initial cost may still be around 5000€ higher, due to the lower cost of maintenance and fuel prices ⁽³⁵⁾.

During the passage of milestone 3 towards milestone 4 a major innovative step is expected to deliver a profound change in the architecture of the electric vehicle. Hence, the future electric vehicle will move away from the base scenarios defined above and pave the way for an advanced type of electric vehicle:

- Electric vehicle with novel platform facilitating lower consumption and thus providing a higher range. Modularity may even allow a convergence of full electric vehicle and plug-in hybrid.

This roadmap focuses on the electrification of the passenger vehicle. Roadmaps on other vehicle types have been developed by the European Technology Platform ERTRAC, addressing both passengers and goods transportation, and covering the entire mobility system. Many aspects within these roadmaps are relevant and draw links with the electrification e.g. the Hybridization roadmap (having an enabling role for electrified mobility); the European Bus System of the Future; Infrastructures for Green Vehicles; Towards an Integrated Urban Mobility System; etc.

Over the course of the next two decades, the following four milestones related to the focus of this document, electrification of passenger cars, can be identified (see Table 4, Figure 2).

- **Current Situation - Milestone 1: Introduction (2012):**

The first step of implementation of electrified mobility is based on the adaptation and conversion of existing vehicles into plug-in hybrid and electric cars. Beyond demonstration and field operational tests, first fleets are evolving for niche applications like, e.g. taxis, car sharing systems, delivery services and other captive fleets. Standards for safety, data communication and billing are being developed, along with testing activities and actions for raising public acceptance. At the same time, major breakthroughs are expected in terms of the understanding of underlying technologies and principles.

- **Milestone 2: Intermediate (2016)**

It is expected that the base technologies for a dedicated 2nd generation electric vehicle providing efficiency gains of all consumers, advanced system integration and high performance energy storage systems will become available at the intermediate time scale. At the same time, an enlarged charging infrastructure allowing dissemination over various cities and regions will develop.

- **Milestone 3: Mass Production (2020)**

Mass production of dedicated plug-in hybrid and electric vehicles may be fully established in Europe. Batteries providing about doubled life time and energy density compared to 2009 Li-Ion technology status at about 30% of 2009 cost will be aimed for. Highly integrated and cheap electrical motors and power electronics, highly efficient and cheap thermal solutions and particularly batteries, the most crucial component, need to be on the market in big quantities. This will make the vehicles sellable without subsidies. The infrastructure for grid integration may be expected to provide on a broad scale advanced levels of convenience through e.g. contactless and (given the availability of appropriate power lines and batteries) quick charging at high efficiencies. Bidirectional energy flow between the vehicle and the grid has great potential to develop to an interesting option for fleet applications.

- **Milestone 4: Fully Revised Electric Vehicle Concept (2025)**

The exploitation of the full potential of electric cars regarding energy savings and reduction of environmental impact requires to not only “electrify” the common car, but to totally revise the automobile concept. This will lead to increased energy efficiency and enable synergies of improvements in various technology fields (e.g. batteries, vehicle weight etc.) which again lead to step changes in energy efficiency and cost. Hence, the achievement of this major innovative step will greatly contribute to the availability of EVs at the cost of an ICE vehicle without incentives.

The 3rd generation electric vehicle will be based on dedicated integrated platforms including a revised ICT reference architecture and middleware. It is envisioned to feature innovative zero-emission drive train systems enabled by distinctly improved energy recovery and batteries with enhanced V2G and fast charging capabilities. Especially contactless charging may be a widely available alternative for more comfort and widely standardized, and charging while driving may be available in dedicated areas. The incorporation of a multi-fuel range extender may be a solution for enhancing the options provided by an EV. Full integration into the multi-modal transport is required for establishing customer acceptance and new use cases.

	Milestone 1	Milestone 2
Energy Storage Systems	Understanding of all relevant parameters for safety, performance, lifetime and their interplay. Concepts for their proper management.	Manufacturing of long life, safe and cheap energy storage systems with advanced energy and power density.
Drive Train Technologies	Concepts of Drive Train components optimized for efficient use and recovery of energy. First implementation in prototypes.	Manufacturing of range extenders & update of electric motors and power electronics for optimized use of materials and functionality.
System Integration	Solutions for safe, robust and energy efficient interplay of power train and energy storage systems. First implementation in prototypes and product lines.	Optimized control of energy and thermal flows based on hard- and soft-ware for the electrical architecture.
Grid Integration	Charging adaptive to both user and grid needs.	Charging at enhanced speed. Standardization for (fast-)charging in place.
Transport System	Road infrastructures and communication tools encouraging the use of electric vehicles.	Extensive integration of electric vehicles with other modes of transport.
Safety	Electric vehicles (tested and inspected for) meeting (new) safety standards at same levels as conventional cars.	Implementation of solutions for all safety issues specific to mass use of the electric vehicle and road transport based on it.

Table 4.1: Description of the milestones.

	Milestone 3	Milestone 4
Energy Storage Systems	Batteries providing compared to 2009 Li-Ion technology status doubled energy density, tripled lifetime at 20-30% of cost compared to 2009 status and matching V2G in mass production.	Move towards Post Li-Ion batteries. Batteries providing 4-5 times higher energy density and tripled lifetime at 15% cost compared to 2009 technology and cost status. Wide spread fast charging and bi-directional capabilities.
Drive Train Technologies	Implementation of powertrain systems providing a range comparable to ICE at sharply reduced emissions in mass produced vehicles.	Drive Train systems based on innovative concepts. Distinctly improved energy recovery. Use of novel materials. Functionality optimized for varying driving modes/conditions. Zero emission EV. Multi-fuel compatible range extenders.
System Integration	Mass Production of novel platform based in overall improved system integration.	Entirely revised EV modular platform including revised ICT-Reference architecture/middleware.
Grid Integration	Standardized quick, contactless and smart charging with bi-directional capabilities.	Full integration into the grid with charging-while-driving functionality. Wide spread use of inductive charging. Enhanced bi-directional energy flow.
Transport System	Semi-automated driving based on active safety systems and car-to-x communication.	Enhanced usage of car-to-x communication for automated and cooperative driving for zero-accident road safety and highly convenient driving. Integration of EV in multi-modal transport system.
Safety	Safety systems and functionalities following innovations in EV development. Enhanced exploitation of active safety measures for electric vehicles including safety of vulnerable road users.	Active and passive safety measures for EVs used in multi-modal transport. Updated safety systems to enhanced modular vehicle platform with multiple integrated functions.

Table 4.2: Description of the milestones.

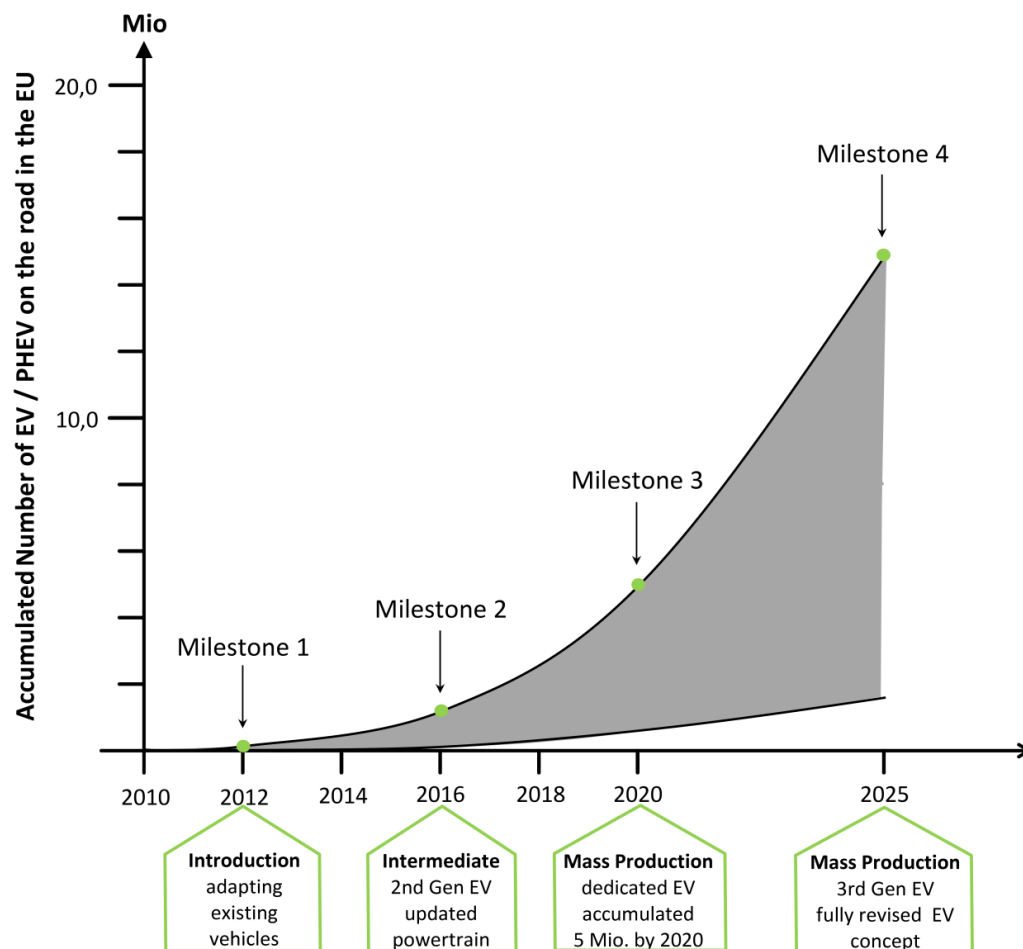
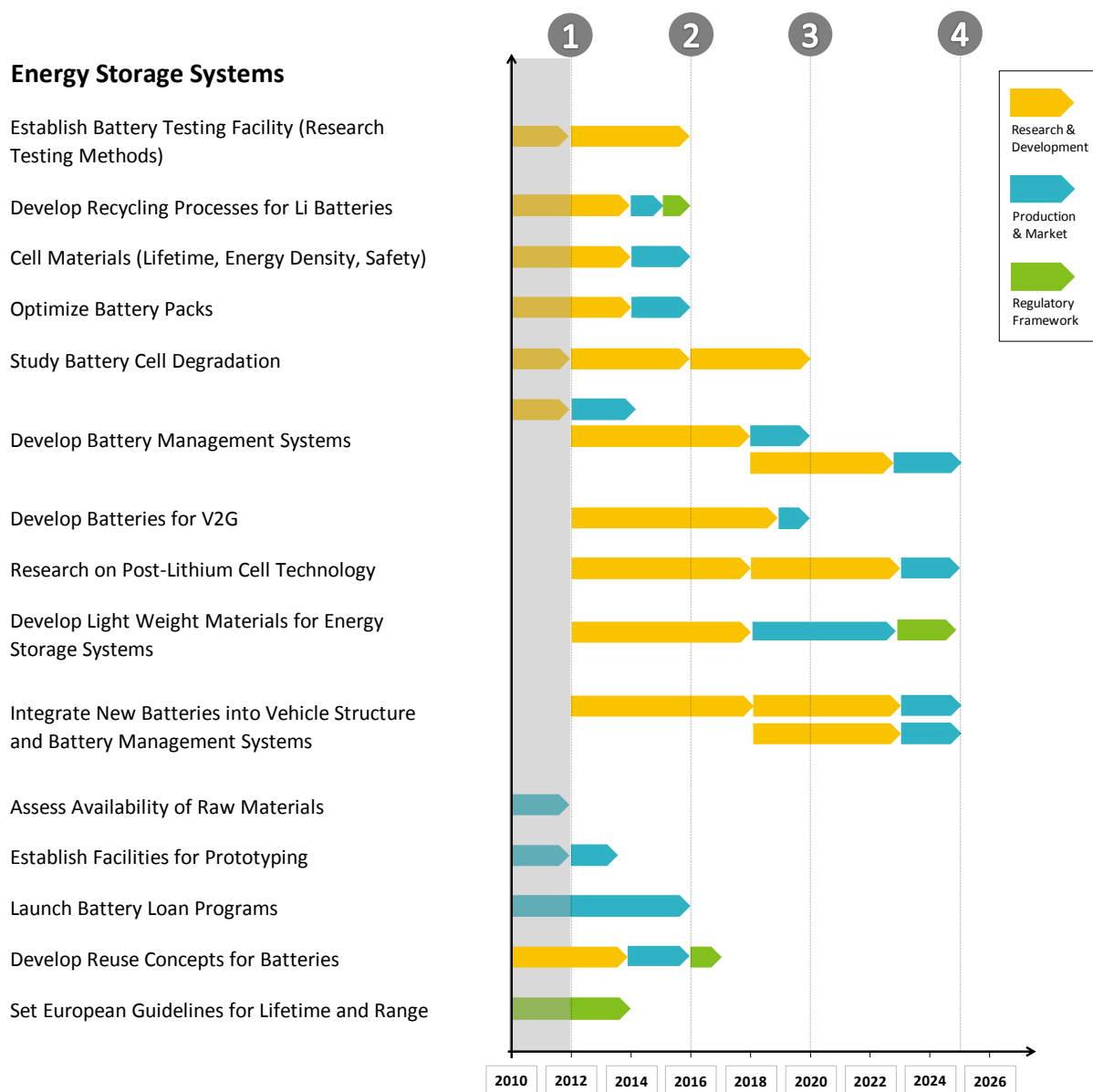


Figure 2: Milestones of the European Industry Roadmap for Electrification of Road Transport. Lower black curve: Evolutionary development of accumulated number of EV/PHEV. Upper black curve: Expected development under assumption of reaching the major technological breakthroughs as described for the six technology fields in table 4.

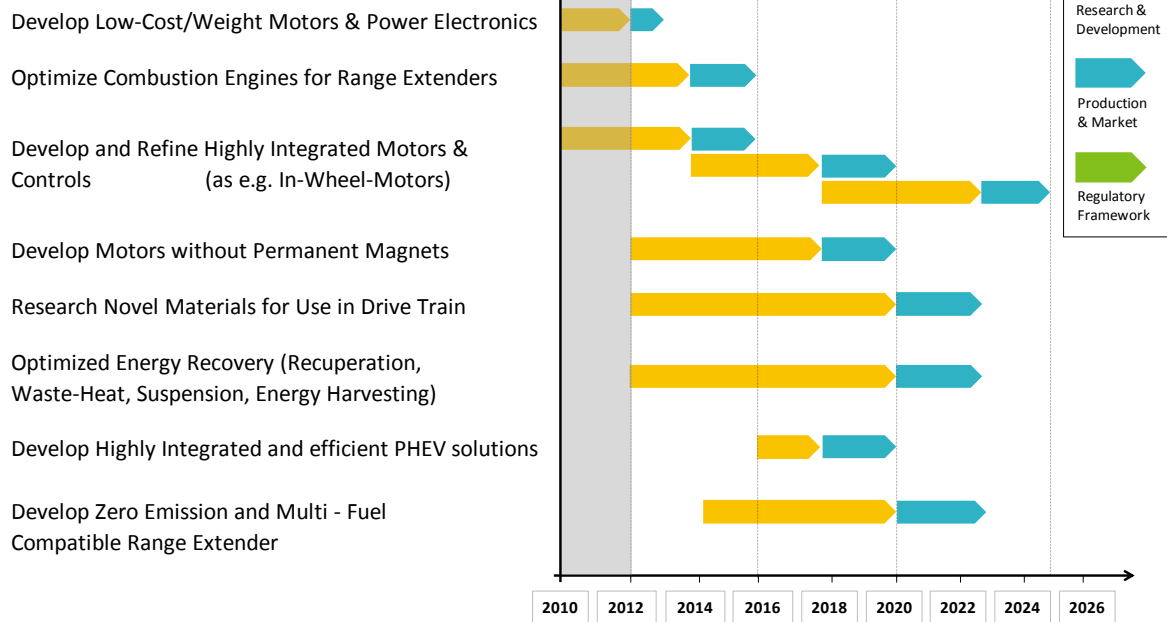
After the initial phase of market introduction and towards mass production the number of electric vehicles will be constantly rising and the accumulated number of 5 million electric vehicles in the EU in 2020 may be reached. Once mass production is reached, the number of produced vehicles will not saturate since further advancements in technology and production processes are expected towards milestone 4. In fact, as described above, following initial mass production of dedicated vehicles a major innovative step is expected leading to a revised EV system and platform which may also open new possibilities regarding production. Thus, the number of produced electric vehicles will continue to increase and considering the lifetime of the vehicles in 2025 an accumulated 15 million electric vehicles may be expected on European roads. Various studies exist regarding the market development of EVs which investigate different scenarios. Under similar assumptions of technology development the derived market development is within the same range ⁽³⁶⁾. Table 4 summarizes the detailed description of the milestones outlining the breakthroughs and developments needed in terms of energy storage systems, drive train technologies, system integration solutions, grid infrastructures, safety systems and road infrastructures as given by the involved companies and organizations from the European Green Cars Initiative.

6 Roadmaps

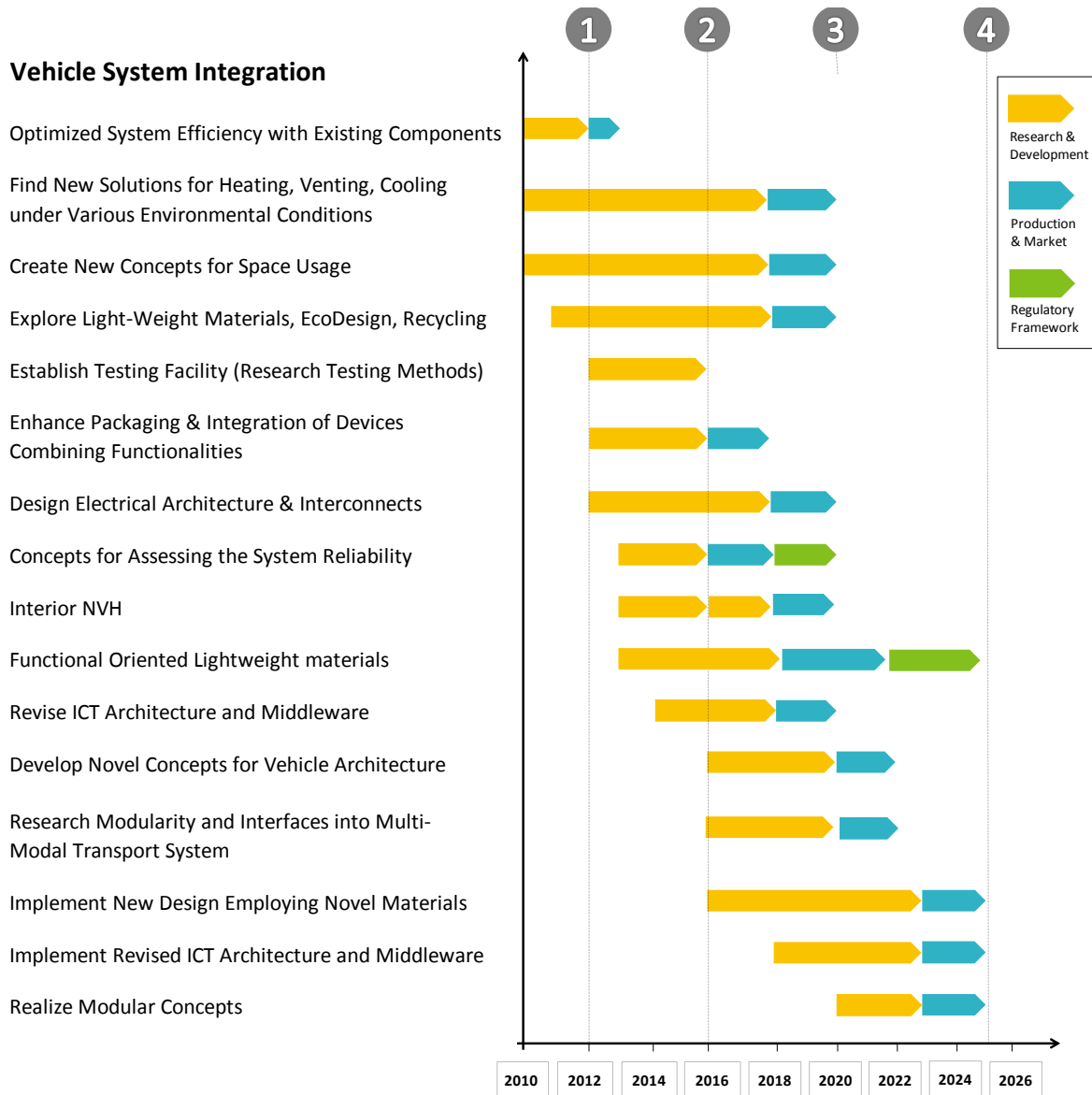
Following the definition of milestones, the involved companies and organisations from the automotive and energy sectors agreed on actions to be taken in order to achieve the stated objectives. Considering phases of R&D, production and market introduction as well as the establishment of regulatory frameworks, dedicated roadmaps were drafted that indicate what has to be done when for a well-timed move of Europe towards the electrification of road transport. Focus topics equal the abovementioned priorities in Energy Storage Systems, Drive Train Technologies, Vehicle System Integration, Grid Integration, Safety Systems, and Integration into the Transport System as a whole (see following figures).



Drive Train Technologies



Vehicle System Integration



Grid Integration

Plug-In Charging

Develop On-Board/In-Plug Charging Dev. Adaptive to User

Create Systems for Information on Charge Status

Create Business Models for Charging

Broad Establishment of Infrastructure

Quick Conductive Charging

Investigate Quick Charging

Broad Establishment of Infrastructure

Contactless Charging

Develop Contactless Charging (First Applications)

Broad Establishment of Infrastructure

Charging While Driving

Investigate & Develop Dedicated Charge While Driving System

Broad Establishment of Infrastructure

V2H & V2G

Develop Simulation, Monitoring, Management Tools

Develop Protocols/Devices for V2G Communication

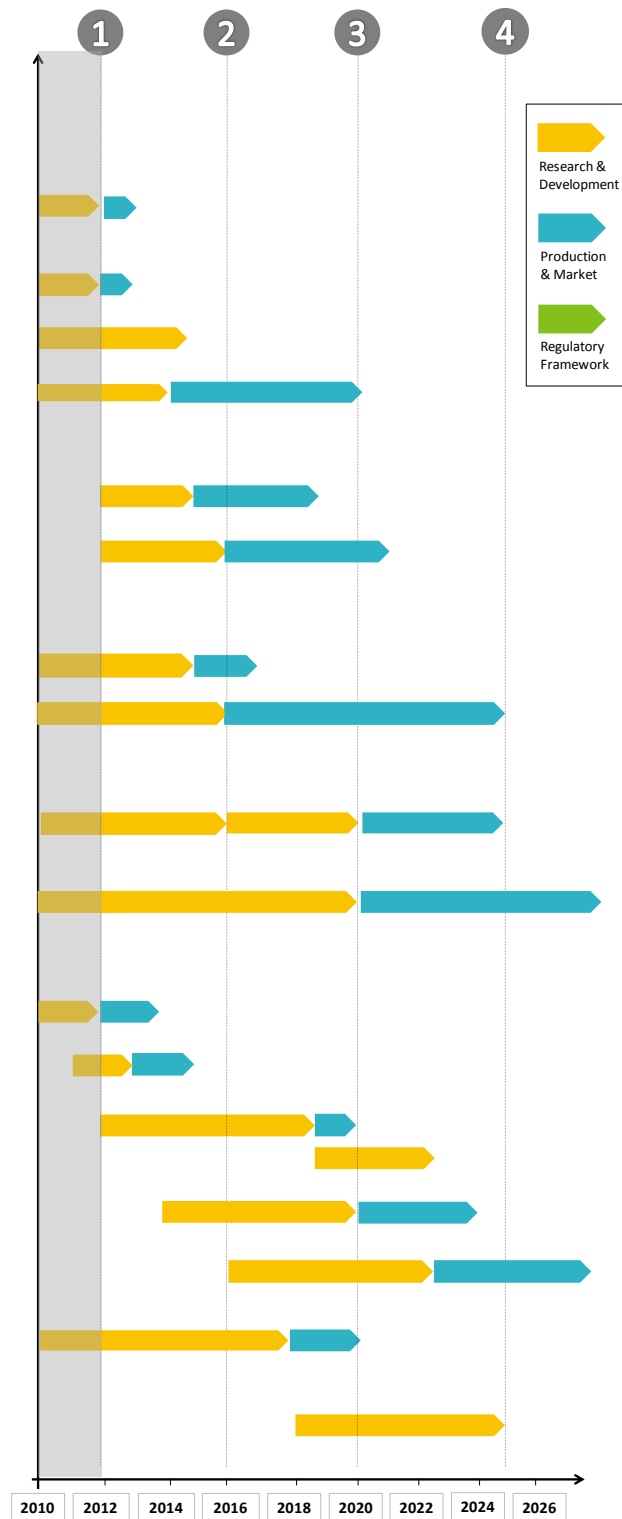
Develop & Refine Bidirectional Energy Flow

Broad Establishment of V2H Functionality in the Grid

Broad Establishment of V2G Functionality in the Grid

ICT & Smart Devices to Fully Integrate Vehicles into Grid

Integrate Post-Li Batteries into Grid
(Quick Charging & Bidirectional Energy Flow)



Grid Integration (continued)

Integration with Renewables

Green Corridors, Hubs & Smart Cities

Connect Dedicated Regions by Highways with Charging Spots

Regulatory Aspects

Regulate Coverage with Charging Spots

Regulation on Business models for Charging

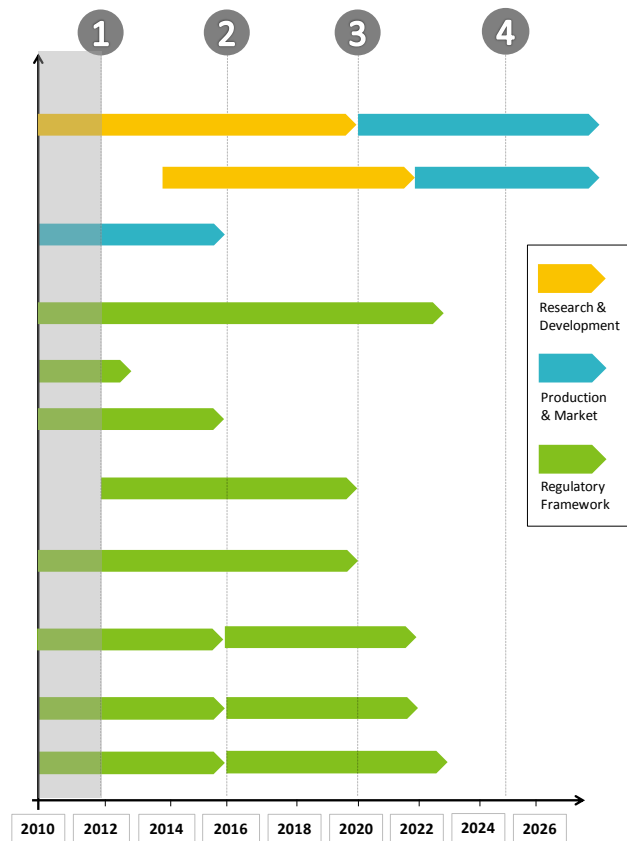
Regulation on Business Model for Bidirectional Trading

Standardization Issues

Interoperability with Mobility Operator, Vehicle & User

Standardize Service, Billing and Use Concepts

Standardize Interfaces



Safety

Develop Integrated Safety Concept (HV, Fire, ...)

Study Relation to Roadside Restraint Systems

Develop Acoustic Perception

Improve Crashworthiness of Lightweight Cars

Post-Crash Treatment of Battery & Vehicle

Active Safety Measures Based on Automated Driving

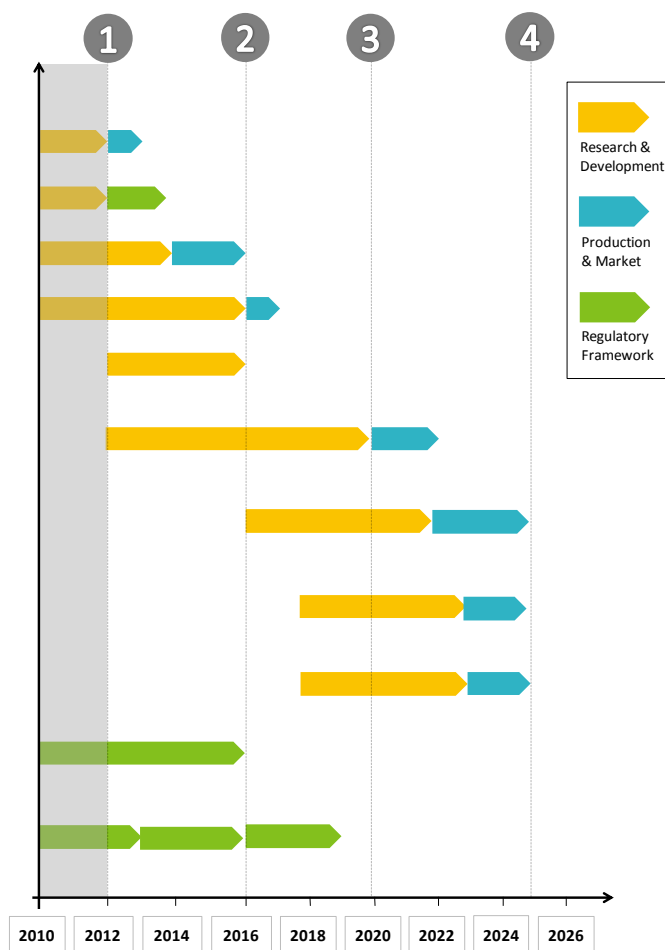
Research and Develop Safety of EV's in Multi-Modal Transport

Safety Issues Related to Integrated Multi-Functionality

Integrated Safety Concepts for Novel Platform

Setup Standards for Emergency Handling Including Roadside and Tunnel Safety

Create & Review Standards for Safety, EMI, Health



Transport System Integration

- Explore Potential of ITS for Energy Efficiency
- Develop Best Practise for Implementation of Road Infrastructure Measures Supporting Rapid
- Provide Convenient Transition Between Modes
- Review Effects of Large Scale Deployment on Future
- Apply & Optimize car2x Communication for Automated and Cooperative Driving
- Integration into Multi-Modal Transport System
- Promote Green Image of Electric Vehicles
- Develop Shared EV ownership concept
- EU Wide Signage of Roads and Vehicles



7 Transversal functions

In order to reach the milestones, a number of topics have been identified that are expected to have an impact on all of the technology areas mentioned above. These topics or support functions are considered to contribute greatly to the success of the electrification efforts and therefore deserve a more in-depth analysis and dedicated roadmaps. In addition to this electrification roadmap, which serves as the base roadmap, additional roadmaps covering these horizontal areas are produced as annexes. The topics identified are:

- Information & Communication Technologies
- Grid Infrastructure
- Materials

These topics will be briefly introduced here outlining their role and the specific challenges they pose for introduction of the EV. It shall be emphasized that there are also other important topics which are partly covered in roadmaps separate from the present Electrification of Road Transport Roadmap. One very important transversal issue for the successful mass deployment of EVs as well as for the securing of Europe's leading position in global markets is manufacturing. Issues within that topic are evolution of production concepts, of supply chains, commodity management, skills etc. These are described in the roadmap European Technology and Production Concept for Electric Vehicles, developed by ERTRAC. It is available for download on the website www.ertrac.org.

ICT for the FEV

The future electric vehicle of the third generation can be envisioned as an energy efficient, safe, comfortable and adaptable electric vehicle. Essential enabling functionalities to develop this 3rd generation electric vehicle are being provided or facilitated by communication technologies and smart systems. For instance, regarding the user's range anxiety as well as cost of ownership, both decisive barriers for the mass introduction of electric vehicles, ICT may greatly contribute to the solution. The replacement of mechanics by electronics e.g. through drive-by-wire will lead to reductions in weight which will complement future advances in battery performance, and also lower the cost of the electric vehicle. This will be further supported for instance by driver assistance systems providing for efficient, comfortable and safe driving, and by ITS providing prediction and connectivity. Hence, in order to tap the full potential of the electric vehicle regarding resource and energy efficiency, emission reduction and user comfort relevant ICT devices and ITS services have to be developed or refined and implemented. The growing number of ICT in the vehicle must not lead to more complexity, but even more simplicity, thus a completely revised ICT reference architecture is required. Thus, the need for a roadmap detailing the research needs in ICT is inherently apparent.

Grid Infrastructure

The widespread electrification of road transport must be accompanied of the adequate electric infrastructure development and the grid integration concept must be widely reached. Even from the very beginning a reliable and minimum critical mass deployment of electricity supply and convenient access to recharging stations must be available for the electric vehicle and plug-in hybrid recharging. For plug-in hybrids, overnight recharging appears to be the main initial requirement, whereas for purely electric vehicles, recharging

opportunities away from home are a more critical concern to achieve widespread demand for and use of vehicles. Efficiency is also an important factor, that will strongly depend on the charging point and charging system. The full integration of these electric vehicles and their flexibility to offer energy grid services must be also correctly addressed.

The mass deployment of the EVs will strictly derive from the adequately and on time development of the infrastructures. The infrastructures needed, should be correctly developed and covered by a coordinated action of the initiatives of the following areas (see also Fig. 4):

- EGCI (European Green Car Initiative), this refers to the part that is directly affecting the car manufacturer and necessary interfaces.
- EEGI (European Electricity Grid Initiative), this includes the part that affects the grid development itself.
- ESCI (European Smart City Initiative), referring to the part that directly affects city mobility, planning and growth.

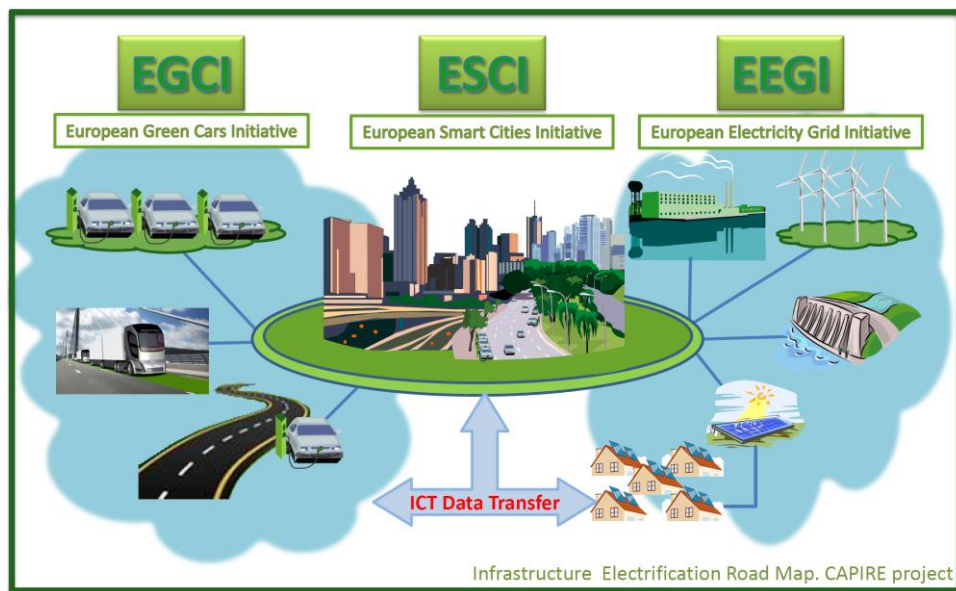


Figure 4: European Technological Initiatives dealing with EV development

When planning the introduction of electrical vehicles on the electricity grid the following issues must be considered:

- Infrastructure planning and costs.
- Quick charging impact.
- Bidirectional energy flow capabilities (V2G).
- Integration with renewable energy.
- Standardization.
- Regulatory aspects (business models, billing issues...)

The Grid Integration Roadmap presented on chapter 6 has only taken into consideration those grid aspects that are affecting the vehicle's design or the necessary interfaces, due to their reciprocal character. Nevertheless, a complete version of the Grid Infrastructure Integration Roadmap will be included in the annexes.

Materials

The European Raw Materials Strategy was initially presented in 2008 and recently updated by the European Raw Materials Initiative. The aims of this strategy are securing access to and a sustainable supply of raw materials for the EU as well as furthering resource efficiency and recycling. Various raw materials are essential in the automotive and especially the electric mobility sector. The materials roadmap will detail research needs regarding possibilities to substitute rare and scarce materials in devices and components, enhance materials efficiency in design and production of electric vehicles, and to maximize recycling options. Furthermore, standards and legislation will be referenced which may help to promote resource efficiency and recycling but also the socially and environmentally responsible resource extraction in compliance with transparency initiatives as e.g. the Extractive Industry Transparency Initiative (EITI).

The second focus will be materials for lightweight construction and functional materials for electric mobility as well as product and process design including manufacturing aspects. Among other, key words will be structural components, functional integration, adaptronics and multi-material design. A link will be made to the work done in the light duty vehicle roadmap prepared within ERTRAC.

8 Review of Milestone 1

With the publishing of the second edition of this report Milestone 1 is reached, and hence, initiatives taken that address roadmap items initially planned to start within the timeperiod 2010-2012 shall be reviewed in the following. In the following figures the respective roadmap items are listed in their technology field and predominantly research projects of the Green Cars Initiative, but also other initiatives (e.g. JTIs ENIAC and ARTEMIS) are mapped against them. The current status is given by colors, where green indicates full and yellow partial coverage, red means that no or very little action has been taken so far.

Energy Storage Systems

Study Battery Cell Degradation	■	AMELIE, APPLES, SmartLIB, SOMABAT
Establish Battery Testing Facility	■	Recommended as Topic for WP 2013
Develop Battery Management Systems	■	ESTRELIA, OpEneR, SmartLIB, Smart-LIC, SUPERLIB
Develop Recycling Processes for Li Batteries	■	AMELIE, APPLES, SOMABAT, ELIBAMA, eICar
Cell Materials (Lifetime, Energy Density, Safety)	■	AMELIE, APPLES, ESTRELIA, EUROLIION, LABOHR, SOMABAT, GREENLION
Optimize Battery Packs	■	SMARTBATT, OPERA4FEV
Establish Facilities for Prototyping	■	Recommended as Topic for WP 2013
Assess Availability of Raw Materials	■	FP7-2012-MATERIALS FOR GREEN CARS
Launch Battery Loan Program	■	EASYBAT, Greening Transportation Infrastructure for Electric Vehicles*
Set European Guidelines for Lifetime and Range	■	

Drive Train Technologies

Develop Low-Cost/Weight Motors & Electronics	■	CASTOR, Hi-Wi, POLLUX, Wide-MOB,
Develop Highly Integrated Motors & Controls	■	E3Car, E-VECTOORC, CASTOR, Hi-Wi, P-Mob
Optimize Combustion Engines for Range Extenders	■	FUEREX

Vehicle System Integration

Optimized System Efficiency with Existing Components	■	E-Future, ID4FEV, MAENAD, POLLUX, P-Mob, WIDE-Mob
Find New Solutions for Heating, Venting, Cooling	■	ICE, SMARTOP
Create New Concepts for Space Usage	■	Elva, E-Light
Explore Light-Weight Materials, EcoDesign, Recycling	■	ECOSHELL, Wide-Mob, E-Light, elCAR

Grid Integration

Develop Adaptive On-Board/In-Plug Charging Dev.	■	eDASH, ELVIRE, P-Mob, POWER UP
Create System for Information on Charge Status	■	ELVIRE, OpEneR
Develop Simulation, Monitoring, Management Tools	■	eDASH, Green Emotion, OpEneR, P-Mob, PowerUP
Develop Protocols/Devices for V2G Communication	■	ELVIRE, OpEneR, P-Mob, PowerUP, SmartV2G
Establish 1st Generation Charging Infrastructure	■	GreenEmotion, Greening Transportation Infrastructure for Electric Vehicles
Connect Regions by Highways with Charging Spots	■	
Create Business Models for Charging	■	ELVIRE, Green Emotion
Regulate Coverage with Charging Spots	■	PowerUP
Standardize Service, Billing and Use Concepts	■	

Transport System Integration

Explore Potential of ITS for Energy Efficiency	■	Ecogem, Enhanced WiseTrip, PICA V
Provide Convenient Transition Between Modes	■	Greening Transportation Infrastructure for Electric Vehicles
Develop Best Practise for Implementation of Road Infrastructure Measures Supporting Rapid Uptake	■	
Promote Green Image of Electric Vehicles	■	Green Emotion
Review Effects of Large Scale Deployment on Future Infrastructure Developments	■	
EU Wide Signage of Roads and Vehicles	■	

Safety

Develop Integrated Safety Concept (HV, Fire, ...)	■	GC.SST.2011.7-1 Specific safety issues of electric vehicles
Develop Acoustic Perception	■	eVADER
Improve Crashworthiness of Lightweight Cars	■	EcoShell, E-Light, Wide-Mob
Study Relation to Roadside Restraint Systems	■	
Setup Standards for Emergency Handling Including Roadside and Tunnel Safety	■	
Create & Review Standards for Safety, EMI, Health	■	EM-Safety

The first two calls of the European Green Cars Initiative have resulted in the initiation of more than 50 projects. Details on those projects can be found in the brochure “Project Portfolio European Green Cars Initiative PPP” which is available on the website of the Green Cars Initiative ⁽³⁷⁾. The first projects started in the fall of 2010 and are seeing their first results, while others have started more recently. Even though it is early days to assess the real impact of individual projects, it can be assumed that good progress is made towards the objectives set by the first edition of this report.

Especially in the technology areas Storage Systems and Drive Train Technologies several projects work on the same objectives focussing on different aspects. Furthermore, electrification issues are not only addressed within the Green Cars Initiative which is funded under FP7. Various projects within the JTIs ENIAC and ARTEMIS are related to the Green Cars Initiative. Other activities outside of FP7 are e.g. the TEN-T programme of DG Move from which the project “Greening Transportation Infrastructure for Electric Vehicles” has been included into the present assessment, and further projects under the CIP program which are not listed here.

9 Advice on international collaboration for the EV

The authors of this roadmap recommend a close cooperation of the PPP European Green Cars Initiative with international partners in the domain of the fully electric vehicle (FEV). Based on their experiences and assessments, the following actions are considered of utmost importance:

- To join the Annexes of the Hybrid and Electric Vehicle Implementing Agreement of the International Energy Agency and its specific working groups.
- To establish an intense exchange of information, people and technology with governments and industry in the U.S. and Japan, e.g. along the electric mobility related roadmaps that have been developed in recent years, and to develop joint programmes and projects
- To establish and strategically manage bilateral contacts of the EU to China and South Korea
- Support exploit, demonstrate and deploy Electric Mobility in megacities, e.g. in Brazil
- To present the European capabilities in the domain of electric vehicle technologies at major international fairs, conferences and events.

10 Recommendations

Based on the indications given in the roadmaps recommendations can be made on how and when the research needs should be covered by objectives of the respective FP7 work programmes in the European Green Cars Initiative (Figure 5).

2010 (Status)

	EGCI Work Programme					
	NMP	SST	ICT	ENV	TREN	
Energy Storage Systems						
Drive Train Technology						
Vehicle System Integration						
Grid Integration						
Safety						
Transport System						

2011 (Status)

	EGCI Work Programme					
	NMP	SST	ICT	ENV	MOVE	
Energy Storage Systems						
Drive Train Technology						
Vehicle System Integration						
Grid Integration						
Safety						
Transport System						

2012 (Status)

	EGCI Work Programme					
	NMP	SST	ICT	ENV	MOVE	
Energy Storage Systems						
Drive Train Technology						
Vehicle System Integration						
Grid Integration						
Safety						
Transport System						

2013

	EGCI Work Programme					
	NMP	SST	ICT	ENV	MOVE	
Energy Storage Systems						
Drive Train Technology						
Vehicle System Integration						
Grid Integration						
Safety						
Transport System						

Figure 5: Actual and suggested future coverage of R&D topics in the FP7 work programmes of the Green Cars Initiative (white: match of programme and R&D need, green: suggested objective in resp. year)

Modes of implementation should include the funding of focused industrial and academic R&D projects (STREPS). Furthermore, a multitude of horizontal challenges (e.g. grid integration, transport system integration) will require large scale actions like Integrated Projects (IPs) and Field Operational Tests. Moreover, there is a significant need for coordination between the sectors (i.e. energy, telecom and transport sector) that are coming together in the novel value chains of the electric vehicle. Standardization should be included in the calls where relevant, in order to facilitate market introduction of the results generated by the future projects.

As practiced with great success in the European Green Cars Initiative, also in the future framework of Horizon 2020 industry, utilities, infrastructure providers, academia and public authorities should join their efforts in specific Public Private Partnerships and joint programs horizontally covering all aspects of electromobility, the involved industrial sectors and their interlinks. Furthermore, it will be essential to create complementarities and coherence between the programmes at European Union and Member States levels, to extend the perspective beyond research and development, towards innovation and implementation.

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Note:

This report is considered a living document that will be periodically reviewed, updated, and made available to the community through the websites of the PPP European Green Cars Initiative

www.green-cars-initiative.eu

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