



European Roadmap Electrification of Road Transport

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Abstract

Seizing the great potential of electrified mobility for climate and resource protection and turning it into opportunities for Europe's automotive and energy industries requires joint and coordinated actions of all involved public and private parties. Cheap, safe and high-performance means of energy storage pose enormous challenges on a par with those of drive trains, vehicle systems, grid interfaces, safety solutions and the wider issues of integration into the transport system as a whole. Fundamental R&D will be needed, but furthermore complemented by measures for the scaling-up of energy storage systems manufacturing, the preparation of markets and an appropriate regulatory framework. The following document is based on the consensus of major companies and organizations from the European Technology Platforms ERTRAC (European Road Transport Research Advisory Council), EPoSS (European Technology Platform on Smart Systems Integration), and SmartGrids. Starting from a general consideration of the potential benefits of the electric vehicle a definition of milestones for the next ten years is made that indicates what action ought to be taken in order to ensure the required efforts are made in a well-timed and balanced manner. This report is meant to stimulate the debate about the multi-annual implementation of the European Green Cars Initiative.

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1. Introduction

Electrified mobility is currently given first priority in the US, Japan, China, Korea and EU. The announcements of 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
- 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.

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 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 bio fuels.

This report has been prepared by a task force team of members of the European Technology Platforms ERTRAC, EPoSS, and SmartGrids led by the chairman of ERTRAC. It complements a previous Joint ERTRAC/EPoSS Strategy Paper published in early 2009 that is pointing out the needs in terms of R&D and demonstration for a smarter, greener, safer and more competitive road transport system. The authors expect that the European Commission and the Member States will 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.

2. Benefits and Challenges of the Electric Vehicle

Primary energy savings (aiming at energy security)

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 ^[1]. Biofuels and natural gas are making an important contribution to fuel security, however just for a small fraction.

To quantify the technological evolution that makes electrical mobility appealing we take as a reference an ideal vehicle whose energy consumption depends only on mass, aerodynamic drag (frontal area and C_x) 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 $120 Wh/km^{[2]}$ 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. From the well to the tank, it takes 8 to 12% of the energy in the extracted oil to refine it into diesel or gasoline. 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 ^[3,4]. These values already include the most advanced innovations in fuel and transmission controls. Hence, in reality the consumption of primary energy is between 522 and 750 Wh/km.

Year	Power Plant Efficiency	Grid Efficiency	Inverter AC/DC Efficiency	Battery Efficiency (Slow Charge)	Power Electr Efficiency (DC/DC, DC-AC)	Motor and Magnetic Gear Efficiency	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	0.90	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 electrical vehicles, and comparison to the conventional power train. #Energy needed to move an ideal mid-sized vehicle in the NEDC. °Reduced battery weight. *Cars smaller than the reference vehicle may have less energy consumption.

The peak efficiency of an electrical motor can achieve 0.95 at defined power and torque values^[5]. 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 electrical 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

electrical 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^[6,7], 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**).

A comparison with the situation ten years ago shows that in the last decade the technological evolutions have radically changed the impact of the electrical 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.

Year	Power Plant Efficiency	Grid Efficiency	Inverter AC/DC Efficiency	Battery Efficiency (Fast Charge)	Power Electr. Efficiency (DC/DC DC-AC)	Motor and Magnetic Gear Efficiency	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.

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.

Clearly the convergence of renewable energies (RE) and electrified mobility appears the most appealing. The emerging awareness of climate change and pragmatic economical reasons will motivate the driver of the electrical vehicle to ask for “clean electrons” which commonly means electricity from renewable energy sources. The EU-27 is paving the way for RE to achieve over 60% of new power installations soon^[8] with the goal that new installations of RE could reach 90% before 2020.

On highways full hybrids due to their higher weight have higher consumption than conventional ICEs, but the hybridisation of conventional (mainly) large and mid-sized ICEs can be considered a first step towards energy efficiency through electrification as it allows energy savings up to 25-35% in urban cycles ^[9]. Its implementation on a large scale will help to comply with the CO₂ targets 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 electrical cars will be developed requiring from the battery to the wheel on the NEDC even significantly less energy than the reference car considered here.

Comparison of various power train types in terms of primary energy savings requires life cycle assessment. In this sense, it has to be noticed that the manufacturing of a conventional ICE car consumes an amount of fossil fuels approximately equivalent to twice the car's final weight, amounting to something like 18-20% of the total fuel consumption during its lifetime ^[9,10,11,12]. The manufacturing of FEVs will require about the same energy (1500 MJ per kWh of Li ion battery) as the production of conventional ICE vehicles, if the full production chain is taken into account ^[13,14]. On the contrary the production of full hybrids requires more energy than either conventional cars or full EVs. Further studies are foreseen to quantify the primary energy needed to produce the different vehicle architectures.

Generally speaking, the path to low cost electrification is complex and involves new approaches to vehicle and power train design as well as a shift to co-modality including a change of the consumers' attitude towards sustainability, environment, and alternative powertrains. Integration of EVs in the transport system therefore is necessary to create customer acceptance.

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 ^[1,15]. 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 ^[15].

The differences between conventional mobility based on internal combustion engines (ICE) and EV in terms of CO₂ emissions are summarised in **Table 3**. The factor of almost 1.5 between the two (for the EU mix) roughly reflects the ratio of energy efficiencies described in Table 1. Considering the electricity production mix of some of the major EU countries, it is evident that EVs may lead to a considerable reduction of CO₂ emissions.

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 EVs is considered a way towards a radical reduction of greenhouse gas emissions.

CO ₂ in g/km / NEDC WTW for the Vehicle and LCA for the E-Energy source			
	Well to Tank (Batteries)	Tank (Batteries) to Wheels	Total CO ₂ emissions
Conventional ICE Car	25 – 35	120 – 180	145- 215*
Electric Vehicle 27% Nuclear, 20% Renewable, 53% Fossils (EU-27 mix 2010)	85-105	0	85-105
Electric Vehicle 11% Nuclear, 20% Renewable, 69% fossils (Italian mix 2010)	120-140	0	120-140
Electric Vehicle 75% Nuclear, 20% Renewable, 5% Fossils (French mix 2010)	20-25	0	20-25
Electric Vehicle 30% Photo Voltaic on board , 60% other Renewables, 10% fossils	18-22	0	18-22
Electric Vehicle 50% Photo Voltaic, 50% Wind (Carbon free communities)	8 5km per kWh and 40g/kWh	0	8

Table 3: Comparison of WTW CO₂ emissions for conventional ICE vehicles and EVs in relation to the electricity mix. **Note:** EU-27 Electricity from renewables > 40% by 2020^[8]: 14% hydro (now), 14-16% wind as projected by EWEA, 12% PV as projected by EPIA, 5% biomass+waste+geothermal electricity. *For some compact ICE cars that are smaller than the reference vehicle considered here the total WTW CO₂ emissions are as low as 100g/km.

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. EVs can 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.

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; however, the effects on road safety caused by low noise levels have rarely been studied so far and need to be further investigated.

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

A mid-sized EV in use for urban mobility will be designed such that it can be operated for most of the day by a single charge. On the contrary on a highway or more generally at velocities higher than 120km/h the energy consumption depends mostly on the speed rather than on the distance covered. As a consequence, due to the limitations imposed by affordable costs 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, split, mild, micro or a serial hybrid, the use of high energy density liquid or gaseous fuels will remain necessary without alternatives in the mid term horizon^[2]. 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 ICEs and electrical motors, as well as in advanced fuel cells. 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 achievement 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.

It is however worthwhile to note that most 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.

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 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 in the mid term^[14,15,16,17]. Learning effects due to large scale productions and further optimisation of the cell structure would very likely lead to more desirable 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. However, the same statement can not be made for battery technology.

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 temperature increase, which requires complex and expensive temperature conditioning including either expensive liquid or forced air cooling of the overall battery compartment.

OEMs and suppliers will accelerate their efforts to build demonstration fleets of high value products using available Li-ion battery systems, but production volumes will remain small until enough hard performance data are gathered to justify the widespread commercialization of the technology. As a consequence large format Li-ion battery supplies will be constrained for several years by inadequate manufacturing capacity which in its turn influences the rate of cost reduction. Considering the size of the plants recently announced to specifically produce batteries for electrified vehicle it can be deduced that the European production will not be sufficient to cover the expected demand by the automotive industry.

Batteries will not be available in adequate volumes during the regulatory compliance period and even insufficiently proven Li-ion batteries will be subject to daunting cost and supply constraints. In a nutshell, cost and supply constraints will leave the booming HEV, EV markets in a critical state of flux for several years.

The second large source of uncertainty is related to the availability of reliable and diversified supply of metals, e.g. copper and permanent magnets that are necessary to assure high efficiency and high power density (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. The move from few and critical sources of oil to a likely even more critical single source of permanent magnets should urgently address the development of both new high efficiency motors using limited weight of permanent magnets and completely new motor designs. 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 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

The public expectations to move towards the electrification of road transport are driven by a multitude of factors and concerns including: climate change, primary energy dependence, public health as well as cost and scarcity of raw materials. However it is the growing awareness that the underlying technology has gained a sufficient level of maturity which is pushing and pulling 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 megacities 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:

- 80% of Europeans live in cities,
 - 16 cities have much more than 1 million people,
 - 70 cities have a population ranging from 800.000 to 1 million people,
 - more than 1000 cities have a population above 100.000 people.
- from 7% to 10% of all Europeans live in areas or aggregations of houses that can potentially be transformed into “carbon free communities” in a few years (because of the current rate of growth of RE).
- 17% of vehicles are purchased by public administrations in the EU

Several cities have already started the experimental use of EVs in their fleets, many others are asking for vehicles in order to do the same. All major cities would be willing to be part of demonstration programmes and are ready to buy EVs rather than conventional ones. Because most charging stations will be located within municipal urban areas, some administrations

could be tempted to manage the EVs infrastructure – public paid recharging stations to generate a profit from both EVs and plug-in hybrids. At the same time, all medium size or large cities will soon have the problem to prepare the needed infrastructure and none of them wants to be the last. If an EV would be sold at a price being not more than 25-30% above what is asked for a conventional one, it is very likely that the majority of the vehicles purchased by public administrations would be electrified. It can be estimated that public administrations alone would currently demand more than 500.000 EVs/year in 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 different scenarios (passenger cars, vans and buses) and considers six major technology fields being:

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

In many cases, further research and development is needed before the phase of market introduction. Furthermore, there is a need for at least Europe-wide standards to ensure interoperability. And the timing of respective measures requires horizontal coordination across the various technology fields.

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 bidirectional smart charging (Vehicle-to-Grid, V2G) capability may be aimed at. 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 requires the definition of safety standards at the charge station as well as regulations to avoid undesired effects when connected to the grid ^[20]. Thus, from the V2G point of view 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 technology and the necessary investments. In this sense the experimentation with large fleets appears necessary so that enough data and experience on best practices could be collected.

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

As a kernel for the roadmaps a scenario for passenger cars based on two technology paths was considered which can be expected to develop at comparable pace:

- The plugin hybrid car providing 50km pure electric range, having an energy consumption of about 200 Wh/km as well as same comfort and same safety as a conventional car. A prize of additional 2000 Euros per unit appears to be acceptable.
- The electrical car providing 100km pure electric range, seating four passengers, having an energy consumption of 200 Wh/km, smart (and on the long run: bidirectional) charging capabilities, same comfort and same safety, at reasonably comparable cost of ownership.

Separate roadmaps may be developed for buses, delivery vans and light duty trucks (i.e. modes of transport being responsible for high levels of noise, CO₂ and noxious emissions), two wheelers, hybrid and conventional powertrains (which have an enabling role for electrified mobility), heavy duty freight transport (where efficiency gains may rather be expected from smart logistics than from electrification) as well as for road infrastructures. Over the course of the next ten years, the following three milestones related to the focus of this document, electrification of passenger cars, can be identified (see Fig. 1).

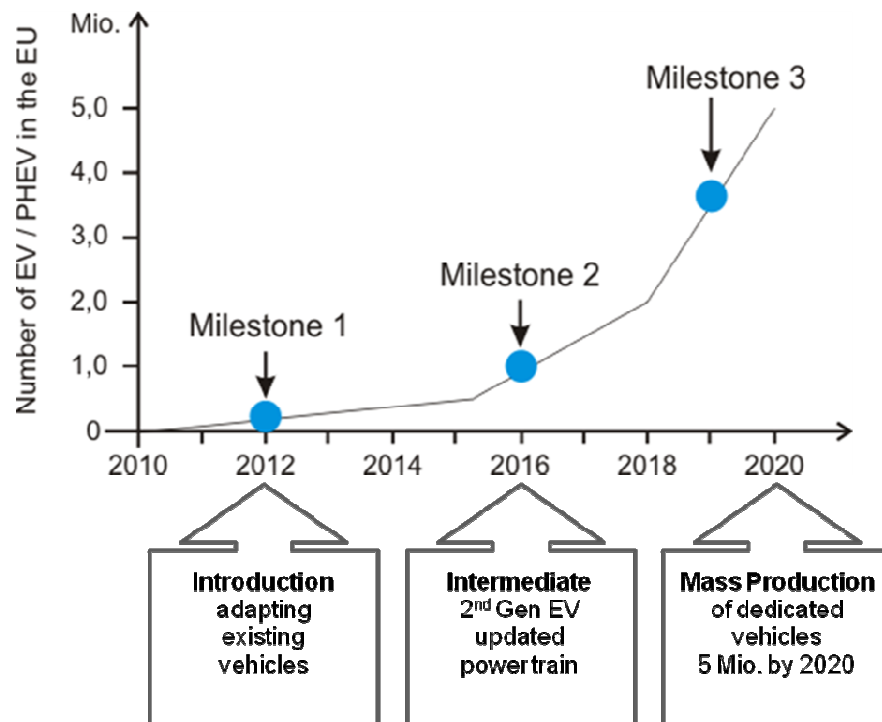


Figure 1: Milestones of the European Industry Roadmap for Electrification of Road Transport

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

The first step of implementation of electrified mobility will be based on the adaptation and conversion of existing vehicles into plug-in hybrid and electrical cars. Beyond demonstration and field operational tests, first fleets may evolve for niche applications like, e.g. taxis, car sharing systems, delivery services and other captive fleets. Standards for safety, data communication and billing will be developed, along with testing activities and actions for raising public acceptance. At the same time, major breakthroughs can be 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 (2018-20)**

In about ten years from today, mass production of dedicated plug-in hybrid and electric vehicles will be fully established in Europe. Particularly, batteries, which are the most crucial component have to be available providing about tripled life time and energy density at about 30% percent of today's cost, and highly integrated and cheap electrical motors need to be on the market in big quantities. This will make the vehicles sellable without subsidies. The infrastructure for grid integration is expected to provide advanced levels of convenience though contactless and quick charging at high efficiencies.

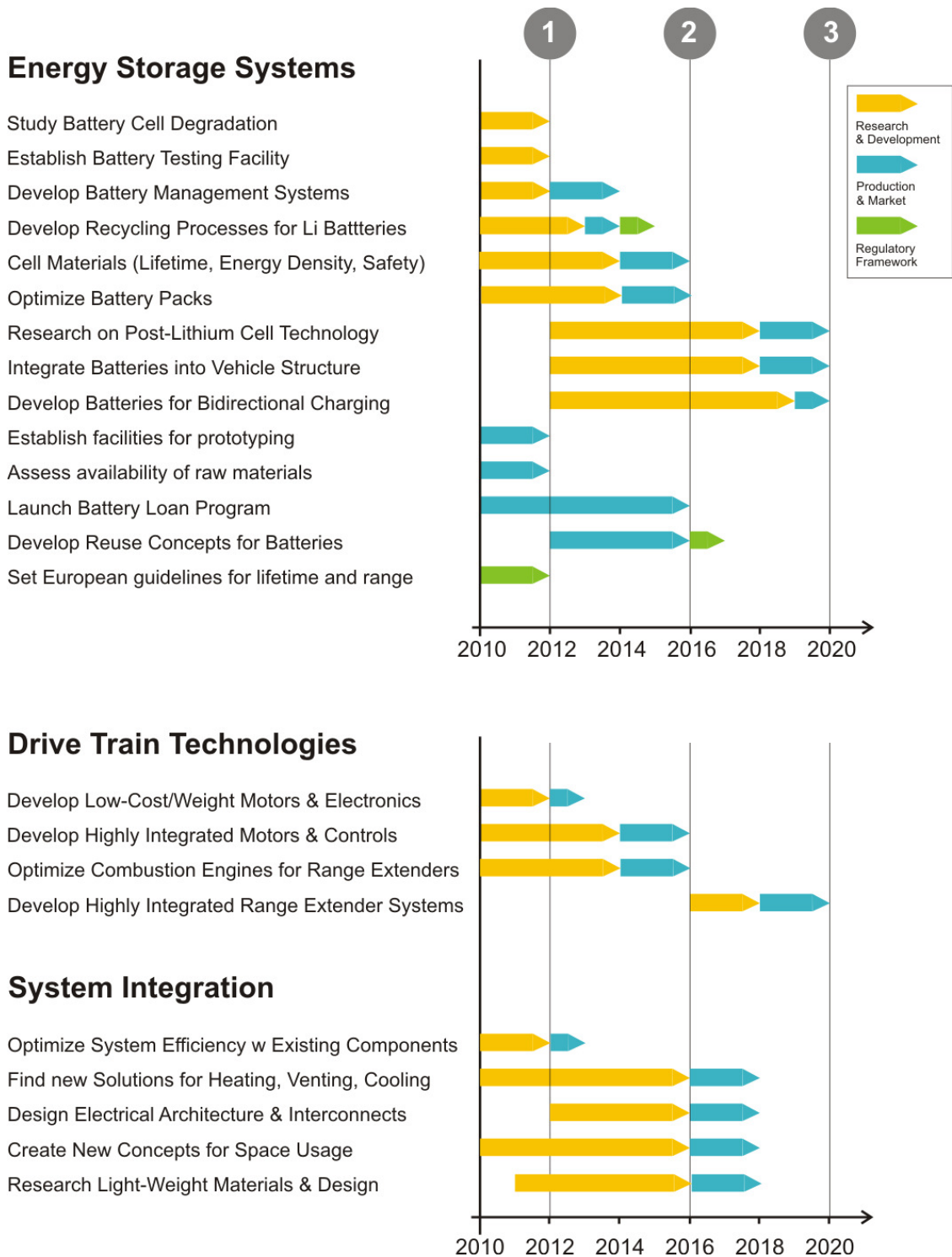
The involved industries agree that eventually after ten years the goal of an accumulated five million pure electric vehicles and plug-in hybrid vehicles on Europe's roads may be achieved. Table 4 summaries the detailed description of the milestones in terms of energy storage systems, drive train technologies, system integration solutions, grid infrastructures, safety systems and road infrastructures as given by the involved companies and organizations from the ERTRAC, EPoSS and SmartGrids platforms.

	Milestone 1	Milestone 2	Milestone 3
Energy Storage Systems	Full understanding and proper management of all relevant parameters for safety, performance, lifetime.	Manufacturing of long life, safe and cheap energy storage systems with advanced energy and power density.	Availability of batteries providing tripled energy density, tripled lifetime at 20-30% of 2009 cost and matching V2G.
Drive Train Technologies	Availability of drive train components optimized for efficient use and recovery of energy.	Manufacturing of range extenders & update of electric motors for optimized use of materials and functionality.	Implementation of power train systems providing unlimited range at sharply reduced emissions.
System Integration	Solutions for safe, robust and energy efficient interplay of power train and energy storage systems.	Optimized control of energy flows based on hard- and soft-ware for the electrical architecture.	Novel platform based in overall improved system integration.
Grid Integration	Charging adaptive to both user and grid needs.	Charging at enhanced speed.	Quick, convenient and smart charging with bi-directional capabilities.
Transport System	Road Infrastructures and communication tools encouraging the use of electric vehicles.	Full integration of electric vehicles with other modes of transport.	Automated driving based on active safety systems and car-to-x communication.
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.	Maximum exploitation of active safety measures for electric vehicles.

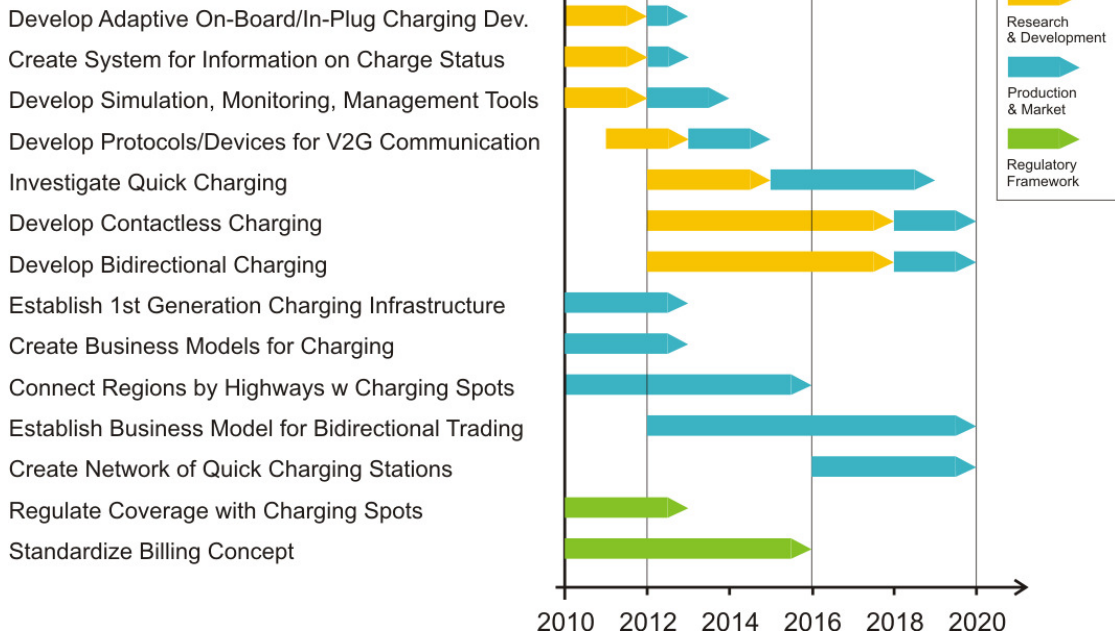
Table 4: Description of the milestones.

6. Roadmaps

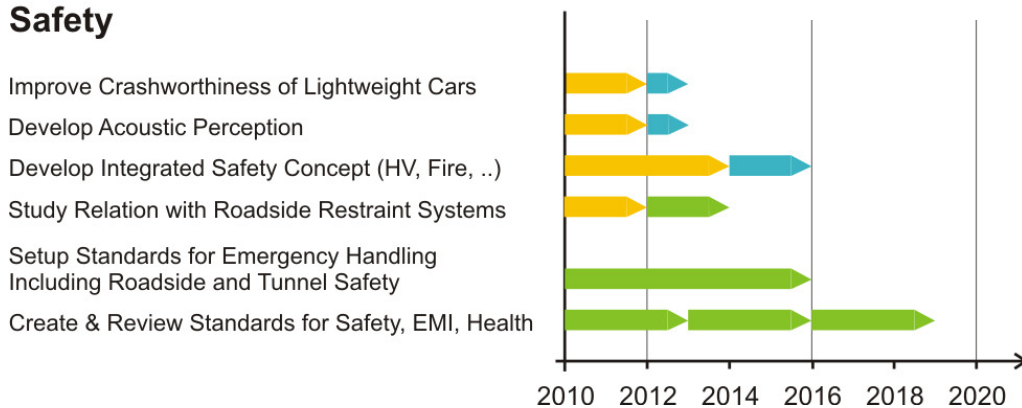
Following the definition of milestones, the involved companies and organisations from the automotive and energy sectors agreed on actions to be taken in order to achieve the stated objectives. Considering phases of R&D, production and market introduction as well as the establishment of regulatory frameworks, 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, System Integration, Grid Integration, Safety Systems, and Integration into the Transport System as a whole (see Figure 2).



Grid Integration



Safety



Transport System Integration

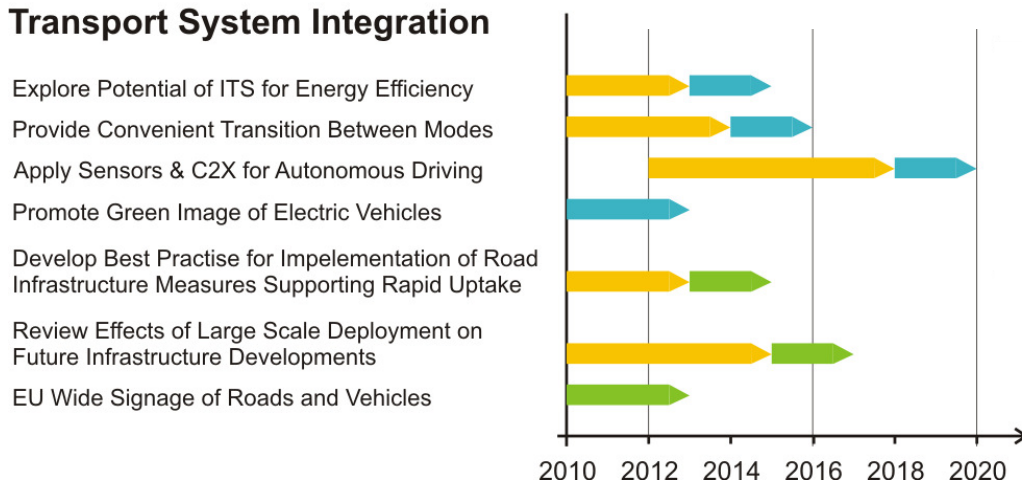


Figure 2: Roadmaps

7. 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 3).

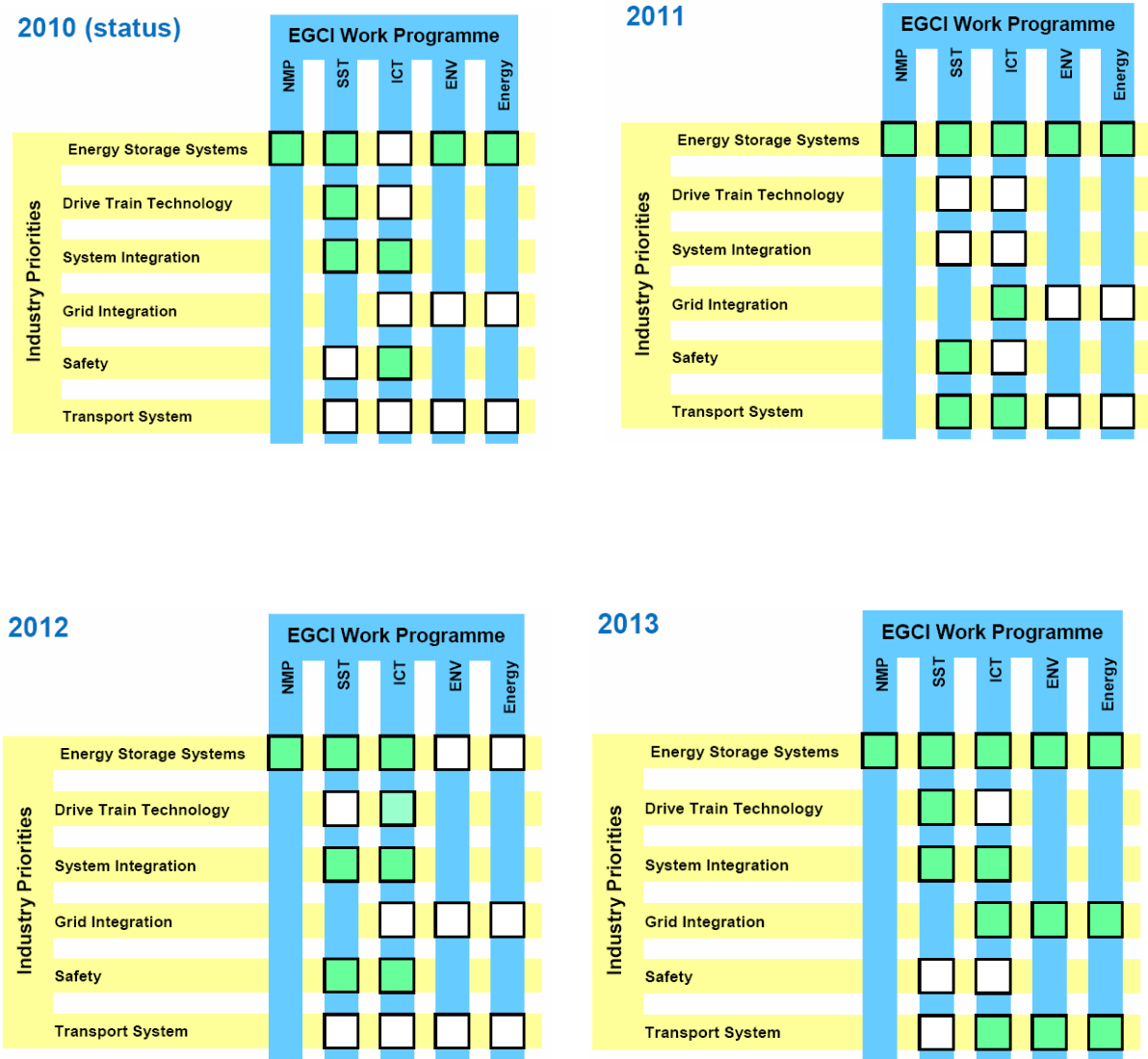


Figure 3: Suggested coverage of R&D topics in the FP7 work programmes of the Green Cars Initiative (white: match of programme and R&D need, green: suggested objective in resp. year)

Modes of implementation should include the funding of focussed industrials 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 that are coming together in the novel value chains of the electric vehicle. Eventually, industry, utilities, infrastructure providers, academia and public authorities at European and Member States levels 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.

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 involved European Technology Platforms, e.g. for EPoSS at www.smart-systems-integration.org/public/electric-vehicle.

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9. Annex

	Milestone 1 (2012) Introduction Adapting existing vehicles 100k accumulated by 2012.	Milestone 2 (2016) Intermediate / 2nd Gen EV updated power train (for production) 1 Mio. accumulated by 2016. <i>Note: US Government goal: 1 Mio. PHEV by 2015</i>	Milestone 3 (2018-20) Mass production of dedicated vehicles 5 Mio. accumulated by 2020.
Impact on Energy Efficiency	<ul style="list-style-type: none"> - 200 Wh/km battery to wheel: (150 kms range full electric 50 kms plugin-in) - Battery charging (slow, 3kW) : 95% - Inverter: 95% - Grid itself 93% - 50% energy efficiency gains (through improved powertrain). 	<ul style="list-style-type: none"> - Battery charging (slow) - Battery charging (semi-quick, 9kW): 95% - Inverter: 96% - Grid itself: 95% 	<ul style="list-style-type: none"> - 150 Wh/km (battery-to-wheel) (1500 kgs, 200 kms full electric 70 kms plugin-in) <i>(Reference: VDA numbers: 1000 kgs, 200kms => 150 Wh/km in 2015)</i> - Battery charging (slow) - Battery charging (quick, 20kW+): 95% - Inverter: 97% - Grid itself: 97%
R&D Energy Storage Systems Milestones	Full understanding and proper management of all relevant parameters for safety, performance, lifetime	Manufacturing of long life, safe, and cheap energy storage systems with advanced energy and power density	Availability of batteries providing tripled energy density, tripled lifetime at 20-30% of 2009 cost and matching V2G.

<p>R&D Energy Storage Systems</p>	<ul style="list-style-type: none"> - Lifetime understanding (material, ageing process, cycleability, calendaric) Research on battery cell degradation (2010-12) - Battery management (voltage, thermal, safety). R&D on battery management systems (2010-12) - Battery safety testing Establish battery testing facility / safety standards / test procedures (2010-12) - Battery materials recycling (handled as self-standing component 95% quota). Develop recycling processes Li-Ion battery (2010-12) 	<ul style="list-style-type: none"> - <i>x%</i> (3x3) tripled energy density tripled life time at 2009 price (rather extended lifetime – life expectancy will be handled- than extended energy density). <i>Note: US DOE Goal for 2014: 2x3 at 1/3 of 2009 cost (they compare power with energy batteries)</i> - Safe battery at less system effort. (e.g. intrinsically safe, robust materials, less redundancy) R&D on cell materials for enhanced lifetime, safety and energy density at reduced cost (2010-16) - Weight reduction through optimized housing. R&D on battery pack optimization (2010-2016) - Basis for next generation batteries. see R&D topic for 2013-2020 	<ul style="list-style-type: none"> - (3x3) tripled energy density tripled life time at 20-30% of 2009 cost. (meeting California requirement: 10 yrs, 180k miles – Today’s directive ZEV. - Availability of post Li-Ion battery cell materials and components for research and samples [keep in mind the need for high investment in engineering and industrialisation of Lio-Ion batteries and the progress to be made in this technology]. R&D on post Li-Ion battery cell technology (2013-2020) - integration of battery housing into the car structure. R&D on battery integration into vehicle structure (2013-2020) - batteries matching requirements of bidirectional charging (full cyclability and full lifetime required). R&D on batteries for bidirectional charging (2013-2020)
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R&D Drive Train Technologies Milestones	Availability of drive train components optimized for efficient use and recovery of energy.	Manufacturing of range extenders and update of electric motors optimizing use of materials and integration of functions.	Implementation of power train systems providing unlimited range at sharply reduced emissions.
R&D Drive Train Technologies	<ul style="list-style-type: none"> - Development of components e.g. power electronics and light-weight motors. Development of low-cost and low weight motors, small size power electronics (2010-2013) - <i>Proofed concepts</i> range extenders. See topic for 2010-2016 	<ul style="list-style-type: none"> - New motor concepts, e.g. wheel motors (with integrated controls) and axle motors with integrated clutch and gear; new materials for magnets. Development of highly integrated motors (on-axle, in-wheel) and controls using aggressive cooling and optimized (or even no) magnetic materials (2010-2016) - Dedicated engines and generators for range extenders. Optimization and down-sizing of combustion engines for use as range extender (2010-2016) - Highly integrated power electronics and components (2010-2016) 	<ul style="list-style-type: none"> - Highly-integrated range-extender system including power electronics. Development of highly-integrated range-extender systems (2017-2020)

R&D System Integration Milestones	Solutions for safe, robust and energy efficient interplay of power train and energy storage systems.	Optimized control of energy flows based on hard- and software for the electrical architecture.	Novel platform based in overall improved system integration.
R&D System Integration	<ul style="list-style-type: none"> - Optimization of overall energy efficiency with existing components. Optimize system efficiency by tuned interplay of components (2010-2013) - Safety & robustness. Develop integrated safety concept for electric vehicles (2010-2013) Noise/Sound management. Solve management of noise (2010-2013) Understand durability and reliability issues related to electric vehicle; first sets of regulations and standards. Create testing methods and procedures (2010-13) 	<ul style="list-style-type: none"> - Efficiency gains of all consumers (<i>e.g. A/C</i>). Find novel energy efficient solutions for all auxiliaries, heating, venting, cooling (2010-2016 first samples) - Integration of charger and inverter (overall optimized electrical architecture). Design electrical architecture and interconnects (2011-2016) - Lightweight construction. R&D on lightweight materials and design (2011-2016) - Novel space concepts. Create new concepts for space usage (2010-2016) 	<ul style="list-style-type: none"> - Novel platform
R&D Grid Integration Milestones	Charging adaptive to both user and grid needs.	Charging at enhanced speed.	Quick, convenient and smart charging with bi-directional

			capabilities.
R&D Grid Integration	<ul style="list-style-type: none"> - Intelligent on-board charging control (adaptive to user / grid needs – requiring simulation and forecast based on statistics of energy supply). Develop an adaptive on-board or in-plug charging control device (2010-2013) - Diagnosis and communication of charge status. Develop system for on-board information (2010-2013) - Simulation, monitoring, management tools for batteries, grids and subsystems. Develop simulation, monitoring and management tools for batteries, grids and subsystems (2010-2013) - intelligent grids: communication between car 	<ul style="list-style-type: none"> - Semi quick charging @9kW (13kW in some places) (option: half the battery in 15 minutes – requires 30 kW / new infrastructures – to be decided). R&D on quick charging (2013-2016) 	<ul style="list-style-type: none"> - Contactless (inductive at high gap – efficiency, safety and health issues solved) or quick charging (convenient options for charging). R&D on contactless charging (2013-2020) - Bidirectional charging. R&D on bidirectional charging (2013-2020)

	<p>and grid operator. Create communication protocols and devices for vehicle-to-grid (2010-2013)</p> <p>- First set of regulations for grid connection, charging, taxation. Regulations for car to grid connection (2010-2013)</p>		
R&D Transport System Milestones	Road Infrastructures and communication tools encouraging the use of electric vehicles.	Full integration of electric vehicles with other modes of transport.	Autonomous driving based on active safety systems and car-to-x communication.
R&D Transport System	<p>- ITS for energy efficiency Explore the potential of ITS and supporting systems and data collection to assist the driver in choosing the most energy efficient road (2010-2013)</p> <p>- Standards and specifications for EV friendly infrastructure measures; considering advice on overcoming restrictions on EV</p>	<p>- Intermodal usage Provide solution for convenient transition between different modes of transport (2013-2016)</p> <p>- Understand the future requirements for planning and infrastructure specification for large-scale use of EVs. Support of review of Directives and standards governing air quality, noise and other effects. Review of effects of large-</p>	<p>- Autonomous driving (due to the need for utmost weight reduction, EV's will require a maximum of active safety rather than passive safety. The sensors and systems of such active safety will facilitate the steps into autonomous driving). Apply sensors and c2x systems for enhanced active safety and to enable autonomous driving (2013-2020)</p>

	<p>access enclosed areas; traffic management practise for prioritising EVs and associated effects.</p> <p>Best practise development for implementation of road infrastructure measures to support and encourage the rapid uptake of EVs (2010-2013)</p>	<p>scale deployment on future infrastructure developments (2011-2015).</p>	
<p>R&D Safety Milestones</p>	<p>Electric vehicles providing same safety levels as conventional cars.</p>	<p>Implementation of solutions for all safety issues specific to mass use of electric vehicle and to road transport based on it.</p>	<p>Maximum exploitation of active safety measures for electric vehicles.</p>
<p>R&D Safety (in order to maintain same safety level as with conventional vehicles, as it we put it under scenario-assumption)</p> <p><i>initially considered part of system integration</i></p>	<ul style="list-style-type: none"> - Partner Safety (small&light EV´s crashing into big&heavy conventional vehicles). - Weight reduction by active safety. <p>R&D on crash worthiness and active safety of lightweight vehicles (including relation with standards for roadside restraint systems) (2010-2013)</p> <p>-Safety issue due to noiseless EV´s → danger to VRU</p>	<ul style="list-style-type: none"> - Review safety regulations due to studies. <p>Review safety standards (2013-2016)</p>	<p>-Maximum exploitation of active safety measures.</p> <p>Implementation</p> <p>-2nd review safety regulations review due to studies.</p> <p>2nd Review of safety standards (2017-2020)</p>

	<p>Develop solutions for acoustic perception of electric vehicles (2010-2013)</p> <ul style="list-style-type: none"> - Understand safety issues related to exposure to electromagnetic fields; first sets of regulations standards. - Periodical technical inspections. <p>Create safety and emissions standards (2010-2013)</p> <ul style="list-style-type: none"> - Power electronics' influence on nano electronics (safety – security). <p>Create EMI standards (2010-2013)</p> <ul style="list-style-type: none"> -In case of accident (labelling, training of emergency personal, maintenance, service). <p>Develop tools and guidelines for emergency handling (including tunnel safety) (2010-2013)</p>		

<p>Production Technologies</p>	<ul style="list-style-type: none"> -Industrialization of batteries -Best cost at low volume. Establish facilities for prototyping and small scale manufacturing of batteries, electric motors and components (2010-2013) - Availability of raw materials. Assess availability and recyclability of raw materials and recommend choice options (2010-2013) 	<ul style="list-style-type: none"> - Reusability of materials and components Explore reusability of materials and components and derive guidelines (2010-2016) 	<ul style="list-style-type: none"> - Global manufacturing and logistics Model, simulate and shape global value chains (2013-2020)
<p>Deployment</p>	<ul style="list-style-type: none"> - Public acceptance, awareness. Promote opportunities and challenges of EVs (2010-2013) - Niche applications: car sharing, delivery services captive fleets. - Pilot regions and cities. Demonstrate EV use and grid integration in public fleets and pilot regions (2010-2013) - 2 to 5 charging spots / car 	<ul style="list-style-type: none"> - Dissemination and inter-connection of regions and cities. Connect and extend pilot regions, e.g. by highways with charging spots (2010-2016) - enlarged charging infrastructure - charging power flexibility for slow charging (3/6/9 kW) Extend coverage by charging spots and allow power flexibility (2013-2016) 	<ul style="list-style-type: none"> -Using car batteries as controllable load for grid stability including bidirectional power flow (required intelligent load control devices, standard protocoll). <i>(see R&D on Grid Integration)</i> - 50.000 quick charging stations (>9kW) Create network of quick charging stations (2016-2020)

	<p><i>Note: in Berlin field test's with Smarts and Minis there will be 500 charging spots for 200 vehicles.</i></p> <p>Create 1st generation charging infrastructure (2010-2013)</p>		
Business Model	<ul style="list-style-type: none"> - <i>Subsidized / public procurement.</i> - Vehicles sold & batteries leased. <p>Public Procurement Program (2010-2013)</p> <ul style="list-style-type: none"> - Business model battery exchange and “anywhere slow charging” is available. <p>Create business models for charging (2010-2013)</p> <ul style="list-style-type: none"> - Green marketing for other sectors then just energy and automotive; stimulate first increase of numbers. <p>Promote green image of electric vehicles (2010-2013)</p>	<ul style="list-style-type: none"> - Sellable without limitation will be general situation. - In addition, lease of batteries, will remain. <p>Battery Loan Program (2010-2016)</p> <ul style="list-style-type: none"> - Re-use of batteries in stationary applications. <p>Develop reuse concepts for batteries (2013-2016)</p> <ul style="list-style-type: none"> - Fully established electricity billing system. <p>Standardize billing concept (2010-2016)</p> <ul style="list-style-type: none"> - Businesses for bidirectional trading of electricity (vehicle to grid) are established. Batteries are qualified in terms of charge/discharge cycles, communication and billing 	<ul style="list-style-type: none"> - Sellable without subsidies. - Reviewed business model based on extended lifetime of batteries. <p>Review business models (2017-2020)</p>

		technologies are available). Establish business procedures for bidirectional trading (2010-2020)	
Regulatory Framework	<ul style="list-style-type: none"> - Europe-wide standards for connectors and grid communication, billing systems (roaming – compare to mobile phone – who was pushing this?). Standardization (2010-2013) - EU-harmonized state aid rule framework Coordination with member states (2010-2013) - European Commission call and demonstration programme for selected cities (to facilitate harmonisation, for study purposes, data collection to accelerate the learning process). see deployment - EU harmonized signage of lane/city access. EU wide / global Signage of roads and vehicles 	<ul style="list-style-type: none"> - Standardization / AUTOSAR compliance. - European Commission subsidy programme for all cities and regions see deployment - Subsidies and tax relief for private consumer. - Facilitation / incentives / support of demonstration of the increased efficiency of the grid. Stimulate market development by facilitation and incentives (2010-2016) 	

	<p>(2010-2013)</p> <p>- Well-balanced European requirements for lifetime and range of batteries. Create European battery performance standard (2010-2013)</p> <p>- Requirements for certain percentage of parking lots with charging. Regulate coverage with charging spots (2010-2013)</p>		
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