STRIA Roadmap
“Electrification”

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1. Executive summary

1.1. Energy Union Targets

How can the considered technology areas contribute to the Energy Union challenges of decarbonization and energy security?

As pointed out in chapter 2 of this document, electrification of transport combines an energy efficient power train system with the opportunity of using any source of energy other than fossil fuels including those from renewable sources.

1.2. Integrated Approach

Where is an integrated approach; both in terms of integration across sectors as well as integration across technologies needed? Within each roadmap clarify what integrated approach means, which are the concrete R&I implications of such approach and specific requirements

The electrification of transport requires the integration of vehicles into a reliable and affordable as well as efficient infrastructure for the supply of energy, e.g. in rail transport by the catenary and in other modes by static or dynamic (conductive or wireless) charging, (economically questionable) battery swapping or hydrogen tank filling. Given the limitations of current energy storage systems, the integration of electric vehicles into IT-based operating systems such as e.g. connected, automated and managed fleets promises increased levels of usability and efficiency, and thus, user acceptance. As can be seen from chapter 4 of this roadmap, synergies between these quickly evolving systems are a matter of future research. Moreover, electrification involves a set of universal engineering skills that are independent of the transport mode and thus support a comprehensive and transferable development approach, an opportunity e.g. for the supply industry.

1.3. Timeline

Outline the timeline of actions and initiatives. Specify which innovations/solutions could be deployed within 5-7 years. Specify as well the possible bottlenecks/barriers related to the actions/initiatives envisaged.

In the four transport modes considered (road, waterborne transport, aeronautics, and rail transport), electrification will be introduced at a highly different pace. In the urban road transport sector, the technology for electric passenger cars, vans and buses is in sight. Electrification for long-range applications, though, e.g. in trucks and coaches, or for long-haul driving remains a matter of further research with other fuel options to be considered as well. Full electric and hybrid propulsion powered by diesel engines will be widely used in different ship types and sizes with increasing adaption to burning alternative fuels e.g. biofuels, and to hydrogen. Zero emission vessels where batteries are used instead of diesel engines will be limited to smaller vessels or those with short distance operations. Fuel cells and combined cycle fuel cell systems will provide auxiliary power or propel smaller vessels with a trend towards the propulsion of larger vessels. For port operations all ships will increasingly plug into the grid (e.g. cold ironing, shore-side electricity supply) so to reduce emissions of e.g. NO_x and particulate matter that affect local air quality. In aviation electrification won't go beyond very small and short range small aircraft or operations on the ground for the next decades. Rail transportation is electrified to a great extent already. Nonetheless, it is important to improve the energy performance of the existing system and provide innovative solutions for reducing pollutant and GHG emissions. Innovations in the road transport sector are expected to spill over into the other modes. Timelines and contents of proposed actions and initiatives are indicated in chapter 4.

1.4. Roles

Which are the roles of the public (EU, national and local level) and private? Who should do what?

The European Technology Platforms (ERTRAC, EPoSS, Smart Grids, ACARE, WATERBORNE and ERRAC) have played a crucial role in the negotiation of R&I funding strategies for the transport domain with the European Commission in the past. Public Private Partnerships like e.g. the European Green Vehicles Initiative (EGVIA), CleanSky and Shift2Rail have shown that joint strategy development by industry and public authorities is a successful approach for innovation in transport. Due to the specific structure of industries, the situation is different in the respective sectors, though. In the phase of implementation, monitoring, standardizing, and regulating further measures by public authorities appear to be appropriate. Their task would be to take the initiative when there is uncertainty what action needs to be taken first to progress innovation and deployment. Regional and city government can play a crucial role in support of electric mobility enabling infrastructure deployment, and by public procurement, appropriate state aids, and structuring charges to encourage cleaner vehicles, vessels and trains, and finally maybe also by restricting or giving vehicle access. Roles and responsibilities are indicated for all proposed actions listed in this document.

1.5. Environmental Impact

What overall impact in terms of CO_2 emission reduction and the use of cleaner energy can be expected by the development and deployment of the considered technology/technology solutions? Specify other relevant impacts resulting from the development and deployment of the considered technology.

With the transport sector being the source of 25% of all CO_2 emissions, electrification can be expected to contribute significantly to green house gas reductions because it is an energy efficiency technology that at the same time enables the use of renewable energy sources for transport. In reality though, the actual CO_2 reduction potential depends heavily on the energy mix of the grid, and to synergies with parallel technology choices, e.g. degree of hybridization, bio fuels use etc. Nonetheless, by providing the opportunity to temporarily store energy and feed this back to the grid (V2G) at times of higher demand or for load management, EV batteries can contribute to a better use of (fluctuating) renewable energy sources like wind and solar power. According to chapter 2 of this document, all sectors need to contribute to the low-carbon transition according to their technological and economic potential. Emissions from transport could be reduced to more than 60% below 1990 levels by 2050. Due to a lack of maturity of energy storage technologies, electrification in the waterborne and aeronautics sector is unlikely to achieve significant reductions prior to 2030. Beyond this, electrification as a technology emitting zero exhaust emissions and less noise will have a positive impact on air quality along road arteries, airports, stations and ports.

1.6. Gaps

Which gaps (science, technology, innovation, market, policy, customer acceptance, user needs) and potential game changers need to be taken into account?

The technical and non-technical gaps are explained in much detail in this document. One common issue relates to the cost, energy density, and lifetime of energy storage systems. It is sufficient for automobile applications in urban areas and may enable the electrification of very small aircraft and boats soon. However, it will remain a major issue for any kind of long range or heavier application as the energy density of batteries will never reach that of fossil fuels. Other issues relate to power density and cost of motors, converters and chargers. Particular in the maritime and aeronautics domain there are no easy to handle ways of recharging or replacing batteries during trips. Leadership in electric vehicles, components and particularly battery technology and manufacturing will be decisive for maintaining a competitive position of the EU automotive industry on the world market. The adaptation of the infrastructure to electrification is a general issue, too. There is also a strong need for training of workers, e.g. in emergency and repair, as well as for battery safety, high voltage handling, and electric magnetic field emissions standards, particularly for frequencies above 50Hz.

1.7. Policies

How policies driven by demand could contribute to the development and deployment of the considered technology (e.g. . public procurement)

Public procurement would be a very effective tool for ramping up markets for electrified transport solutions, particularly for electric road vehicles such as cars, trucks and buses which could be efficiently deployed in public fleets, for hybrid rail vehicles and electrical infrastructure for ships in ports. This would also create public awareness of the technology's maturity, and may influence vehicle manufacturers' portfolios if collective purchasing power is exerted. To make such public procurement even more effective, the Clean Vehicles Directive[1], which introduced sustainability obligations into public procurement in the EU, has to be revised. The options that are currently being assessed by the European Commission include broadening of the scope, more robust compliance requirements and procurement targets. Beyond the public, also the private sector should be targeted, e.g. by appropriate incentives to stimulate the electrification of taxis and rental cars, which would also support growth of the used vehicle market, and thus help to stabilize the residual value of electric vehicles. Furthermore, CO_2 and particle emissions regulations are proposed to buses and trucks, rail and maritime transport. Also, all scooters, general aviation and drones should be zero emission. Port and city charges can be structured to encourage cleaner vehicles and vessels.

1.8. International Cooperation

Where does international cooperation in R&I represent an added value? How?

The opportunities of international cooperation in the electrification of transport are many-fold. They range from information exchange (e.g. on R&I programs and projects) to standardization of components and protocols (e.g. on wireless or en-route charging, batteries etc.). Stronger participation of the EU in the Technology Cooperation Programs (TCP), such as the Hybrid and Electric Vehicles TCP of the International Energy Agency and its working groups (tasks) is highly recommended.

1.9. Sum Up Table

The list of proposed actions for each mode is part of chapter 4.

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[1] Directive 2009/33/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of clean and energy-efficient road transport vehicles.

2. Policy Targets and Objectives

Topics to be discussed:[2]

- *Can transport electrification contribute to the EU climate and energy policy (decarbonisation, uptake of renewables and efficiency). Can the contribution be quantified? (E.g. what percentage of the -40 %GHG goal by 2030 can be delivered? Where relevant consider also the goals of the Transport White Paper)*
- *Can specific targets be identified and quantified for 2030 and 2050? (e.g. Electrification: increased ranges for EVs). Which are the main uncertainties and what are the estimated implications?*
- *Which transport specific issues of the technology roadmap beyond the EU climate and energy policies, need to be addressed? (e.g. safety, automation, competitiveness, air quality etc.)*
- *What is the impact of electrified transport to the EU competitiveness, growth and job creation in the EU?*

In this chapter, the objectives and targets for the implementation of electric mobility in Europe are highlighted from the perspective of the European Union. Strong emphasis is put on the opportunities and challenges in terms of energy and climate policy, competitiveness and integrated transport solutions. All of the four transport modes, road, waterborne, aeronautics and rail are considered in a comprehensive way. The analysis is based on political framework documents by the European Commission and on assessments by the independent experts that participate in the STRIA process.

2.1. EU targets for climate protection and energy security

Besides better air quality, the potential to reduce greenhouse gas emissions and energy consumption are the most important motivation for the electrification of transport. Electricity does not only allow to deliver energy from renewable sources to the vehicle, but also to use vehicle batteries connected to the smart grid for temporary storage of energy from fluctuating sources such as solar and wind.

The goal of preventing average global temperature to rise by more than two degrees Celsius above pre-industrial levels is generally accepted as the necessary objective to avoid dangerous climate change. 195 nations have agreed upon this goal at the COP 21 UN Climate change conference in Paris in 2015. Moreover, these nations have expressed their intention to drive efforts for limiting the temperature increase even further to 1.5 degrees Celsius above pre-industrial levels.[3]

Contributing to the two degrees target, the European Commission already in its 2020 Climate and Energy Package has committed to cutting its greenhouse gas emissions in general to 20% below 1990 levels by 2020. As the EU is progressing rapidly towards these targets, the Commission recently presented a policy framework for the period up to 2030 which suggests a further emission reduction of 40% below 1990 levels.[4] The achievement of this target is intended to serve as a base for further progress of the EU towards meeting its objective of cutting emissions by at least 60% by 2040 and 80% by 2050.

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[2] According to the guidance by the European Commission's internal scoping paper for the Working Group.

[3] United Nations, Framework Convention on Climate Change, Adoption of the Paris Agreement, FCCC/CP/2015/L.9/Rev.1 (2015)

[4] A Policy Framework for Climate and Energy in the Period from 2020 to 2030. COM (2014) 15

The use of energy from renewable sources in combination with increasing energy efficiency is key for cutting greenhouse gas emissions. The EU aims to get 20% of its energy from renewable sources by 2020. The 2030 policy framework also sets a target of at least 27% for renewable energy and energy savings by 2030. Impressive progress has been made in the implementation of renewable energy sources in Europe, recently.

Since transport is one of the major source of CO_2 emissions within the EU, the need to reduce emissions in this sector is key. Thus, for transport, the European Commission stated the goal to reduce the greenhouse gas emissions by around 20% until 2030 compared to emissions in 2008, and by 60% until 2050 compared to 1990.[5] In a recent Communication, the European Commission has re-emphasized the 2050 goal, and expressed the expectation that transport should "be firmly on the path towards zero" by then.[6]

Recognizing that GHG emissions from transport can be lowered by using renewable fuels, and that market development and investment in infrastructure for alternative fuels could stimulate economic growth and employment, the European Union in 2013 adopted the Alternative Fuels Strategy.[7] According to this strategy, there is not a single fuel solution, but rather a need for a comprehensive mix of options (electricity, natural gas i.e. CNG and LNG, hydrogen, biofuels) specific for the respective transport modes. The choice of available options is expected to change dynamically over time, and technology neutrality is strictly kept in that strategy. It is pointed out that electricity and hydrogen are universal energy carriers that can help to diversify the primary sources of energy for transport, which would increase the security of energy supply.

The other alternative fuels considered in this context all have their benefits and drawbacks: Natural gas (methane) can be used in established combustion engines, with performances fully equivalent to petrol or diesel units and a significant potential for reduction of other emissions like NO_x, SO_x and elimination of particulate matters. The contribution of natural gas to the decarbonisation of transport can be increased significantly with the use of biomethane and synthetic methane (i.e. power to gas technologies). The use of LNG in maritime transport supports the long-term objectives for the reduction of greenhouse gases and permits the sector to meet the requirements for decreasing the sulphur content in maritime fuels in the Sulphur Emission Control Areas. Nevertheless, any methane slip must be avoided to maintain the levels of GHG reduction. And, biofuels with no or low indirect land use change emissions, and in particular advanced biofuels produced from feedstock that do not create an additional demand for land, can contribute significantly to the decarbonisation of transport.

Furthermore, the use of electricity in transport is expected to contribute significantly to the security of energy supply. It not only increases the energy efficiency of vehicles but also diversifies the energy sources for transport. This is of particular importance in view of continuously unstable political situations in many of oil and gas exporting countries which will cause the oil prices oscillating in the future. Moreover, it has significant socio-economic impacts: Europe spends about one billion Euros a day to import hydrocarbon fuels for transport, and to cover associated increasing cost of protecting the environment[8]. It is harder and harder to improve conventional engine technologies in terms of greenhouse gas emissions. At the same time the complexity

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[5] White Paper: Roadmap for a single European transport area. COM (2011) 144.

[6] European Commission, A European Strategy for Low-Emission Mobility, COM (2016), 501.

[7] European Commission, Clean Power for Transport: A European Alternative Fuels Strategy, COM (2013) 17.

[8] http://ec.europa.eu/transport/themes/urban/cpt/index_en.htm

and environmental impact of liquid-gaseous hydrocarbon extraction and refinery-purification increases. The extraction of oil from bituminous sands, another alternative source under discussion now, is much more carbon intensive than the extraction of conventional crude oil, besides it requires large quantities of water and natural gas[9]. Clearly, shale gas, bituminous sands and shale oil cannot be considered the answer to slow down the process of climate change. Nonetheless, using technology like power-to-liquid (or gas) can also help us to achieve CO_2 goals even with internal combustion engines.

2.1.1. Road Transport

Since light duty vehicles (LDV), cars and vans, represent the majority of transport emissions and are responsible for 15% of overall CO_2 emissions within the EU, specific targets have been set. For cars, manufacturers are obliged to ensure that their new car fleet does not emit more than an average of 130 g CO_2/km by 2015 and 95 g CO_2/km by 2021. This compares to an average of almost 160 g in 2007 and 132.2 g in 2012.[10] For vans the mandatory target is 175 g CO_2/km by 2017 and 147 g by 2020. This compares with an average of 203 g in 2007 and 180.2 g in 2012.[11]

Heavy duty vehicles (HDV) – trucks, buses and coaches – on the other hand, are responsible for 25% of CO_2 emissions from road transport ,i.e. about 5% to the EU’s total greenhouse gas emissions. Despite some improvements in fuel efficiency, their emissions rose by some 36% between 1990 and 2010 and another significant increase is expected between 2010 and 2030. Therefore, the EU adopted a Heavy-Duty-Vehicle strategy in May 2014 which is the EU’s first initiative to tackle emissions caused by HDVs.[12] Measures for the certification of CO_2 emissions and fuel consumption of those vehicles and for the monitoring and reporting of the certified data are currently being prepared.[13]

Moreover, the production-related emissions as well the contribution of materials must also be taken into consideration. Lightweight, hybrid and electric powered vehicles and fuel cell cars lead to lesser emissions during the usage phase, however production emissions are higher. Production processes, maintenance and disposal/recycling contribute approximately 16% of the GHG emissions whereas the embedded GHG emissions in materials used in the vehicle account for around 60% of all manufacturing emissions. The proportion of total GHG emissions due to vehicle production and disposal emissions will most likely increase significantly by 2050, since vehicle efficiency will rise and energy GHG intensity is anticipated to drop at a faster rate than the embedded emissions of materials used in the vehicle.[14]

Significant efforts will be needed after 2020 to achieve the European GHG emission targets. The Transport White Paper sets out additional goals and benchmarks: a 50 percent reduction of conventionally fueled cars in urban transport by 2030, and phasing them out in cities by 2050, as well as essentially CO_2-free city logistics in major urban centers by 2030.[15]

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[9] Michelle Mech, A Comprehensive Guide to the Alberta Oil Sands, May 2011

[10] http://ec.europa.eu/clima/policies/transport/vehicles/index_en.htm

[11] http://ec.europa.eu/clima/policies/transport/vehicles/vans/index_en.htm

[12] European Commission, Strategy for reducing Heavy-Duty Vehicles' fuel consumption and CO2 emissions, COM 2014 (285)

[13] European Commission, A European Strategy for Low-Emission Mobility, COM (2016), 501.

[14] EU Transport GHG: Routes to 2050 II

[15] European Commission, White Paper: Roadmap for a single European transport area. COM (2011) 144

Electric mobility is expected to play a major role for achieving these goals for three reasons: (a) The electric power train is significantly more energy efficient than the conventional one, (b) electricity can make use of energy from renewable sources available for transport, and (c) when connected to the power grid, batteries of electric vehicles could stabilize the grid and balance supply and demand facilitating the integration of renewable sources.

The International Energy Agency recently derived from the two-degrees target some general market development scenarios for vehicles based on alternative fuels and new propulsion systems worldwide (see figure 1).

Under the assumption of a reasonable 2030 mix of passenger car propulsion technologies (20% EV, 40% HEV, 10% FCEV, and 30% conventional), an overall 70% reduction of CO_2 emissions from passenger cars can be expected.

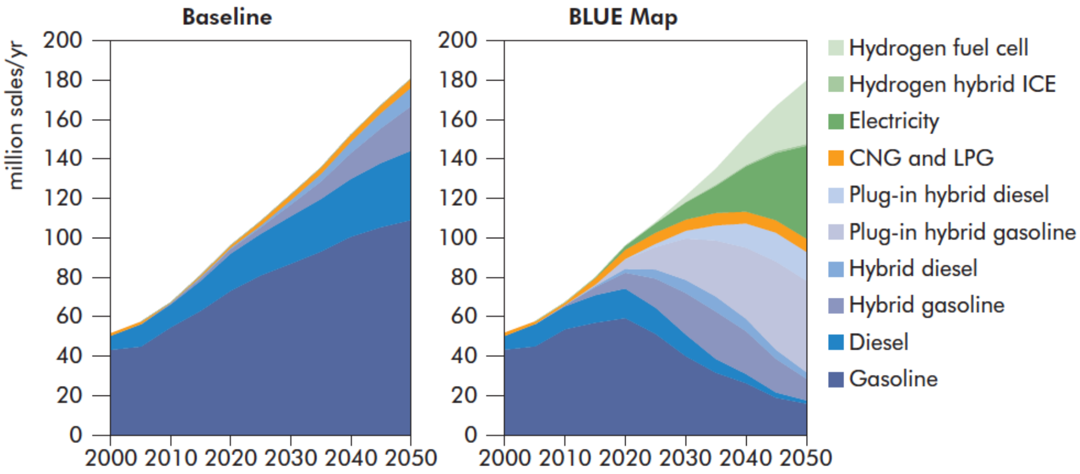

Fig. 1: *Global annual market shares (millions) of various alternative propulsion technologies in a baseline scenario (left) and the BLUE map scenario derived from the two-degree target of climate protection the International Energy Agency.*[16]

2.1.2. Waterborne Transport

Emissions from ships have been of increasing concern. Currently shipping produces about 2-3% of all anthropogenic CO_2 emissions worldwide, a similar level to that of Germany. Atmospheric emissions can be attributed to burning fossil fuels, primarily residual fuel oils, in ships' diesel engines. Despite ships' diesel engines being efficient, up to 55% with waste heat recovery, the International Maritime Organisation (IMO) and national authorities within territorial waters have moved to reduce emissions through regulation.[17] Atmospheric emissions are now regulated by their type and by area in which ships operate, namely Emission Control Areas (ECAs). In addition to CO_2 pollution other airborne emissions from shipping are of concern and regulations are currently applied to Sulpher emissions (regulated through fuel specification), oxides of Nitrogen (NO_x - regulated through engine certification), whereas CO_2 emissions regulated indirectly through the use of an Energy Efficiency Design Index (EEDI). Tougher regulations, increasingly applied, can be expected from IMO in the coming years as the industry strives to reduce its environmental impact through improved efficiency and reduced emissions.

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[16] IEA, Energy Technology Perspectives 2010.

[17] http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Air-Pollution.aspx

Electrified drives were introduced for ships at the turn of the 20th Century including several notable warships and passenger liners. Today, around 4,000 ships (5% of the global fleet) are driven using electrical means in diesel-electric propulsion, hybrid propulsion and all electric 'battery' drive systems. All electric drives provide significant opportunities to reduce emissions and zero emission shipping is a distinct possibility in the future (using new and renewable technologies such as fuel cells and alternative fuels) but a significant step forward in technology is needed to achieve this. However the accepted vision is for ships to be more efficient in the future and for shipping to generate less CO_2 and other emissions.

Ships' power and propulsion systems are currently being designed to operate more efficiently e.g. by the introduction of Tier 3 engines and IMO EEDI regulations. Large ships operating on international routes at constant are more efficient cargo carriers than small coastal vessels due primarily to the cubic law. Electrification of the propulsion system of large ships is not foreseeable at the rate of energy storage technology development. Diesel-electric propulsion would introduce unnecessary additional conversion stages leading to reduced efficiency. Alternative fuels are likely a solution to reducing harmful emissions from large ships together with plugging into the power gird (cold ironing) when berthed. Coastal vessels, both cargo and passenger, are smaller requiring much less power. So the vision of zero and ultra-low emissions ships is realistic here through the development of fuel cells and/or energy storage systems integrated with efficient power converters, propulsion motors and onboard electrical loads e.g. lighting, pumps and fans, etc.

A key vision is to develop energy storage systems (ESS) for use onboard with high energy densities and also shore based recharging facilities so vessels can recharge using renewable energy from the grid and therefore operate as zero emission ships on increasingly longer voyages: Volumetric and gravimetric dense ESS and zero emission generation e.g. fuel cells, are primarily needed to expand the number of zero emission ships. Current technology has significant limitations that would restrict vessel speed and range.

Increasing shore based grid connection facilities will allow all ships to connect to an electrical supply whilst in port thereby reducing ship emissions and offering other benefits such as reduced noise, primarily improving passenger comfort. As ESS densities in zero emission ships improve shore based facilities will need to be upgraded so as to allow recharging in port. Such facilities would make the use of zero emission short sea shipping and inland shipping more attractive.

Increased availability of alternative marine fuels such as LNG has facilitated the development of NG burning engines – initially 4 stoke diesel-generators and latterly the 2-stroke large propulsion engines. The latter has reduced emissions (including CO_2 emissions reductions in the region of 20%) and improved efficiency since waste heat recovery is improved with permissible reductions in exhaust gas temperatures (the particular issue being the Sulpher in the exhaust of diesel engines). The eventual replacement of diesel engines with fuel cells such as Solid Oxide technology has the capacity to provide power in the several MW range. 10 MW combined cycle fuel cell systems with very high efficiencies for shore based power are starting to be deployed commercially[18]. The challenge will be to develop this into a robust reliable technology that is suitable for a marine environment. Although initially fuelled with LNG, fuel cell technology would be a natural step towards a hydrogen-based economy.

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[18] https://www.ge.com/sites/default/files/GE_FuelCells.pdf

The overall vision is therefore: To achieve lower emissions from shipping and to extend the use of zero emissions ships through the development of new electrical technologies over the coming decades. However the shipping industry is diverse with the power requirements for propulsion and power range from a 100's kW to 100's MW. The size, speed and range of vessels varies significantly as do the cargos carried. Some vessels spend weeks at sea and only a few days in port whilst other vessels are regular port vessels. Power and propulsion solutions for one ship type are not necessarily suitable to another ship. The problem cannot be analysed as a single industry problem but should be considered as many different industries

A suitable approach could potentially be to: (a) Divide the shipping sector into market segments by analysing the types and roles of ships, (b) establish the range of electrical technologies that may be used by ships to contribute to the reduction of emissions, and (c) establish other benefits of electrical technologies related to improved vessel control, and increased reliability.

2.1.3. Aeronautics

By 2050, it is expected that the forecast growth in the aviation industry will drive the need to deliver revolutionary technology solutions at an increasing rate while securing the path to sustainable energy supplies to mitigate fully the impact on the atmosphere. Therefore, to protect the environment and energy supply; the European Flightpath 2050 vision[19] has set up key goals for aviation as a whole:

- In 2050 technologies and procedures available allow a 75% reduction in CO_2 emissions per passenger kilometre and a 90% reduction in NO_x emissions. The perceived noise emission of flying aircraft is reduced by 65%. These are relative to the capabilities of typical new aircraft in 2005.
- Aircraft movements are emission-free when taxiing.
- Air vehicles are designed and manufactured to be recyclable.
- Europe is established as a centre of excellence on sustainable alternative fuels, including those for aviation, based on a strong European energy policy.
- Europe is at the forefront of atmospheric research and takes the lead in the formulation of a prioritised environmental action plan and establishment of global environmental standards.

Significant reductions of CO_2 emissions can be achieved by improvements of existing technologies such as better aerodynamics, jet engine efficiency, air traffic management, or the use of bio fuels. But these enhancements will reach a limit, therefore non propulsive electrification systems for large aircrafts will be part of the solutions to reach the overall target.

Complementary to this, a specific target will consist in the first full small electric aircraft for passenger aviation on medium ranges (up to 200kms) for 20 to 30 passengers which could be operational by 2035; such a plane would require 1MW per engine.

Electrification of ground supports and movements which has already begun in many airports should be increased. The European Directive on the deployment of alternative fuels infrastructures[20] in its article 3, says that each Member State while adopting a national policy framework for the development of the market as regards alternative

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[19] European Commission, Flightpath 2050: Europe's Vision for Aviation. Report of the High Level Group on Aviation Research, 2011.

[20] Directive 2014/94/EU.

fuels in the transport sector and the deployment of the relevant infrastructure shall consider the need to install electricity supply at airports for use by stationary airplanes.

2.1.4. Rail Transport

The performance of rail transport in terms of GHG emissions is illustrated for freight and passenger transport respectively with the following charts.

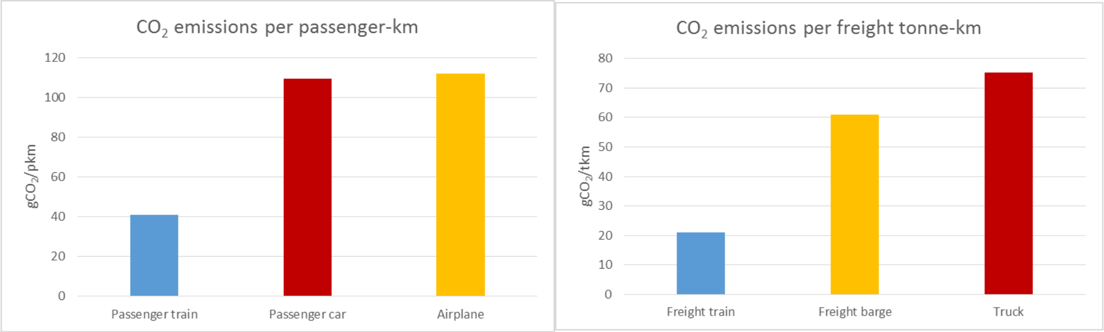

Fig. 2: *CO_2 emissions of various transport modes. Source: European Environment Agency, 2013.*

Rail in Europe is mostly electrified and therefore a key to decarbonising transport. Especially in urban areas, rail almost exclusively runs on electricity already today. Regarding main lines, 60% of the European rail network is already electrified and 80% of traffic is running on these lines. There are no technical obstacles to further electrification, but the cost for upgrading and electrifying the existing rail infrastructure and the expected carbon reduction need to be considered on a case by case basis, with EU funding support where necessary.

Railways have improved their energy efficiency, thus becoming more CO_2-efficient for both passenger and freight transport. For instance, the energy consumption of vehicles improved by 20% from 1990 to 2010. On certain types of vehicles the savings are estimated to represent as much as 50%. In 2015 the European railways have committed to reducing their specific CO_2 emissions from train operations by 40% by 2020 compared to 1990. They also have committed to a 30% reduction of the total CO_2 emissions by 2030 relative to 1990, despite the envisaged modal shift in line with the White Paper goals.

Rail is expected to achieve further energy savings thanks to lighter materials in vehicles and wider use of energy recuperation devices (e.g. regenerative braking or energy storage technologies).

Electrified rail is already using a significant share of renewable energies and further increasing their use.[21]. According to the International Energy Agency, 40% of the electricity mix used by railways in Europe is low-carbon, which originates with an average of around 20% from renewable sources.

New vehicle concepts for non-electrified railway lines are being developed. For example, manufacturers of rail vehicles are testing emission-free trains equipped with fuel cell drive. Hybrid diesel-electric locomotives are able to operate in emission-free mode as well. In parallel, the European rail supply industry has declared energy efficiency as one of the key topics to be addressed by the Shift2Rail Joint Undertaking.

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[21] Rail as a key to decarbonising transport, Position Paper UNIFE and CER, Brussels, 3 June 2016

2.2. Issues beyond climate and energy policy

Realisation of the four freedoms of the European Union – goods, capital, services and people - is fully dependent upon an accessible, affordable and efficient system of transport and mobility. Personal mobility for all who need or desire and efficient transport of goods are fundamental for the society, enabling social and business contacts and contributing to cohesion amongst the peoples of Europe. A mobility system that is accessible to all, including those with special needs, that is affordable, seamless and that enables people to travel by their chosen method is a fundamental part of the EU's landscape. The growing urban and suburban areas are putting additional requirements on the mobility system. Technology should therefore play its part in enhancing the mobility opportunities for all whilst continually reducing the costs and impacts of mobility.

Electric mobility is offering a multitude of opportunities in this regard: First of all, it is locally, a zero emission technology, and zero CO_2 emission if produced from renewable energy sources, with strong benefits in terms of air quality and noise.

Air Quality

The effects on health of transport-related air pollution have become one of the leading concerns about transport. The last decades have witnessed an immense reduction in the level of transport- related emissions such as sulfur dioxide (SO_2), carbon monoxide (CO) and hydrocarbons (HC), particulate matter (PM) and nitrogen oxides (NO_x) due to stringent tailpipe emission limits and new vehicle technologies. However, the exposure to particulate matter (PM) and nitrogen oxides (NO_x) continues to present challenges in the area of environmental policy.

Noise

Against the background that the majority of traffic-related air pollutant emissions can be significantly reduced in the European Member States, traffic noise is increasingly being seen as a health risk. In addition, noise exposure levels are increasing in comparison to other stress factors.

2.2.1. Road transport

Air Quality

Despite substantial reductions in pollutant emissions over the various Euro steps, road transport emissions still represent a main contributor to certain air pollutants. It will remain a significant contributor to air pollution in cities across the European Region, and estimates indicate that 100 000 deaths a year in these cities could be linked to ambient air pollution, shortening life expectancy by an average of a year. A significant fraction of these deaths and a range of other adverse effects on health are attributable to transport-related air pollution.[22,23].

Problems in meeting NO_2 concentration limits in European cities can be partly explained by the fact that tailpipe emissions of vehicles can be significantly higher under real driving conditions than those obtained during a standard type-approval certification. In a study performed by the JRC, five Euro 5 diesel passenger cars were tested showing emissions in the range 620 ± 190 mg/km NO_x, while the corresponding

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[22] http://www.euro.who.int/en/data-and-evidence/evidence-informed-policy-making/publications/hen-summaries-of-network-members-reports/what-are-the-effects-on-health-of-transport-related-air-pollution

[23] http://www.oecd.org/environment/cost-of-air-pollution.htm

Euro 5 emission limit for NO_x is 180 mg/km.[24] These findings led the International Council on Clean Transportation (ICCT) to contract West Virginia University for on road emissions measurements of diesel light-duty vehicles under real driving conditions.[25] Real-world NO_x emissions were found to exceed the U.S. emission standards by a factor of 35 – a fact that eventually revealed fundamental issues in the domain of diesel emissions, recently.

According to the Clean Air Programme for Europe, the aim is for the regulations applicable to be adhered to by no later than 2020. Moreover, according to the new air objectives for 2030, the health effects of air pollutants should be reduced by a third.[26]

At present, the limits for particulate matter are exceeded in over a third of the EU's air quality zones and those of nitrogen dioxide are exceeded in a quarter of the zones. Infringement proceedings for non-compliance with the PM_{10} limit values are currently pending against 17 member states.[27]

Therefore a proposal for a revised National Emission Ceilings Directive (NEC-Directive) was established in addition to the Clean Air Directive.[28] In this document for the first time, there are also objectives for the transport-induced primary particle $PM_{2,5}$.[29]

Being of fundamentally zero tailpipe emissions, electrification of the vehicle, in particular in the form of vehicles propulsed by an electric motor fed by a battery or fuel cell, has the potential to contribute to the reduction of harmful local emissions: Electric energy generation from fossil fuels creates low NO_x emissions, while they are higher for SO_x (but only for coal- and oil-fired power plants). In any case pollutants from power plants are normally emitted far from large concentrations of population and therefore have a much lower health impact than vehicular emissions in cities.

Noise

Since road traffic is mainly concentrated in urban areas, it is a major contributor to the surrounding noise level. Traffic noise is found to affect almost every third person health-wise in the WHO's European Region.[30]

The first report on the implementation of the Environmental Noise Directive, published in June 2011, identified a number of achievements and remaining challenges for the implementation of the Directive. In response, the majority of the Member States have adopted legally binding noise limits at source. Due to continuously increasing traffic, the traffic noise level remains high though. In the urban areas of the EU, approximately 40 million people are exposed to street noise of over 50 dB at night. Circa 25 million people are exposed to the same noise level outside metropolitan regions near major roads. In 2014 the EU adopted a regulation on

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[24] M. Weiss, P. Bonnel et al. "Analysing on-road emissions of light-duty vehicles with Portable Emission Measurement Systems (PEMS)", EUR 24697 EN - 2011

[25] G. J. Thompson et al., In-Use Emission Testing of Light Duty Diesel Vehicles in the United States. Final Report. Center for Alternative Fuels, Engines & Emissions, West Virginia University, 2014.

[26] A Clean Air Programme for Europe, COM/2013/0918 final is a part of the Clean Air Policy Package, adopted by the Commission in in December 2013

[27] DG Environment published on its website an updated list of Air Quality Zones related to the environmental objectives PM10 and NO2: http://ec.europa.eu/environment/air/quality/legislation/

[28] The new NEC-Directive draft recommends stricter national emission reduction targets for the four original air pollutants, which include NO_X, compared to the Directive of 2001.

[29] Revision of the NECD 2001/81/EC: http://ec.europa.eu/environment/air/pollutants/rev_nec_dir.htm

[30] http://www.euro.who.int/en/health-topics/environment-and-health/noise/noise

the sound level of motor vehicles and of replacement silencing systems, setting maximum dB standards for all types of road vehicle from 2016 onwards.

Existing studies show that especially at the city-typical slower and medium speeds (up to 35 km/h), where tire- and wind noises are low, electric passenger cars have a certain noise reduction potential.[31] In particular the electrification of light- and also heavy-duty vehicles, which are generally higher motorized, shall have a significantly noise reduction potential in cities.

The silence of EV's is even reflected in the EU vehicle legislation. In order to retain traffic safety and simultaneously ensure that only adequate sound generating devices are used, the EU added the Framework Directive 2007/46/EC in April 2014 a specific annex on the minimum noise of electric and hybrid electric vehicles.[32] However, further studies have to be made. Nevertheless, especially in cities with high volume of traffic, noise reduction is another important motivation for the deployment of EVs.

2.2.2. Waterborne transport

In terms of CO_2, shipping is a relatively clean transport mode with CO_2 emissions of up to 60 grams per tonne-kilometre compared to road transport 180 grams per tonne-kilometre. Consequently the transport of freight using short sea shipping or with inland waterways is attractive compared to road. There is considerable variation between vessel types but CO_2 emissions per tonne cargo generally decreases with vessel size such that for example a smaller container feeder ship (with capacity up to 500 TEU) produces three times higher emissions than a large Post Panamax container ships (having a capacity of 4,400 TEU). This difference is even larger for dry bulk ships, with a difference of more than a factor 10 between the smallest vessels (up to 5000 dwt) and capsize vessels (> 120,000 dwt). However in terms of the volume of CO_2 emitted from shipping then the larger vessels engaged in intercontinental trade account for nearly three-quarters of the total. Larger vessels have the potential to use waste heat recovery with their direct diesel drives so improving their efficiency whereas small vessels use engines with poorer efficiencies. CO_2 emissions is the subject of continuous ongoing research but the IMO have stipulated that improvements must be achieved by setting EEDI reductions in the coming years with permissible limits for each are strictly stipulated in MARPOL Annex 6. As a result shipping was excluded from the COP21 climate change agreement, however this decision was somewhat controversial

Estimation of the expected future development of various emissions (CH_4, CO, CO_2, NO_x, SO_x and particulates) in 2050 compared to 2011 levels are given in figure 3. As it is seen from this graph emissions of all types is set to increase with expanding shipping industry responding to increasingly globalised trade. Ships are the largest source of pollution within port areas with emissions from heavy fuel oils that can be up to a hundred times dirtier than road fuels. Other sources of air pollution around ports include heavy trucks, locomotives, straddle carriers, and other kinds of machinery.[33]

To reduce these emissions then there must be increased efficiency of ships, change of fuel types, improved means of propulsion, use of cold ironing (shore side power) and where possible zero emissions ships. For zero emission ships the main barrier is lack

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[31] Noise from electric vehicles – state of the art' literature survey, internoise Austria, 2013:

[32] Regulation (EU) No 540/2014 of the European Parliament and of the Council of 16 April 2014 on the sound level of motor vehicles and of replacement silencing systems

[33] NABU, Clean Air in Ports, 2014.

of energy storage systems that offer good volumetric, weight and cost, shore-based infrastructure to enable fast charging. For fuel cells the challenge is to provide sufficient reliable power within a marine environment. Moreover for both technologies lifetime is a key cost driver with battery life dependent on the duty cycle and which with present technology requires replacement every 5-7 years. For fuel cells the technology deployment is presently restricted to high cost applications using hydrogen within military submarines and a few experimental ships. For commercial applications, fuel cells using Solid Oxide appears the most promising technology for multi MW marine propulsion. However although being developed together with a combined cycle for shore based power, the technology is at an early stage of marinisation. In this respect the increased availability of LNG fuel should facilitate use within Fuel cells and the achievement of higher efficiencies than conventional diesel propulsion.

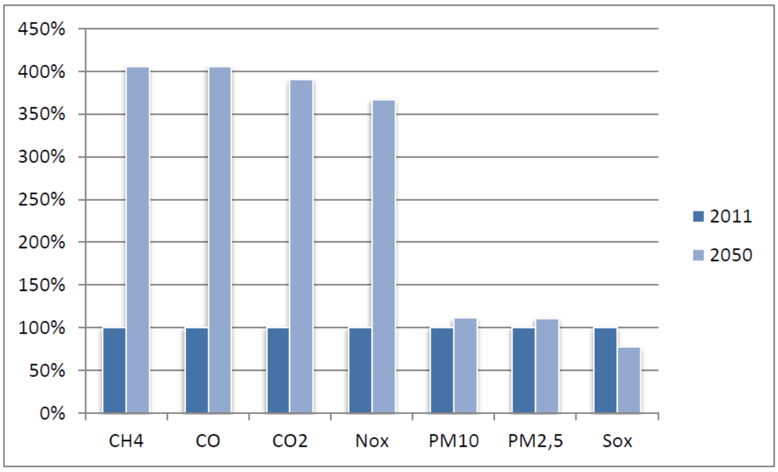

Fig. 3: *Emissions from ships*

Noise from ships is less of a concern than for road vehicles and trains. Noise levels within ports are dominated by port activities not ships' engines. Consequently electrification to reduce ship noise pollution is not a significant objective;

2.2.3. Aeronautics

For aeronautics, electrification will improve simultaneously air quality and noise impacts

Air quality

Aircraft engines emit pollutants that affect air quality, particularly for those working and living near an airport. However, this is not the only source of air pollution associated with aviation. Ground vehicles operating at airports, along with passenger and employee transport and delivery vehicles all also emit pollutants. These can include carbon monoxide, polycyclic aromatic hydrocarbons, benzene and 1,3-Butadiene.

Aircraft emissions can be reduced if airports provide fixed electrical ground power. This would allow aircrafts to switch off their auxiliary power units at terminal gates, reducing fuel burn and pollutants.

Mitigation measures for other airport pollution sources include modernizing power plants, ground equipment and vehicle fleets. Electric powered vehicles and equipment are the most efficient with regards to the reduction of pollutant emissions although they require the corresponding infrastructure

Many airports, in cooperation with the local authorities have introduced measures to reduce road traffic, improve ground traffic flow and encourage less polluting methods of transport to and from the airport. This includes access prioritization for electric vehicles and implementation of charging stations

The quality of the air that passengers and aircrews are exposed to on board commercial transport airplanes has been at the core of a continuing debate over past decades, both from the health and the safety points of view. One of the most critical safety aspects of an aircraft is the air quality. When in operation; an aircraft needs to maintain a specific internal pressure while ensuring a volume of outside air for persons on board (17 m3/hr per person for normal operation) to heat, cool, vent human CO2 emission and to provide oxygen to the cabin. Without the management of air quality and its supply, the cabin air temperature would rise up to 50% within 15 min and only after 5 minutes, CO2 concentration and shortage of oxygen would make a deadly journey. Beside the issues of safety, cabin air quality addresses also specifically two distinct risks: single air contamination events - e.g. due to potential oil leaks - which result in short-term peaks of air contamination (acute); and the intrinsic quality of the cabin air in normal operating conditions (chronic). In addition, whilst a causal association between cabin air contamination by oil mists and ill-health in commercial aircrew could not be identified, a number of incidents with a temporal relationship between an event and acute ill-health effects indicated that such an association was nevertheless plausible and worth of further investigation.

Noise

Aircraft and airport noise are complex subject matters which have been studied for decades and are still the focus of many research efforts today. Several actions have been experimented with existing aircrafts like free glide approaches and landing.

Electrification (partial or full) will obviously decrease noise impacts. Renewable powered systems could be used for landing, take off as wall as for taxiing. Moreover, as the aircraft touches down, kinetic energy can be captured for future use. For example, it might power on-board systems during taxiing or the ground-based propulsion system used for take-off

At shorter term, electrification of support vehicles will also reduce the noises around the airport.

2.2.4. Rail Transport

Air Quality

Electric trains do not directly generate air-pollutant emissions locally; any emissions that occur are created when traction current is generated, and new filters are helping to reduce these emissions as well.

With regards to diesel propulsion, newly purchased engines for rail vehicles are regulated by the Non-Road Mobile Machinery Directive[34], which significantly reduced the particulate matters and NOx emissions of engines used for rail applications. In addition, modern diesel multiple units and locomotives with diesel-electric drive system provide fewer pollutants. They are sometimes equipped with

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[34] Directive 1997/68/EC

several engines that can be partially switched off when not required, and particulate filters are mounted on these engines.

Another approach to reduce air-pollutant emissions for electric traction is to increase the percentage of renewable energy sources in the traction current mix, something that e.g. DB has done continuously over the past few years. Renewables accounted for 42 percent at the end of 2015.

Enclosed railway stations hosting diesel trains are at risk of reduced air quality as a result of exhaust emissions that may endanger passengers and workers. Air quality measurements were conducted inside London Paddington Station, a semi-enclosed railway station where 70% of trains are powered by diesel engines. The comparisons indicated that train station air quality was more polluted than the nearby roadside[35]

Particulate matter (PM) in the underground subway micro environments are of great concern since many people spend considerable time commuting on a daily basis, and the exposure to this pollutant in the subway systems has been linked to adverse human health effects [36] [37]. Particles in the subway system are mainly generated by mechanical wear and friction processes at the rail–wheel–brake interfaces, and at the interface between power conductive materials providing electricity and the current collectors attached to trains, as well as by the erosion of construction material and re-suspension [38] [39]. This leads to specific PM composition, different from outdoor transport

Noise

Rail freight noise is the most sensitive environmental problem of the railway sector and a serious nuisance for citizens living close to railway lines. 12 million EU inhabitants are affected by it during the day and 9 million during the night. A study edited by the European Commisson’s Directorate General for Internal Policy lists measures, funding and regulations to reduce it.[40]

For electric trains, pantograph noise is also significant at high speed. Pantographs are generally higher than noise barriers, and for high-speed trains these are a major source of noise. Rather than making noise barriers even higher or all-enclosing, an alternative approach is to focus on aerodynamic design and new materials. Pantographs can be shielded and/or carefully shaped, and thereby achieve noise reductions of 5-10 dB in each case. [41] It has been shown that porous covers can reduce aerodynamic noise of pantographs.[42]

2.3. Impacts on competitiveness, growth and job creation

It is important to recognize the contribution of transport to the European economy. The transport industry directly accounts for almost 5% (in some regions even much

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[35] Air quality evaluation of London Paddington train station Uven Chong1, Jacob J Swanson, and Adam M Boies1, Environmental Research Letters, Volume 10, Number 9 (2015).

[36] Bouchal et al., Biological effects of particles from the Paris subway system. Chem. Res. Toxicol., 20 (2007), pp. 1426–1433.

[37] Bigert et al., Blood markers of inflammation and coagulation and exposure to airborne particles in employees in the Stockholm underground Occup. Environ. Med., 65 (2008), pp. 655–658.

[38] Jung et al., Source identification of particulate matter collected at underground subway stations in Seoul, Korea using quantitative single-particle analysis, Atmos. Environ., 44 (2010), pp. 2287–2293.

[39] Loxham et al., Physicochemical characterization of airborne particulate matter at a mainline underground railway station, Environ. Sci. Technol., 47 (2013), pp. 3614–3622.

[40] Study on Reducing railway Noise Pollution, EC Directorate general for internal Policy, 2012

[41] Talotte 2000, Talotte et al. 2003.

[42] Sueki et al. 2009.

higher) of GDP and 5% of employment[43], and the economic contribution of the manufacturing of transport vehicles and equipment adds to this. All in all 27% of EU GDP are generated by industrial goods. By definition goods are transported, therefore this portion of the economy is fully dependent on a productive and efficient transport system. The part of the economy represented by services is also partly dependent on the transport sector, requiring mobility of people providing those services. Infrastructure investments could provide further indications for determining the performance in the transport sector. However, past research has been restricted by the lack of appropriate data. Despite the importance of the transport sector, there is a lack of cross- country comparison of inputs, outcomes and efficiency. [44]

To support the economy and society most effectively innovation in mobility should aim to ensure that increasingly productive transport and greater personal mobility in the EU are offered with higher efficiency at reduced costs, at the same time it should intend to maintain and further strengthen the related industrial sectors. This general objective applies to any other kind of mobility, and should hold for electric mobility as well, particularly in cities.

Electrification as a new and promising technology may exert quite some dynamics on conventional value chains in the conventional transportation industries. This may also affect the labor market. Concerns about jobs getting lost are faced with the opportunity that skills for electrification are highly transferrable between modes.

2.3.1. Road transport

Due to the move towards electric and low emission mobility and to other trends, the automobile industry sector is under continuous change and heavily investing in research and innovation. Recent developments in diesel emissions tend to accelerate the dynamics in the value chain. Recently, new actors emerged in the value chain for instance from the infrastructure, service and information sectors. Optimistic studies on job creation in the European automotive industry like “Fuelling Europe’s Future”[45] indicate that EU-wide employment could increase by 850,000 to 1.1 million in 2030 with a rapid move to electric mobility. By 2050, jobs may increase by 1.9 million to 2.3 million in all low-carbon scenarios examined. Many of these new jobs will be created within sectors away from the traditional automotive value chain though. This transition requires anticipative investments into training, smart specialization and industrial restructuring though.

In the domain of electric vehicles, in particular, global competitiveness of the European automobile industry is at risk. It will be essential to develop technology leadership in vehicle concepts and architectures, energy storage systems, and other components and systems. Furthermore, the automotive supply chains may face significant change.

2.3.2. Waterborne transport

In terms of tonnage, 90% of international trade and around 40% of intra-European trade is moved using waterborne transport. As of May 2016, the global merchant fleet stood at 91,514 vessels (above 100 GT when excluding naval vessels, private yachts, small fishing vessels, and offshore structures) with a combined 1.2bn GT (1.8bn dwt). 40% of the world fleet is European owned. European marine equipment and ship

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[43] ec.europa.eu/competition/sectors/transport/overview.html

[44] Understanding the Value of Transport Infrastructure, International Transport Forum, 2013

[45] Fuelling Europe's Future, Cambridge Econometrics (CE), Ricardo-AEA, Element Energy, 2014

building industries employs 500,000 persons with an annual turnover of around €72bn. Globally, virtually all very large passenger and cruise ships are constructed in Europe at a cost for cruise ships approaching €1Bn per vessel. The environmental image of cruise ships is an important commercial factor and as a result such vessels are early adopters of new technologies.

The north European ports of Rotterdam, Hamburg and Antwerp handle a major share of EU external trade and millions of containers per year. From the port of Rotterdam millions of containers are fed to other European destinations using short sea or inland waterways which is equivalent to removing millions of lorry journeys from European roads. 40% of the EU's population lives within a coastal region and consequently there is a large potential to decarbonise and decongesting road freight by transferring to short sea (coastal) and inland waterways.

Globally, as of April 2016, 2.7m GT of new ships entered the world fleet and 3.1m GT of demolition was reported combined with a 60% reduction in orders within the first four months of 2016 in terms of GT.[46] However the situation is not uniform, Europe specializes in advanced marine equipment and vessels such as cruise ships and vessels supporting offshore renewable energy and with the exception of the oil and gas sector these markets remain buoyant.

Electrification of ships will be achieved primarily through the development of technologies for other industries such as road vehicles and power industry. For instance battery technology is being driven by the automotive sector. The same is true for fuel cell technology which can draw upon developments within the power industry. There may also be technology transfer from the military which is for example developing large scale rail guns that require large energy storage units.

In general Europe's maritime industries are innovative and have benefited from the development and commercialisation of technology to meet tighter environmental regulations. The same opportunities could be expected within Europe with respect to the increased electrification of waterborne transport where Europe is a leader within key domains such as marine power electronics, hybrid ships and the marinisation of fuel cells. Consequently, increased electrification of shipping would be expected to benefit Europe both economically and in terms of employment. The challenge will be to ensure adequate IPR to protection retain these benefits within Europe.

2.3.3. Aeronautics

Electrification will influence the competitiveness of the whole supply chain, considering the entire aeronautic transport system including all airport services.

Main stakeholders are already involved and develop adequate competences, however, aircraft electrification will induce changes in smaller companies and might also involve new partners e.g. for motorisation, energy storage etc.

The installation of electricity supply at airports for use by stationary airplanes is one key operational opportunity for terminals to minimize fuels consumption and the resulting noise and CO2 emission. Such facilities typically requires capital investment but often realizes substantial fuel/maintenance savings while addressing the risk of health related issues for ground personal and passengers at terminals.

The growth and job increase for these companies will be related to the growth and innovative power of the aviation transport sector. At present, aviation helps sustain 58

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[46] Clarksons Research https://clarksonsresearch.wordpress.com

million jobs and $2.4 trillion in economic activity. In 20 years' time, aviation is expected to support around 105 million jobs and $6 trillion in GDP (IATA source, 2015).

2.3.4. Rail Transport

The European rail supply industry is a diverse and geographically widespread industry – from thousands of SMEs to major industrial champions; from rail supplies in rolling stock to signaling systems and infrastructure, including all components and subcomponents. In total the European rail supply industry employs no less than 400.000 people all over Europe. With absolute sales of €47 billion, the European rail supply industry still accounts today for 46% of the market for rail products in the whole world. The world leadership of this export-oriented industry is also attributed to its R&D capacities. The European industry currently invests 2,7% of its annual turnover in R&D and that has come up with innovations such as the high speed train, ERTMS (European Rail Traffic Management Systems) and automated metro systems.

Electrification and energy management being an integral part of most new mass transit and main line railway system, it is critical for the European railway industry to remain leader in this area.

3. Baseline and State of the Art

Topics to be discussed for each of the three modes considered:

- *What is the current state of the art in electrified transport technologies?*
- *Identify barriers and gaps (including regulatory frameworks) hindering further evolution and deployment of the technology and how to address them. Identify as well positive elements to be retained.*
- *What is the competitiveness of the EU industry within the domain?*

Complementary to the presentation of motivations and targets for the implementation of electric mobility in the previous chapter, an analysis of the state of the technology development is made here for all four transport modes. Furthermore, barriers and gaps for the development and deployment of electrified solutions are discussed and success stories are told. Finally, an assessment of the competitive position of the European industry is made. This shall serve as a basis for establishment of roadmaps for strategy and action plan at the end of the document.

3.1. State of the technology development

The achievements in technology development for electric vehicles have been impressive in recent years, technical targets have been met and increasing demand can be noticed. Electric mobility is developing all over the world, reflecting people's awareness of the ever increasing problems of providing primary energy and raw materials, of climate change and of the impact of noxious emissions on health. Nonetheless, significant differences exist between the four transport modes considered

3.1.1. Road transport

Electric mobility is truly a disruptive technology that does not just change the powertrain of the automobile, but may also influence the conditions of its use, e.g. the underlying business and financing models. This may lead to completely new user behaviors and preferences.

The number of battery-electric and plug-in hybrid vehicles on the road is still small but steadily increasing after vehicle manufactures have launched dedicated models to the market, grid operators installed public charging infrastructures and governments worldwide funded multiple demonstrations and pilots, and created framework conditions and incentive for purchase and use of electric vehicles.[47] See table 1 for the state of deployment of electric passenger cars end of 2015.

In addition to that, electric bicyles and pedelecs are commonplace now. Also, electrification of road vehicles has been extended to delivery vans, light trucks and buses recently, and prototypes of larger electrified trucks are developed as well.

Electric bus pilot and early fleet projects are growing in Europe. With current battery technology (approx. 110 Wh/kg) electric opportunity charging electric buses with a real-use range of more than 100 km[48] is feasible without compromising the passenger capacity of the bus. On high capacity routes these buses today can offer zero emission at nearly a similar total cost of ownership as diesel buses. Plug-in hybrids are also

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[47] Implementing Agreement Hybrid and Electric Vehicles of the International Energy Agency, Hybrid and Electric Vehicles – The Electric Drive Commutes. Annual Report on 2015, 2016. www.ieahev.org

[48] ZeEUS project, ZEroEmission Urban bus System, FP7 project, http://zeeus.eu/

viable options using less battery and having a combustion engine offering more route and range flexibility.

Electric urban trucks are today emerging from niche makers; several automotive manufacturers propose efficient vehicles.[49] Current energy density of battery packs limits range and load capacity, especially for the short wheel base trucks typically employed in inner cities. Compared to buses, the volumetric energy density of the battery pack is more critical for truck packaging. At battery cell prices below 250 USD/kWh (to commercial vehicle specification) and pack level volumetric energy density of around 200 Wh/l, urban medium duty full electric trucks will be cost competitive over new diesel trucks with respect to total cost of ownership. Depot charging trucks will be able to use automotive charging standards.

Due to their high energy demand, electric high duty vehicles such as long-haul trucks and coaches in the future scenario require another source of energy beyond batteries, either a range extender or a roadside solution for continuous charging as demonstrated in so called electric road systems. Power transfer to the vehicle can be solved in many ways, e.g. catenary with overhead lines inductive or conductive from the road. First demonstration projects on public roads show that such electric road systems are a technically viable solution.[50] The main enabler for a large scale adoption will be international standardization.

Major achievements can be stated for all parts of the electric powertrain of the automobile including batteries, power electronics, electric motors and transmission systems as well as the interfaces of the vehicle to the infrastructure[51]. The following examples are particularly relevant in the context of this roadmap.

Country	**Battery-electric vehicles**	**Plug-In hybrid vehicles**
Austria	5.000	1.500
Belgium	3.900	4.700
Denmark	7.600	500
Finland	600	1.500
France	44.000	10.600
Germany	25.500	10.800
Ireland	1.000	200
Italy	4.200	500
Netherlands	9.400	78.200
Portugal	1.300	800
Spain	3.600	1.100
Sweden	4.800	9.800
Switzerland	6.300	2.700
Turkey	200	n.a.
U.K.	20.000	27.000
Norway	70.700	12.100
USA	214.600	191.900
Canada	7.900	7.700
China	199.800	81.800
South Korea	8.800	1.500
Japan	76.900	55.200
Australia	2.500	1.300

Table 1: *Numbers of electric passenger cars on the road (end of 2015)*

Batteries

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[49] FREVUE, Freight Electric Vehicles, in Urban Europe, FP7 project, http://frevue.eu/

[50] Trafikverket, First electric road in Sweden inaugurated. Press release 22 June 2016. http://www.trafikverket.se/en/startpage/about-us/news/2016/2016-06/first-electric-road-in-sweden-inaugurated

[51] Roadmap Information and Communication Technologies for the Fully Electric Vehicle (Draft), ICT4FEV Project, 2013.

Batteries[52] are one of the most important parts of the electric powertrain, as they determine the range, cost and safety of the vehicle system. Since 1990 the specific energy (Wh/kg) of Li-ion cells has increased significantly: The highest gravimetric energy density achieved for Li-ion cells to date amounts to about 250 Wh/kg[53]. A typical gravimetric energy density at battery pack level is 110 Wh/kg, while a volumetric energy density – which is equally relevant for automotive applications – is 275 Wh/l[54]. Even though the theoretical limit of the specific energy of Li-ion cells has not yet been reached, future improvements can rather be expected at the material and battery pack level: including wiring, electronic control circuits and conditioning components, more than 50% of the weight of a battery pack consists of non-active materials[55]. Hence, there is considerable room for automotive-specific battery designs. Even without new chemistries, such designs could also lead to slight improvements in specific energy and increased manufacturing productivity (output in Wh per unit time).

The high cost of lithium-ion batteries is widely seen as the biggest barrier to mass adoption of EV, others are standardization and manufacturability. Currently commercial Li-ion automotive-grade cells for EVs cost about 350€/kWh. With an average cost for active materials of about 75€/kWh for EVs, depending on chemistry and cell architecture, and requiring about 6kg active materials per kWh, the US Advanced Battery Consortium’s once ambitious cost goal is about 200US$/kWh is indeed an achievable target. With the creation of its gigafactory, Tesla Motors is aiming at economies of scale in mass production of EV batteries.[56] In spite of the many research projects on post-Li-ion batteries which aim at higher energy densities at lower cost, there has not been evidence of a system ready for manufacturing so far. However to ultimate reach the goal of the EV’s autonomy being comparable to the one of a conventional car new chemistries have to be applied, such as Si-based anode, high voltage electrolyte and cathodes or Li-S and Li-Air systems[57].

Right sizing of batteries, and thus, vehicle autonomy, to actual user needs (in most cases fixed trips of some tens of km per day only) in combination with smart mobility services, renting systems or transition to public transport is an option to complement to the efforts in further improving the performance and affordability of EV batteries in the short to mid-term.

Motors and Transmission Systems

Most EVs in the market are based on a single electric motor. Nevertheless, considerable deployment efforts have been spent on a twin motor powertrains providing the possibility of four wheels drive. Automatic, computer-controlled multi gear boxes are able to differentiate the torque to each wheel in relation to speed, acceleration, steering angle and road conditions. These are going to be introduced in the market soon. High-end electric powertrains with multi-motor propulsion

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[52] The same holds for fuel cells if hydrogen is used for energy storage

[53] M. S. Whittingham, “History, Evolution, and Future Status of Energy Storage”, IEEE Proc., 100: 1518-1534 (2012).

[54] A Review of Battery Technologies for Automotive Applications, A joint industry analysis of the technological suitability of different battery technologies for use across various automotive applications in the foreseeable future, EUROBAT, ACEA, JAMA, KAMA, ILA.

[55] Moss, R., Tzimas, E., Willis, P., Arendorf, J., Tercero Espinoza, L., 2013. Critical Metals in the Path towards Decarbonisation of the EU Energy Sector. EUR 25994, European Commission, Joint Research Centre, Institute for Energy and Transport, Petten, The Netherlands.

[56] https://www.tesla.com/de_DE/blog/gigafactory

[57] J. Cho, P. G. Bruce et al., Challenges Facing Lithium Batteries and Electrical Double-Layer Capacitors, Angew. Chem. Int. Ed. 2012, 51, 9994 – 10024

embedding vehicle stabilization functions and distributed regenerative braking are in an advanced development phase as well. Efficient electrical motors with low or no contents of rare permanent magnets are successfully competing with rare earth-based permanent magnet synchronous motors. Most automotive companies produce their own motors and transmission systems addressing a high level of system integration towards a single mono-block including power electronics, motor and transmission.

Power Electronics

Semiconductor technology has evolved towards devices with higher junction temperatures, recently, while packaging solutions have led to compact and efficient power devices that allow a radical simplification of the cooling systems. The drastic reduction in power dissipation of both IGBT and MOS technologies have enabled smaller, highly efficient and cost effective DC-DC and AC-DC converters capable of driving electric motors with >200kW nominal power. At the same time, low voltage, low cost and compact air cooled motor controllers for peak powers >50kW are commercially available. The semiconductor content of electric drivetrains is expected to more than double compared to the 2012 conventional powertrain by 2020 [58]. This can be expected to lead to economies of scale and synergies of efficient semiconductor materials with further advancements in efficiency, miniaturization, cost reduction of all key components, e.g. SiC and GaN based devices are close to entering the market[59].

Charging Technology and Infrastructure

The broad deployment of electric vehicles pushes for public charging infrastructures, both for high power (or fast) charging enabling longer distance travels, and normal/medium power charging points in public areas, notably in urban dwellings where electric vehicle users or owners may not have access to a private garage or a house, but need to regularly perform overnight charging.

For high power charging, The CCS Combined Charging System has been agreed at EU level as Common standards for High Power DC Charging while Type 2 as common normal power AC charging in the directive 2014/94 on the deployment of alternative fuels infrastucture The combined charging system (CCS) integrates single-phase AC-charging, fast three-phase AC-charging, faster DC-charging at home and ultra-fast DC-charging at public stations into one vehicle inlet.[60]

Resonant wireless charging is another quite interesting and practical technology with efficiency around 90% from the main to the battery (plate to plate efficiency can reach 98%). The limitations on the maximum power transmissible and more specifically the limit on power density are likely to restrict the use of wireless charging to normal/medium power charging. The technology has been proposed to provide continuous charging on highways when the car is in motion[61] but the cost of the related infrastructure appears to be prohibitive. Ongoing standardization issues on inductive charging are part of the European Commission mandate (M533) approved by the CEN/CENELEC in 2015. There is a general consensus to consider wireless charging a promising optional charge solution to be added to the conventional conductive one and likely to spread as a basic element of the city infrastructure,

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[58] Sources: NXP, STMicroelectronics and Infineon 2012.

[59] Julian Styles, GaN Systems: The end of the silicon era – how new semiconductors will transform electric and hybrid vehicles, September 2013, USA.

[60] Directive 2014/94/EU

[61] A. Gilbert: Wireless Charging: The future of Electric car. In: G. Meyer (Ed.), Advanced Microsystems for Automotive Applications 2012, Springer 2012, Berlin.

especially for bus station/stop applications as it is currently exploited in routes 507 and 521 in London. The charging technology is equally interesting for airport platform vehicles.

The availability of a fast charging infrastructure has demonstrated to positively influence driver's behavior in terms of average distance travelled, reduction of range anxiety and general higher confidence with electric vehicles[62]. Other than slow charging or battery swapping, fast charging thus may imply a less complex business model. Fast charging corridors may be made operative all across Europe by equipping only 10% (or about 20,000) of all gasoline stations[63] with fast charging points. Thanks to several European projects focused on charging and infrastructure developments, it is now clear that the charging infrastructure is less costly than originally expected if a clearer distinction is made between the charging needs in private and public locations. Despite of reductions in the capital cost of fast charge equipment the installation costs, associated civil engineering works and utility connection costs still remain unchanged. Fast charging with battery buffering is also a promising way for countryside implementations when grid connections cannot supply sufficient power at once.

Additionally to charging power, charging infrastructure also depends on whether charging is conducted in an uncontrolled manner which could, depending on when the charging is taking place, result in large and therefore costly electricity peak demands or in a controlled way with load management. The latter alternative will not only allow for cheaper charging but it will also facilitate faster charging without a corresponding increase in the cost. It is therefore important to note in this context that charging with normal power (up to 22kW) provides more opportunities for flexibility such as storage or load management, whereas high power charging, due to the expected shorter duration, could be less relevant for such flexibility services.

Despite these obvious advantages of fast charging, it is obvious that the choice for low/medium or high power charging depends on the specific use pattern. The existing experimentation with passenger EVs as well as extensive data analysis of urban and regional drive patterns has proven that–normal or medium power charging points at home, near home or work together with high power charging points installed at conventional service stations can meet most of the demands[64,65,66]. The normal, medium and high power charge infrastructure is developing very quickly.

3.1.2. Waterborne transport

Ships use electrical power onboard to support service and hotel loads. This includes fans, pumps, compressors, cranes, lighting, heating, electronics and computing. On board electrical loads range from a few hundred kW in smaller cargo vessels to tens of MW in larger ships such as cruise-liners.

Ships are propelled by mechanical and electrical means. Around 2,500 ships in the world are powered by electric propulsion including cruise liners, shuttle tankers, offshore support vessels, LNG tankers and ferries.[67] Electric propulsion is selected

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[62] UK's first rapid charging network allows EVs to cross the whole country. CARS21, 08 June 2012

[63] G. Mauri, "Charging made easy", INTRASME Workshop 25, September, 2013.

[64] De Gennaro, M., Paffumi, E., Scholz, H., Martini, G., GIS-driven analysis of e-mobility in urban areas: An evaluation of the impact on the electric energy grid, (2014) Applied Energy, 124, pp. 94-116.

[65] Paffumi, E., De Gennaro, M., Martini, G., Scholz, H., Assessment of the potential of electric vehicles and charging strategies to meet urban mobility requirements,(2014) Transportmetrica A: Transport Science

[66] M. Duoba, Developing a Utility Factor for Battery Electric Vehicles, SAE, Int. J. Alt. Power. 2(2): 2013.

[67] Clarksons Data Base https://clarksonsresearch.com

because it offers advantages in performance and/or efficiency over traditional mechanical drives which are more popular in vessels that operate over long distances.

Propulsion Type	**EU (flag state) Total**	**EU (owner) Total**	**World Total**
Diesel-electric	541	770	2533
Hybrid mechanical + Electrical	4	3	54
Combined[1]	15	5	31
Sub-total	*560*	*778*	*2618*
Battery ships[2]	9	11	26
Sub-total	*9*	*11*	*26*

Table 2: *Numbers of electrified ships (1: Gas turbine generators with diesel-generators are used to generate electricity, 2: Batteries provide the main means for propulsion and/or auxiliary power)*

Ships driven by electrical means have either an integrated full electrical propulsion (IFEP) system or a hybrid electric propulsion (HyeP) system or an all-electric 'battery' system. In IFEP and HyeP systems the electrical power is generated on board the ship whilst in all-electric systems electricity is generated ashore stored energy from batteries, although other energy storage systems have been considered.

IFEP systems are commonly found in ships from passenger vessels, LNG tankers, shuttle tankers, cruise ships, ferries, offshore support vessels. Typically diesel-generators generate alternating current at constant voltage and constant frequency which is distributed to both service and propulsion systems. Power converters are generally used to control propulsors thrust.

In hybrid systems the propeller can be driven using a prime-mover and/or electrical motor which are usually integrated using a gearbox to a common shaft line. The system operates as a power-take-in or a power-take-off depending on the vessel operating speed. A variation of this system is used onboard large cargo ships and tankers e.g. Emma Maersk whereby electricity is also generated by a waste heat rankine cycle and excess power injected onto the propulsion shaft.[68]

When operating at sea ships' generate their electricity predominantly using diesel-generators which emit the atmospheric pollutants described above. When in port the same diesel-generators are used unless a ship's electrical system can be connected to a shore supply – a system known as cold-ironing. Whilst some ports offer this facility others do not. Quite often cost is quoted as the reason for not providing this facility.[69]

More recently battery operated vessels have been built and have entered service. These vessels, which tend to be small, or undertaking short ferry routes carry battery packs that are used to power the service, hotel and propulsion loads. The largest battery currently available commercially is a Lithium Ion battery of 56 MWh. [70]

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[68] http://www.shippingpodcasts.com/blog/wp-content/themes/commoditypodcasts/images/Efficient_Propulsion.pdf

[69] http://www.theguardian.com/environment/2016/may/21/the-worlds-largest-cruise-ship-and-its-supersized-pollution-problem

[70] http://www.prnewswire.com/news-releases/kokams-56-megawatt-energy-storage-project-features-worlds-largest-lithium-nmc-energy-storage-system-for-frequency-regulation-300229219.html

Specialised fuel cell technology is used to power military submarines but these types use liquid oxygen and are generally unsuited for commercial shipping and there has been some testing of relatively small Solid Oxide Fuel Cells (SOFC) within a commercial marine environment. SOFC fuel cells up to 10MW using LNG are becoming commercially available for shore based power and for use together with a combustion engine in a combined cycle to achieve a high electrical efficiency. However combined cycle is a volume intensive power/propulsion solution and in its current form remains unattractive. In power stations excess heat can be used to heat homes but in ships the demand for low grade heat is limited typically to some passenger ships and crude oil tankers. The Maritime safety agency are undertaking a study concerning safety and fuel cells. As yet there is no large scale application of fuel cell technology for commercial marine propulsion.

Fuel cells at small scale are now available for small craft as an alternative to diesel engines, using fuels such as methanol. The market is currently small though and the cost of the fuel cells and fuel remains high.

3.1.3. Aeronautics

The aviation sector can be considered to be in the midst of a pioneering era with regards to electro-mobility. As a result, dramatic and disruptive changes to component/sub-systems technologies coupled with experimentation of propulsion and power systems (PPS) architectures and/or aircraft morphologies are currently taking place.

At this point in time, electro-mobility for aircraft only exists in the single/twin-seater categories and typically consists of retrofits of existing conventional designs with reduced payload capability.[71] The 1970s until around the end of the 1990s were witness to several experimental aircraft, but most of these focused on solar power as a source of electric energy. From around the early 2000s until today, a proliferation of experimental aircraft utilizing electro-chemical means of energy supply has emerged. It is around the same time a series of glider/ultra-light/light-sport aircraft integrators, namely, Air Energy, Electraflyer, Yuneec International, Sonex Aircraft, Schempp-Hirth Flugzeugbau, Lange Aviation, Electravia, PC-Aero, Pipistrel and Cessna have undertaken the step of offering or are scheduled to offer production aircraft to the light aviation sector.

Regarding fixed-wing commercial aviation, at current technology levels the development of even a hybrid-electric passenger aircraft appears challenging. Irrespective of these difficulties, one of the world’s leading commercial aircraft integrators, Airbus Group, has recognized the potential of electro-mobility for aeronautical applications, and has committed resources to the so-called “E-Aircraft Programme”. It is an industry lead initiative conceived by Airbus Group in order to pave the way forward in a piece-meal fashion for commercial aircraft to operate with fully-electric propulsion as the ultimate goal. At this moment in time, active projects include: the Dimona DA36 e-Star 2nd Generation Project, a two-seat hybrid-electric aircraft in conjunction with Diamond Aircraft and Siemens AG, and the E-Fan, a fully electrically-powered pilot training aircraft.

Contemporary approaches to electrical systems integration are the so-called More-Electric Aircraft or All-Electric Aircraft (MEA/AEA) architectures. Irrespective of the extent of electrification they require mechanical off-take from a gas-turbine power

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[71] Pornet, C., Isikveren, A. T., “Conceptual Design of Hybrid-Electric Transport Aircraft”, Progress in Aerospace Sciences, Elsevier, Vol. 79, November 2015, pp. 114-135, doi: 10.1016/j.paerosci.2015.11.002.

source, and can result in a diverse bill-of-material and complex overall architecture. Isikveren postulates that the MEA/AEA architecture will realise characteristic peaks of component and sub-systems efficiencies by year 2025-2030.[72]

Cell-Level Gravimetric Specific Energy (GSE) is a key metric when quantifying battery technology targets. Lithium based technology has rapidly developed to become the most capable type of battery today, with a commercial GSE of 200-250 Wh/kg. Also, the Gravimetric Specific Power (GSP) of electrical machines, which have to serve as propulsor drives or as generators are of great importance in order to fulfil power and mass constraints of aircraft. For industry application electrical machines with a GSP of 0.5-1.0 kW/kg are standard. Current research and technology projects have demonstrated 5.0-6.0 kW/kg at TRL 4. Driving an electric-PPS at a higher system voltage (kilo Volts) helps to reduce the mass of the wiring between the components. 500-800 VDC is currently being investigated, but this technology has not achieved certification status at this point in time.

3.1.4. Rail Transport

Rail transport is currently by far the most electrified transport mode in Europe. Especially in urban areas, rail almost exclusively runs on electricity already today.

Regarding main lines, 60% of the European rail network is already electrified and 80% of traffic is running on these lines. There are no technical obstacles to further electrification, but the cost for upgrading and electrifying the existing rail infrastructure and the expected carbon reduction need to be considered on a case by case basis. On busy lines electrification makes most sense economically and from a carbon savings perspective. On low-density lines there is today no proven cost-efficient solution to replace diesel-powered trains. Electrification of main lines is progressing in Europe as some countries e.g. UK are pursuing an intense program of electrification to increase line capacity, to offer better services and to reduce impact on the environment. For low-density lines various research projects are investigating the possible use of hybrid or dual-mode propulsion systems, or even fuel cells to reduce the scope of diesel engines.

On main line however, there is an additional interoperability issue as historically various voltages have been selected for different national networks: thus, an international train has to be able to adjust to a variety of traction currents among 750 V, 1.5 kV, 3 kV, 15 kV and 25 kV.

Rail has been the first transport mode to introduce emerging technologies of power electronics such as GTO in the past and IGBT silicon-based one 15 years ago. The introduction of those technologies has lead to better energy efficiency, more reliable components. since the last few years, the railway industry has been working on the SiC (Silicon Carbide) technology using 1200V chips for auxiliary converters and developing intense R&D Programs on higher voltage (3,3kV) for traction applications. New traction drives based on the SiC technology is one of the major cutting edge developments of the cooperative SHIFT2RAIL program operated by the Joint Undertaking between the Commission and the Railway Industry under H2020.

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[72] Isikveren, A.T. (SAFRAN SA), “Hybrid-Electric Systems and Propulsion for Aircraft conducting REgional and Short-haul Operations (HESPARES)”, Horizon 2020 RIA MG-1.4-2016-2017, Proposal No. 723340, European Commission Directorate General for Research and Innovation, 20 January 2016.

The development of new electric motors has always been and is still at the spearhead of R&D efforts of the railway industry. The first generation of TGV (1981) was using DC motors with a ratio of 2,9 kg/kW. The next generation of TGV (1989) was using synchronous motors with a ratio of 1,35kg/kW. The Eurostar that started operations in 1994 was using induction motors with a ratio of 1,23 kg/kW. An important step was made in the 2000s with the development of Permanent Magnet Motors, PMM (NTV AGV trains in Italy), characterized by a ratio below 1 kg/kW. This new generation of self-ventilated and maintenance free traction motors first introduced for very high speed applications is now equipping tramways, tram-train and regional trains.

Energy efficiency of traction drives have been drastically increased not only from the advances in power electronics and new motors as such but also through the combination of the technologies. Thus, SiC technology will allow the control of PMM at higher frequency (kHz) than asynchronous motors (a few 100Hz) reducing significantly harmonics and losses. As an important side-effect, the introduction of new technologies has lead to drastic reduction of the mass and volume of the traction sub-systems resulting in higher capacity and lighter trains.

Nonetheless, when return of investment for electric wiring is not possible due to the frequency and the usage of certain lines, Hydrogen and fuel Cells can be considered as an alternative. In Northern Germany and in Latvia, train companies are starting to use hydrogen based technologies. However, the application of fuel cells technology in the rail sector poses specific challenges in terms of mechanical and thermal stress, reliability, availability and lifetime. The specific thermal ambient conditions for rail might require further specific development for cooling and heating modules. The lifetime of the fuel cell system should also be looked at separately (a train is operated 15 000 hours, against 6000 hours for a car). Also, the integration of fuel cell systems on locomotives and hydrogen storage will need further development.

3.2. Barriers and gaps; as well as success stories

Apart from rail, electrified transportation technologies still lag behind conventionally powered systems in terms of range, cost and appropriate refueling systems. Issues also include secure access to raw materials and appropriate ways of battery recycling.

Another major barrier for the adoption of electrified transportation technologies is the access to recharging systems. The Clean Power for Transport package aims to facilitate the development of a single market for alternative fuels for transport in Europe. Part of it is a Directive on the deployment of alternative fuels infrastructure[73] which has been adopted by the European Parliament and the Council on October 22nd, 2014. It will ensure the build-up of both normal and high power (AC and DC) recharging and refueling points across Europe with common standards for their design and use, including a common plug for recharging electric vehicles.

Under the directive, each Member State will adopt a national policy framework for the market development of alternative fuels infrastructure, outlining its national targets for putting in place new recharging and refueling points and relevant supporting actions. It must send its framework to the Commission within two years from the entry into force of the directive. Minimum infrastructure shall be provided, differentiated according to needs and technological maturity, for electricity, hydrogen (for Member States which decide to include hydrogen refueling points accessible to the public in their national

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[73] Directive for the Deployment of Alternative Fuels Infrastructure, COM (2014) 94

policy frameworks) ,and natural gas (in gaseous form as Compressed Natural Gas (CNG), and in liquid form as Liquefied Natural Gas (LNG).

3.2.1. Road transport

A first European roadmap on electrification[74], edited by the industry, was published in 2009 and has been updated in 2012. Yet another update is currently carried out. The roadmap identifies barriers and gaps and identifies related needs for action in the timeline. It also addresses in quantitative terms the benefits of electric vehicles associated to primary energy saving, reduction of greenhouse gas emissions and radical reduction of noxious emissions in cities. It was demonstrated that in 1998 a mid-sized EV was leading to 30+% higher primary energy consumption than a mid-sized ICEV, while with only ten year of technology advancements in 2008 the situation was reversed with the EV leading to a considerable primary energy saving up to 25%. Similar studies followed from several associations and public agencies confirming as well a reduction of the emitted Green House Gases up to 50% with respect to ICEVs state-of-the-art solutions. The roadmap also describes the deployment of electric and plug-in hybrid vehicles in Europe in terms of both a baseline evolutionary scenario and an expected development under the assumption of major technological breakthroughs.

The potential achievements are expressed in terms of milestones linking the absolute market penetration to the availability of key technologies: 2012 (introduction: adaptation of existing vehicles), 2015 (intermediate: 2nd generation EV with updated power train), 2020 (mass production of EV, 5 Mio units accumulated), and 2025 (mass production of 3rd generation fully revised EV concept, 15 Mio units accumulated).

The European Commission has funded research and development on electric vehicles and their subsystems and components since 2010 in the framework of the European Green Cars Initiative PPP (EGCI) and its successor in Horizon 2020, the European Green Vehicles Initiative PPP (EGVI) which is focused on energy efficiency and alternative power trains. Electrification of transport is a priority as it offers a way to introduce renewable energy sources into the transport system. In the FP7 and H2020 frameworks, successful projects on electric mobility are testing and demonstrating the best solutions to develop a sustainable market for electrification of road transport (e.g. Green eMotion for electric vehicles mass deployment which ended recently, ZeUS on electric urban bus systems and Frevue on electrification of the "last mile" freight movements in urban centres). Further success stories are covered by the impact assessment of the EGCI PPP. A comprehensive inventory of all funded projects is contained in the TRIP portal[75] and in the publications of the EGVIA, e.g. the Portfolio of European Green Cars projects[76].

The task force in charge of editing the update of the electrification roadmap concluded that the original 2012 milestone has been passed successfully, and the one of 2015 is a good description of the state of the art. They also drafted a new milestone for 2030 (redesigned electrified road transport meeting the requirements of the future connected society) which shall also cover the potential synergies of electrification, connectivity and automation. The work of the task force is on-going and may still change at the release of this roadmap.

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[74] European Roadmap Electrification of Road Transport, 2nd edition. ERTRAC, EPoSS, Smart Grids 2012.

[75] www.transport-research.info

[76] www.egvia.eu

3.2.2. Waterborne transport

Currently, most merchant and passenger ships use the diesel engines for power and propulsion either through direct drive or via diesels electric systems. Compared to other diesel engine applications, marine engines are very efficient. Electric propulsion applications for automobiles have greatly improved fuel efficiency and reduced emissions as both a hybrid or as a fully electric vehicle. These benefits also apply to shipping while also reducing the other pollutants typically associated with marine fuel. Consequently there is an increasing and ongoing trend to build more diesel electric, hybrid electric and fully electric vessels. The introduction of electric propulsion for ships offers several advantages:

- Flexibility of ship design and build with cables linking key components rather than complex gearboxes and shafts.
- Flexibility of ship operation allowing choice of prime movers supplying the propulsion shaft and also the on-board power requirement. Such prime-movers can be adapted to dual-fuel or use biofuels or else there is a possibility to operate with fuel cells.
- Silencing of on-board noise which is important in passenger vessels and also warships.
- Improved fuel efficiency during travel due to the ability to constantly maintain diesel engines in the power range that offers good fuel efficiency.
- Hybrid drives allows batteries to work with diesel engines so that the latter may be operated efficiently with on/off technology e.g. when loitering or running at low speeds.
- Battery powered ships can use containerised batteries to power the ship with speed and range determining the amount of battery required. Currently batteries are not at sufficiently low cost or energy density to be considered for applications other than short routes at modest speeds. A four-fold increase in energy density and accepted vessels speed reductions from 16-20 knots to 6-10 knots would make battery powered cargo vessels more attractive. For the latter high power recharging facilities or battery swap systems could be developed.

The main disadvantages of all electric drives which increases with more electric technology include a higher initial cost when compared to propulsion systems based on internal combustion engines, increased energy conversion loss from fuel to propulsion, and a larger system volume due to the large number of component parts, and the issue of energy density in vessels with batteries. Electric propulsion systems are often used on ships such as icebreakers or oceanographic research vessels that take advantage of the aforementioned operational benefits, or large passenger cruise ships and others that emphasize cost and silent operation. More recently these propulsion system types have been used in hybrid form for offshore platform support vessels (including wind farms) and battery ferries over short distances.

Presently, in 2016, the relative cost of electrification compared to fuel oil is the principal barrier to the development and deployment of innovative electric propulsion. Oil prices are at all time low, so that efforts to improve fuel efficiency and increase electrification are driven more by regulation and public intervention rather than cost.

Batteries remain expensive and to be competitive as a fully electric power source for 48 hour sailing of a typical short sea vessel the cost per KWh would need to drop significantly. Also the power density would need to increase. Such an objective is not impossible considering the increase in battery performance achieved over the past ten years with automotive and consumer electronics being key drivers.

Adequate charging infrastructure is another barrier. Electrified vessels would required very high peak charging currents to ensure an adequate turn around time and this places very high demands on the local grid. As a result the initial deployments of fully electric ferries have required on sure storage capacity so as to smooth the high peak demand and enable a faster turn around. These issue will be event more significant with larger ships with higher battery capacities.

Safety of battery systems must be assured in terms of heating, fire and risk of explosion.

For electric fuel cell technology the challenge is to move high power systems from the lab to become competitive reliable technologies within a marine environment. Regulatory approval is also required. However the systems are inherently less complex than a mechanical engine and should be able to achieve higher levels of reliability.

3.2.3. Aeronautics

Challenges are ahead for the development of leading edge technology on electric propulsion for large commercial aircrafts, however to pave the way for the electric integration, the development at component level technology is required according to key principles: inexpensive sub-scale technology development to demonstrate (ground testing, validation, flight testing) this capability for light aircrafts under specified operational conditions (speed, range, payload; ultra-high efficiency; low carbon emission; low operating costs..). Design of new wing system with high lift/low drag and integration of propellers; apply new technologies on energy storage and supra conduction, development of flight control according to flight envelope and improve the reliability of electric motors. Dual use system concept for hybrid electric under solid oxide fuel cell power system could catalyze the full electric propulsion deployment. In the future, hydrogen could also join electricity as an important energy carrier. Moreover, the lack of infrastructures at airports need to be addressed while certification, safety, assurance should be part of the deployment equation.

Barriers and gaps are also present domains ranging beyond technology, e.g. in management and competences:

Regarding management, standardisation is an issue. Currently there is no real approach on standards, however, to make the supply chain efficient, it will be necessary to develop specific standards even concerning the definition of components (e.g. is an electric motor considered as a propulsion engine?). Regulations and certifications must be adapted to costs/ taxes/prices handling (for instance for taxes to consider a CBA including all factors).

In terms of competences, it should be considered that the integration of all components requires a systemic approach of the aircraft by all engineers and technicians working in this domain. However such an approach and related methodology are not often part of the courses delivered to students, which hinder their ability to have a holistic view.

At short term, the evolution towards electrification of aeronautic transport also require training for many of the workers involved in this domain and the acquisition of specific certifications to handle electric equipment.

3.2.4. Rail Transport

On main line, railway electrification has slowed down due to the lack of a business case on low-density lines. On the other hand, there is not yet affordable and proven alternative to diesel propulsion for rolling stock so many regional trains are still using that propulsion.

A significant proportion of international freight locomotives also operate on diesel engines, as it has no interoperability issue. However, the tractive effort of electric locomotives is much higher so the market trend is in favor of electric locomotives.

Improved energy-efficient solutions and new vehicle concepts for non-electrified railway lines are being developed. For example, manufacturers of rail vehicles are experimenting emission-free trains equipped with fuel cell drive, as, one day, hydrogen might become competitive compared to catenary electrification. Hybrid diesel-electric locomotives are able to operate in emission-free mode as well and some dual mode (electric and diesel) locomotives are also under development.

In parallel, the European rail supply industry has declared energy efficiency as one of the key topics to be addressed by the Shift2Rail Joint Undertaking - a major Public Private Partnership of €920 Million for the period 2014-2020 which aims at increasing the attractiveness and competitiveness of rail transport. The support to rail research and innovation (Shift2Rail, Horizon 2020 and beyond) is vital to ensure that energy efficient innovations can be deployed swiftly across the rail system. The objective of the next generation of Very High Speed trains (starting operations in the 20s) is an increase of 20-30% of energy efficiency.

In urban area, there is no alternative to electrification and no significant gap. The challenge is the optimization of the energy management of the system.

3.3. Competitiveness of the EU industry

3.3.1. Road transport

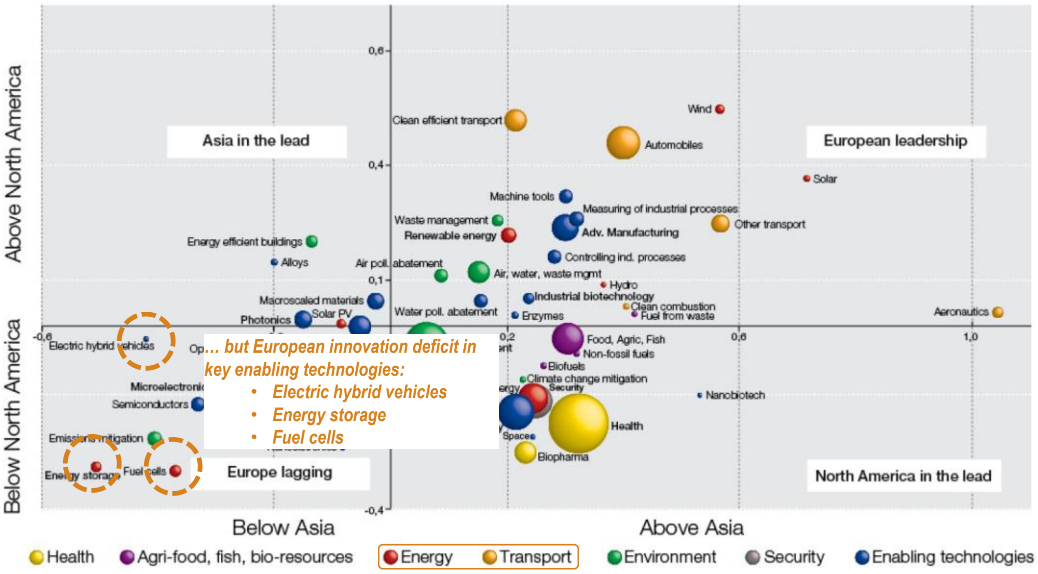

***Fig. 4:** EU innovation gap in key enabling technologies for hybrid-electric vehicles*

In a working paper related to the Horizon 2020 EC FP for Research and Innovation[77] the EC has illustrated technological leadership and innovation capability using the global share of patents as a metric. The chart in Fig. 4 shows the EU innovation gap in key enabling technologies for future hybrid-electric vehicles. It can be observed European companies presently enjoy a position of leadership with respect to

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[77] EC, 2011.

automotive (and aeronautics) related patents with North America. However, this leadership is at risk as the transportation enters the era of hybrid-electric mobility. As (both) terrestrial (and aeronautical) transport industries undergo a transformation towards hybrid-electric and universally-electric vehicles, the relevant know-how in “Enabling” technologies, shown in blue in Fig. 5, and in “Energy” technologies, shown in red, need to be aggressively developed, or acquired through co-operations.

3.3.2. Waterborne transport

European industry is world leaders in electric propulsion of ships, but the rest of the world is catching up with this technology especially USA and Japan. European companies include ABB, GE Marine, Rolls Royce, Siemens, Alstom and many others.

Additionally Europe is innovative in developing new concepts such as battery ships and European governmental organisations have been encouraging to develop new concepts from solar powered boats to battery powered ferries.

Whilst electric propulsion technologies are well developed in electric motors, podded drives, power electronics and electric auxiliaries there is a substantial gap in the development of battery technologies per se with USA and Asia dominating the development of new electro-chemical batteries and other forms of ESS e.g. flywheels, SMES, etc.

Developing skills in engineers in scientists and encouraging companies to invest in developing electro-chemistry and ESS generally should be encouraged so that they may lead the technology revolution in electrification.

3.3.3. Aeronautics

The United States is taking bold steps in order to develop alternatives to aircraft systems design and integration that will have far reaching effects in reducing the anthropogenic impact to the environment. In NASA N+3, a fuel burn reduction of 70% compared to the Boeing 737-800 with CFM56-7B engines was originally required. The updated NASA N+3 goal required a 60% fuel burn reduction by the YEIS 2025. There are indications that continuous improvements of conventional technologies may not be sufficient to fulfil such an aggressive requirement. As analysed within the SELECT Project contracted by Northrop Grumman for NASA, the original N+3 fuel burn goal could not be achieved assuming evolutionary improvements. One envisaged path is the investigation of integrated energy-power system configurations. The SUGAR Project conducted by Boeing under contract with NASA has shown that the integration of a hybrid battery-Joule/Brayton cycle PPS might permit a dramatic reduction in mission fuel burn for short-range applications. This approach and other technologies are further elaborated in the NASA N+4 task.[78]

3.3.4. Rail transport

With absolute sales of €47 billion, the European rail supply industry still accounts today for 46% of the market for rail products in the whole world. However, competition with the Asian companies is increasing.

Electrification-related markets cover: On the infrastructure side electrification comprises products and the engineering and installation of catenary, third-rail and traction power supply systems. On the rolling stock side: the supply of electrically-powered trains, their modernization with new traction systems, and their maintenance.

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[78] Bradley and Droney, 2012

Reliable market data is unfortunately not available for market segments related to modernization and maintenance, in particular due to the lack of market accessibility faced by European suppliers in various countries.

Data from the UNIFE World Rail Market Study 2014 indicates that within a €30bn yearly market for infrastructure, the accessible market to European suppliers represents €20bn and out of this the electrification market represents a volume of €4.5bn per year. Regarding main line, the market is focused on Europe, Asia Pacific and the CIS countries: networks in the Americas, Middle-East and Africa are so far rarely electrified. It is a very fragmented market and as of today there is no available figure indicating the market share of European suppliers – nevertheless they hold a dominant position.

On the rolling stock side, the total yearly market volume stands at €47.9bn, out of which €40bn is accessible to European suppliers. Within the total market, trains with electric traction (from trams to Very High Speed) account for a market of about €32bn per year, while diesel-powered locomotives and trains represent a market of €4.9bn per year. The remaining market accounts for freight wagon and coaches, which do not have their own traction systems. There again, European suppliers still hold a strong market position.

European stakeholders (suppliers, infrastructure managers and operators) are investing heavily in improving the rail system's energy efficiency and energy management. That requires innovation at all levels, from improved design of traditional electrification systems, use of lightweight materials, to a better brake energy recovery, storage and usage, to drivers' training.

4. Strategic Implementation Plan

Topics to be discussed:

- *Which are the milestones that will allow the realisation of transport electrification targets? (E.g. batteries efficiencies, number and features of recharging points?); gaps and objectives for each stage of the research and innovation chain?*
- *Where does Europe stand in this field internationally—strengths/weaknesses?*
- *Which regulatory legal liability/international trade issues need to be addressed to enable/promote the deployment of electrified transport?*
- *What are the current main barriers holding back uptake/deployment?*
- *Which are the requirements for large scale deployment of electrified transport solutions?*
- *Are standards needed to facilitate the uptake of innovation?*
- *Which are the other sectors that could benefit from/contribute to electrified transport and ways to interact? (this includes highlighting links with other relevant initiatives; eg. SET-Plan initiatives, Sustainable Transport Forum, Intelligent Transport System, Gear 2030 etc).*
- *Which are the expected impacts of socio-economic aspects (eg demographics etc).*
- *Which areas require further studies?*
- *Identification of the timeframe and KPIs.*

While in chapter 2 the policy targets and objectives regarding electric mobility were described “top down”, the baseline and state of the art were reviewed “bottom up” in chapter 3. Now, a strategic implementation plan for electric mobility leading from the state of the art to the objectives is presented. It contains a roadmap with milestones, actions and responsibilities for each of the three transport modes considered. The international context is covered by means of a SWOT analysis which points out Europe’s strengths and opportunities, and identifies opportunities and threats.

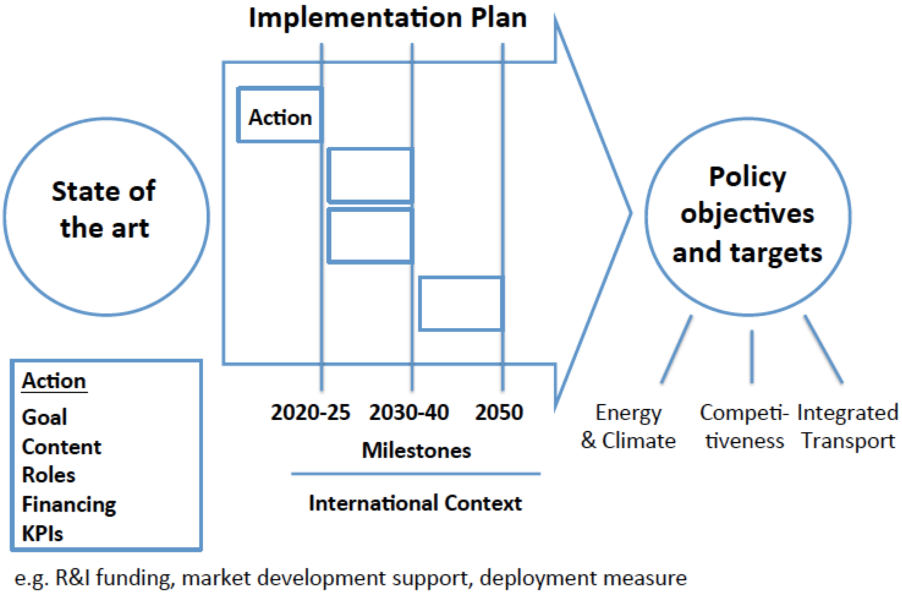

Fig. 5: *Approach for the strategic implementation plan based on roadmaps*

4.1. Roadmaps

The strategic implementation plan for electrification is focused on selected scenarios, which promise high leverage effects as they overcome initial hurdles for demand. The development of these scenarios is described by means of milestones until 2050 indicating what progress in research and development, product development and operating models and deployment are needed in order to achieve these milestones. Furthermore, specific actions supporting the milestones are proposed. The content and the timing of the milestones and the actions are mode-specific.

4.1.1. Road Transport

	Milestone 2020	**Milestone 2030**	**Milestone 2050**
Deployment	5-10% market share for electric passenger cars, even higher in the urban environment (bikes, buses, vans)	60% market share for electric vehicles, half of those battery-electric, and 100% in the small vehicle segment	100% CO_2-free road transport, mostly electric and minor portion of vehicles powered by other fuels
Product Development and Operating Models	Business models based on total-cost-of-ownership considerations, e.g. fleet applications, car sharing, delivery vans	Operating models supported by availability of energy storage systems and infrastructures meeting user demand for clean, economic and convenient mobility	Different world of operation with electric vehicles seamlessly integrated into the transport and mobility systems
R&I	*(Refer to initiatives listed in the roadmap of ERTRAC / EPoSS Smart Grids)*	Synergies between various technology fields (electrification, automation, connectivity, energy efficiency, light weight, charging..)	Big data, artificial intelligence, quantum computing

Table 3: *Milestones of the Implementation Plan for Electrification in Road Transport*

Strengths:	**Weaknesses:**
- Leadership in vehicle and electric and fuel cell components / architecture engineering - Leading global players in LDV and HDV industries and their supply chains - Knowhow in science, engineering, system integration of batteries and fuels	- Less stringent in CO_2-emissions regulations - Divergence of views in governments and industry about long term powertrain choices - Resistance of customers to change - Electric vehicle portfolio, ranges, prices

cells - High reliability of the electricity grid - Highly developed public transport services - Fast-growing share of renewable energy sources	and marketing - Limited automotive battery and fuel cells technologies manufacturing - Individualized transport behavior - Long established urban centers with existing street infrastructure
Opportunities: - Desire for higher quality of life in EU cities from better air quality and less noise - Savings on fuel could keep money in the EU - Electrification is a key enabler for a low carbon energy future - Electric mobility sector is still evolving so EU companies can still play a strong part in shaping it	**Threats:** - Loss of global competitiveness of EU automobile industry - Imports from Asia enter EU value chains for electric mobility - Deployment of electric mobility in EU harder than in more systemically oriented countries, e.g. Japan, Korea, and China

Table 4: *SWOT Analysis of Europe's international position in electric* road transport

Proposed actions:

- **Promote a 400kms and more electric passenger car offer**
  Goal: Meet EU customer expectations
  Content: R&I program on EV concepts / components (particularly batteries) allowing economies of scale and related business models (e.g. on battery ownership)
  Responsible: EC
  Timing: Short Term
  Financing: 70-100% according to Horizon 2020 rules
  KPI: range
- **Development of small and light smart electric vehicles**
  Goal: Introduction and acceptance of right-sized and energy efficient EVs
  Content: R&I program on EV concepts / components enabling radical reduction of energy consumption, e.g. through fully active safety in connected and automated EVs; to be supported by new mobility, car sharing service and business models and to complemented by appropriate regulation and financing of infrastructure
  Responsible: EC
  Timing: Short Term
  Financing: 70-100% according to Horizon 2020 rules
  KPI: >50% weight reduction at same or better passenger and road safety
- **Progress and demonstration in urban bus electrification**
  Goal: No compromise electric bus system
  Content: R&I program on energy storage systems, thermal comfort as well as low energy air-conditioning
  Responsible: EC
  Timing: Short Term
  Financing: 70-100% according to Horizon 2020 rules
  KPI: Carry all energy for a one day trip on the bus

- **Public and commercial procurement of EVs**
  Goal: Kick-off the market and create awareness of electric vehicles' maturity and stabilize the residual value of electric vehicles
  Content: Adaptation of the Directive 2009/33/EC of the European Parliament and the Council of 23 April 2009 on the promotion of clean and energy-efficient road transport vehicles in favour of alternatively fuelled (including electric and fuel cell technologies) for use[79], and establishment of incentives for the electrification of taxis and rental cars.
  Responsible: EC
  Timing: Short Term
  Financing: n/a
  KPI: Above average share of electric vehicles in public and private fleets

- **Certification of electric vehicles performance**
  Goal: Better comparability of EV types, also for commercial applications, by providing reliable information on parameters that are critical from a customer perspective, e.g. range, battery life, impact of thermal conditions as well as life cycle comparison of WTT and TTW energy consumption
  Content: Develop test / drive cycle, implement independent testing facility, educate customers and prepare standardization
  Responsible: EC
  Timing: Short Term
  Financing: Depending on kind of action
  KPI: Customer trust

- **Develop electro-chemical systems for future high-density EV batteries**
  Goal: Gather unique knowhow for potential European leadership in battery technology production.
  Content: R&I programme on advanced electrochemical systems
  Responsibility: EC
  Timing: Mid to Long Term
  Financing: 70-100% according to Horizon 2020 rules
  KPI: Energy density >300 Wh/kg at cell level

- **Support local production of batteries, components and electric vehicles**
  Goal: Defend jobs in the EU
  Content: Awareness action for smart specialization and governance in anticipation of value chain disruptions due to shift from conventional to electrified vehicles, e.g. attracting foreign investment, diversifying product portfolios, creating regional clusters, stimulating creativity and fostering innovation.
  Responsible: EC and governments of Member States affecting by changing supply chains
  Timing: Short Term
  Financing: 5-10 Mio. Euro per action (50:50 EU/MS)
  KPI: Shift of company activities from conventional to electric vehicle technologies

- **Demonstration of electrified road systems for HDVs**
  Goal: Compensate limited range of battery-electric high duty vehicles through charging en-route
  Content: Cost-benefit assessment and cross boarder demonstration and piloting of

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[79] The website http://www.cleanvehicle.eu/ that was created to support the original directive with a database is currently unavailable; the website http://www.clean-fleets.eu contains only general information and an inconvenient Life-Cycle-Cost calculator based on a ECSEL sheet

electrified road systems based on wired or wireless charging or battery swapping.
Responsible: EC and Member States
Timing: Mid to Longer Term
Financing: about 1 to 2 Mio. Euro per km
KPI: Sustainability of use case after demonstration

4.1.2. Waterborne Transport

For the milestones of the implementation plan on waterborne transport, a distinction is made for EU general shipping, international shipping, as well as small vessels.

	Milestone 2025	**Milestone 2035**	**Milestone 2050**
EU General Waterborne transport	Adoption of cold-ironing in ports. Targets: The majority of shipping equipped with standard connecters to facilitate cold ironing. All EU trading ports to offer electric plug in for ships allowing the ships engines to be switched off. Cost structures to reflect this. Hybrid electric systems are increasingly deployed, including on inland waterways and have significantly larger battery capacity in comparison to 2016. Fully electric vessels deployed for urban waterborne transport. SOFC technology can reliably use LNG fuel to provide continuous	Expansion of ESS ships in EU territorial waters Targets: Ships operate using ESS technologies on an increasing number of routes. Vessel transiting between ports between 20-30 miles distant should be able to operate on ESS alone. Ports to be able to offer recharging facilities for ESS of 100 MWh during a normal turn-around (3-4 hours) Fuel cell technology has been marinised and demonstrated to reliably provide 100% propulsion power on a short sea vessel.	ESS ships using either batteries or fuel cells are the majority of those operating in EU territorial waters Targets: Vessel transiting with sailing times of 48 hours (typ 500 miles) should be able to operate on ESS alone. Ports to be able to offer recharging facilities for ESS of 400 MWh during a normal turn-around (4-8 hours). Zero emission, 100% hydrogen fuel cell ship operating commercially short sea services within European waters.

	10MW electric power with a fuel efficiency at least 10% greater than a marine diesel engine.		
International Shipping	Adoption of cold-ironing in ports. Targets: All EU trading ports to offer electric plug in for ships when docked so as to supply electricity directly to the ship allowing ships engines to be switched off. Increasingly ships transiting European ports are equipped to benefit from shore side power.	All ships arriving from outside EU should operate on ESS when entering and leaving port (e.g. 2 miles off) Targets: Intercontinental ships can use ESS to reduce emissions when entering and leaving port and use cold ironing when alongside. Fuel cell technology has been demonstrated at a scale appropriate for intercontinental shipping and cruise liners.	All ships arriving from outside EU should operate on ESS when entering a EU emissions free zones Targets: Intercontinental ships can use ESS to reduce emissions when entering and leaving an EU emissions free zones (to be defined) Marine diesel engines are fitted within the minority of new build shipping. Fuel cells are the technology of choice. Research is concentrated on the next step towards fully hydrogen propulsion.
Small Vessels	Quantify emissions from small boats across the EU and globally. Targets: Prioritise actions required for small boats to meet the emission standards applicable to non road mobile machinery. Increasing sales of	All small boats, within Europe to meet the emission standards applicable to inland vessels within the non road mobile machinery regulations. Targets: Electric or fuel cell propulsion represents at least 25% of the small	Elimination of diesel engines in all boats. European emission standards for small boats are increasingly adopted globally. Targets: Small boats meeting European emissions are more than 50% of the global fleet.

	electrically propelled boats.	boat market.	

Table 5: *Milestones of the Implementation Plan for Electrification in Waterborne Transport*

Strengths:	**Weaknesses:**
- EU Industry leads in marine equipment, passenger ship building and marine electrical technologies - EU public tuned to and sympathetic to environmental issues including maritime - EU citizens have an expectation that EU will improve the environmental performance of shipping. - EU industry is good at green technology and benefits from advances in environmental standards.	- EU Battery R&D is weak - ESS technologies are not being researched sufficiently well - Due to higher labour and production costs, European ship building is not focused on the large volumes of merchant ships which represent the majority of the world fleet. - Oil prices are low and this is a disincentive to invest in new technology
Opportunities:	**Threats:**
- General trend towards reducing pollution - EEDI provides credit for use of innovative technologies. - Important patents in electro-tech rest in the EU - Large EU fleet (nearly 8000 vessels and 40% of the world) and a major trading area - Large number of ferries many on short routes - Cruise ships are early technology adopters and these are almost all European. - Increased take up of LNG facilitates fuel cell applications. - Fuel cell for power applications now at levels suitable for marine propulsion. - Fast development of battery technology being driven by the automotive sector.	- Oil prices remain low - IPR is lost outside of Europe - Associated employment is outside of Europe - Conservative industry – likely to resist change, IMO do not support measures. - Low political priority within Europe. - Class and safety approval is too heavy. - No first adopter to take up radically new technology commercially. - Technology is not transferable from automotive to marine. - FC's cannot be made robust and reliable.

Table 6: *SWOT Analysis of Europe's international position in electric shipping*

Very efficient battery storage with high weight and volumetric densities at acceptable cost is one essential technology for electrification in waterborne transport, the other being the ability to recharge. Development of fuel cells of adequate power that are marinised for reliable operation is another. Also, education and training is the essential human ingredient – both to develop skills and to appreciate awareness. Finally, shipping industry is low margin – there are not excessive amounts of cash to for investment.

Proposed actions:

- **Public Awareness**:
  Goal: Ensure EU peoples appreciate: our dependence on shipping, the environmental benefits of moving to more electric ships, the health benefits of moving to more electric ships, benefits of more electric ships on climate change
- **New Materials**:
  Content: Fire protection methods with respect to some ESS technologies e.g. Lithium, light weight higher strength materials, improved electro-chemistry knowledge: Poisoning of batteries, improved energy densities
- **Innovative Financing Tools**:
  Content: Collective investment (private, public, community) to fund change for good, Infrastructure impact such a grid – spread costs across EU
- **Education and Training**
  Content: Develop new skills to feed into new industries such as in battery technologies, other ESS technologies, Appreciation of EU strategists of ‘moving technology’ and ‘operational changes’ together.
- **Research and Development**
  Content: More basic research in materials (EU funding most reflect basic research and applied research needs)
- **New Business Models**
  Content: Battery roll-on/roll-off container technologies so as to battery swap when in port e.g. battery leasing companies.

4.1.3. Aeronautics

For the milestones of the implementation plan on aeronautics, a distinction is made for comemrcial aviation (50-70 seats), commercial aviation (>70 seats), personal aviation and the airport environment.

	Milestone 2025	**Milestone 2035**	**Milestone 2055+**
Commercial Aviation (50-70 seats) and equivalent cargo < 7 tons)	Electrification of auxiliary power unit (APU) and of all non propulsive systems Targets 2020: C[80] 350Wh/kg G 5kW/kg Normal conducting; Emergence of adaptive structure (flow control); Decentralised architecture;	At least 30% Hybridisation for power At least 10% hybridisation for energy Targets 2028: C 750Wh/kg G 10kW/kg Normal conducting Implementation of distribution propulsion and /or boundary layer	Full electric aircrafts, operational modes for very short haul At least 50% hybridisation for power At least 20% for energy Targets 2048: C 1300Wh/kg G 20kW/kg Full high temperature super conducting (HTS)

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[80] G is at cell level

	Standards for e-planes	injection technologies	Fully operating distribution propulsion and /or boundary layer injection technologies and adapted structures
Commercial Aviation (>70 seats and equivalent cargo >7 tons)	Targets: Engagement on low TRL for HTS, Demo HTS	Electrification of auxiliary power unit (APU) and of all non propulsive systems Targets: HTS at TRL 6, components using HTS	At least 30% Hybridisation for power At least 10% hybridisation for stored energy Targets 2045: Beginning of HTS in retrofit
Personal Aviation	More than 50% hybridisation; First flights short range	Full electric aircrafts Medium range flights (200kms)	Full electric flights more than 500kms
Drones	More than 50% hybridisation;	Full electric aircrafts	
Airport Environment	Electrification of services Targets: All support vehicles electrified; Airports equipped for charging auxiliaries	Mild electrification Introduction of induction charging for aircrafts Targets: All airports: Infrastructure available for charging small planes (<70 seats)	Full electrification Wide scale induction charging Targets: All airports: Infrastructure available for charging all planes

Table 7: *Milestones of the Implementation Plan for Electrification in Aeronautics*

Strengths: - Competencies in R&D, exploitation in aviation, batteries and energy storage management - Trans domains technology leads to synergies	**Weaknesses:** - Low TRL at the moment, especially in HTS - Lack of interdisciplinary competences (system engineering) - Lack of standards and regulations for electric aviation
Opportunities: - General objectives of pollution reduction, CO_2, NO_x, noise	**Threats:** - Competition, mainly US on avionics and batteries

- New airports more away from the cities (new market for small e-aircraft landing in or near the cities)	- Real industrial agility among supply chain components

Table 8: *SWOT Analysis of Europe's international position in electric* aeronautics

Very efficient energy storage and management is the basis for electrification of aircraft. Electrification has to be taken into account in the different levels of governance (EU standards to local airports).

Proposed actions:

- **Energy Storage Systems**
  Goal: to reach at least 750 Wh/kg for cells
  Content: Continuous effort on R&D, industrialisation and manufacturing processes on batteries and hybrid energy storage
  Responsible: Research institutes and storage manufacturers
  Timing: mid term (20 years)
  Financing: EC and national governments
  KPI: 750Wh/kg
- **High Temperature Superconductors**
  Goal: To achieve maturity compatible with product development launch
  Content: Continuous R&D effort on HTS, including machines, cooling, wiring
  Responsible: Research institutes and electrical suppliers
  Timing: mid term
  Financing: 50%EC and 50% industry (clean sky)
  KPI: TRL 6
- **Electric Aircraft Design**
  Goal: To achieve ultra low emission for personal aviation and drones
  Content: Introduction of new design methodologies to take into account the change of fuel (e.g. replacements of tanks in wings)
  Responsible: Industry, OEMs with close support of research institutes
  Timing: Short term
  Financing: Industry 80%
  KPI: More than 50% hybridisation
- **Airport Electrification: Support Vehicles**
  Goal: Zero emission and very low noise airports considering support vehicles
  Content: Deployment of electrified support vehicles on airports
  Responsible: Airport authorities
  Timing: Short term
  Financing: Government, managing authorities, EC
  KPIs: 80% for NO_x and 50% for CO_2 and noise compared to 2000
- **Airport Electrification: Charging Infrastructure**
  Goal: Ultra low emission and noise airports
  Content: Study and deployment of specific charging infrastructures and/or renewable energy production infrastructures
  Responsible: Airport authorities
  Timing: Mid term
  Financing: Governments, managing authorities, EC
  KPIs: Fully equipped for charging small aircrafts and hybridise larger aircrafts, and at least 60% reduction CO_2, 84% NO_x, 55% noise

- **Skills and Competences**
  Goal: To have a specialised interdisciplinary work force
  Content: Development of skills and competences in system engineering (high level education), technologies (engineers, technicians, employees: integration, design, exploitation and maintenance, etc), and security/safety aspects
  Responsible: All levels of education system
  Timing: Short term
  Financing: Governments and EC
  KPIs: Degrees at all levels of education (certificates, master courses…

- **Regulations**
  Goal: To decrease cost, and increase product development speed
  Content: Development of regulations (e.g. integration in the electrification in the airport fees/taxes…) and standards for E Planes
  Responsible: EASA and manufacturers
  Timing: Mid term
  Financing: EC and governments
  KPIs: Standards

4.1.4. Rail Transport

The White Paper identifies two segments of the transport market where it would particularly welcome a greater share for rail. These are long-distance overland freight, and medium-distance passenger travel, notably through the expansion of high-speed rail. Milestones for the coming years are illustrated in the table below in which the base line is 1990 base and the measures are calculated per passenger-km (passenger service) and ton-km (freight service).

	Milestone 2025	**Milestone 2035**	**Milestone 2055+**
Climate Change	Reduction of specific average CO2 emissions from train operation by 30%	Reduction of specific average CO2 emissions from train operation by 50% In addition, by 2030 the European railways will not exceed the total CO_2 emission level from train operations in absolute terms even with projected traffic growth	Carbon-free train operation by 2050 Including new power (fuel cells)
Energy consumption		Reduction of specific final energy consumption from train operation by 30%	Halving their specific final energy consumption from train operation by 2050

NOx and PM emission		Reduction of total exhaust emissions of NO**x** and PM**10** by 40% in absolute terms, even with projected traffic growth compared to the 2005 base year	Zero emission of nitrogen oxides (NO**x**) and particulate matter (PM**10**)
Noise and vibrations			Noise and vibrations no longer being considered a problem for the railways – meaning that noise levels are socially and economically acceptable and allow for 24-hour passenger and goods operations
R&I	See ERRAC Roadmap on the Greening of Surface Transport 2020	See ERRAC Roadmap on the Greening of Surface Transport 2030	See ERRAC Roadmap on the Greening of Surface Transport 2050

***Table 9:** Milestones of the Implementation Plan for Electrification in rail transport*

Strengths: - EU global leadership on rail research and innovation - Large electrified network - Holistic approach of the railway system innovation by researchers and industry	**Weaknesses:** - Last miles solutions - Electrification of secondary network - Limited capacities for freight - Variety of standards among EU countries - Small scale level of project cases, low ROI
Opportunities: - Great contributor to decarbonisation of transport - General objectives of pollution reduction, CO_2, NO_x, noise in cities and territories - Immediate benefit for RE utilisation - New propulsion energy	**Threats:** - Competition, with manufacturers mainly from China - Competition with other transport modes - Limited financing capacity of public investment for infrastructure - Failing to meet customer satisfaction and serve users' needs

***Table 10:** SWOT Analysis of Europe's international position in rail transport*

Proposed actions:

- **Electrification of secondary network**
  Goal: Increase the potential of utilisation of electric motorization
  Content: Implement adequate infrastructure along most utilised lines.
  Responsible: Authorities in charge of infrastructure
  Timing: Continuous action
  Financing: EC and Governments
  KPIs: tba

- **Development of new motorisation**
  Goal: Minimise pollution and nuisance impacts, improve reliability and comfort
  Content: Research and innovation on new engines and new power; transfer technologies from other domains (e.g. batteries or fuel cell) and develop specific knowledge
  Responsible: Manufacturers, research institutes
  Timing: Mid-term
  Financing: EC and industry (manufacturers, operators..)
  KPIs: tba

- **Intensify electric freight rail transportation**
  Goal: Maximize the tons/kms transported by electric rail
  Content: Several sub actions might be undertaken either on the long distance routes (e.g. specific locomotives), mid distances (e.g. proximity rail operators), short distances (specific trams for passengers/ freight mixity)
  Responsible: Manufacturers, operators local authorities
  Timing: Continuous action
  Financing: EC and stakeholders
  KPIs: tba

- **Develop intermodal hubs in cities**
  Goal: Increase the use of electricity as power for all vehicles
  Content: Develop charging stations for all vehicles (from bikes to busses) at rail stations/terminals
  Responsible: Infrastructure managers, local authorities
  Timing: Mid-term
  Financing: EC, local authorities, governments
  KPIs: tba

- **Develop light vehicles**
  Goal: Increase the electric rail modal share in small and medium size cities (passengers and freight)
  Content: Research, innovation and implementation on such vehicles
  Responsible: Manufacturers
  Timing: Mid-term
  Financing: EC, governments, local authorities and manufacturers
  KPIs: tba

- **Smart power grids for rail**
  Goal: to minimise the losses in the electric railway infrastructure
  Content: Continuous effort on R&D, industrialisation and manufacturing processes
  Responsible: Research institutes and manufacturers
  Timing: mid term

Financing: EC and national governments
KPI: tba

- **Increase energy saving**
  Goal: Minimize utilisation of fossil energy
  Content: Increase the share of renewable energy, develop the production of renewable energy in rail infrastructure, energy storage systems and optimise the utilisation of regenerated energy
  Responsible: Operators, research institutes
  Timing: Variable according to actions
  Financing: EC, governments, operators
  KPIs: tba
- **Regulations**
  Goal: Harmonise energy characteristics for rails in EU
  Contents: Develop standards
  Responsible: EC
  Timing: Mid-term
  Financing: EC
  KPIs: tba

4.2. Public and private roles

Included in description of actions under 4.1

4.3. Resources and financing

Included in description of actions under 4.1.

4.4. Potentials for transfer and synergies

Regarding electrification, transfer potentials can be expected in all considered modes. Furthermore, synergies are expected between the electrification-related and other parts of the STRIA roadmaps.

4.4.1. Transfer between modes within electrification

- Rail to road: On route charging for electrified road systems
- Road to aeronautics: EVs add to CO_2 targets for airports
- Aeronautics to road: High-temperature superconductors for power trains
- Aeronautics to waterborne: Electrification of auxiliaries (“more electric” X)
- Rail to any other mode: Electric/electronic architecture, high voltage technology
- Road to any other mode: Vehicle and power train innovations
- Between all modes: Batteries, power electronics, motors
- Between all modes: Transferable electrical engineering skills

4.4.2. Synergies of electrification with other STRIA topics

- Connectivity and automation: Electric/electronic architecture, energy efficiency, light weight design, inductive charging and parking/or driving, big data
- Smart mobility: Cost reduction/convenience of managed fleets e.g. in car sharing, and support of right sized electric vehicles by long-range alternatives
- Vehicle design and manufacturing: Light weight, distributed propulsion
- Infrastructure: Charging stations, batters swap, hydrogen stations
- Traffic Management: e-Horizon, energy recovery in decent
- Alternative fuels: Fuel cells

4.5. Conclusions and Recommendations

200 to 300 km electric range are the state of the art for electric road vehicle with today’s Li ion batteries (130 Wh/km). If there were appropriate battery manufacturing capabilities for safe, long-lasting and affordable cells in Europe, 60% of all new road vehicles (and 100% in the small vehicle segment und in buses) could be electrified within the next 10 years. If significant breakthroughs in battery cell technology lead to 3 to 5 times higher energy densities, even the electrification of long haul trucks, small aircraft and of vessels would become attractive on the mid-to-long term, and so would the electrification of vessels.

Current limits in range and affordability of batteries can be compensated on the short – to-mid term by more systemic electrification solutions, namely charging on route or battery swapping. Also, fuel cell or waste heat recovery based range extenders will probably play a more important role on the way to fully electric long-haul driving, and even more in rail, aviation and waterborne transport. Furthermore, smart mobility services and highly energy efficient vehicles such as fully connected and automated car enable more electrification, particularly if combined with systemic business models like e.g. car sharing. The basic skills are transferrable between all modes. In addition to that synergies between the modes and the other topics of STRIA can be referred too.

Therefore, electric mobility can be expected to flourish in many aspects. Europe should further strengthen its efforts to maintain a competitive leadership position in the transition from conventional to electrified powertrain and technologies and related dynamics in the value chains. Research and innovation funding should be complemented by public-private investments and smart regulation such as access rights for city centers, or procurement decisions in favour of environmental protection. This in turn implies a need for harmonization and coordination in Europe and also for actions creating awareness of e.g. battery safety issues. Moreover, participation of the EC and European stakeholders in the international information exchange, e.g. the Technology Collaboration Programme of the International of the International Energy Agency is recommended.