Chapter 1

Present and Future Role of Battery Electrical Vehicles in Private and Public Urban Transport

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Additional information is available at the end of the chapter

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1. Introduction

"Electricity is the thing. There are no whirring and grinding gears with their numerous levers to confuse. There is not that almost terrifying uncertain throb and whirr of the powerful combustion engine. There is no water circulating system to get out of order – no dangerous and evil-smelling gasoline and no noise." [1]

The OECD estimates that more than 70% of the developed world population lives in urban environments[2], which explains a larger concentration of vehicles there. In the EU-27, there were about 230 million passenger vehicles in 2007 and the new vehicle sales were nearly 16 million vehicles in that year. Notwithstanding the improvements in regulated air pollutants from road transport, the urban population remains at higher risk levels by directly suffering the impact of conventional vehicles because of their closeness to the pollutant source. On one hand urbanization means that people when travelling in their urban environment will typically travel less than 100 km a day. And on the other, that a large percentage of all transport and delivery of goods will take place in urban areas. Acceleration and deceleration frequency, traffic jams, thus energy efficiency and pollution per km are worst within urban traffic. Many business cases exist for urban electrified road transport because these offer a lower Total Cost of Ownership (TCO) than conventional means already today. The above

1 Thomas Alva Edison (February 11, 1847 – October 18, 1931)

2 See e.g., p. 17 in " Trends in Urbanisation and Urban Policies in OECD Countries: What Lessons for China?", OECD and CDRF, http://www.oecd.org/urban/roundtable/45159707.pdf

reasons make the urban area the cradle where the electrification of road transport can deploy its full potential of positive impact, both environmentally and energetically.

There are several bottlenecks on the take-up by economic operators and the public at large of this technology, mainly: price of purchasing of an electric vehicle (EV), its limited range (range anxiety) and long charging time. Most of them are related to the present available battery technology. Improved batteries, maybe together with super-capacitors (so called hybrid power-packs) will most likely represent the core of the developments. The integration of the electrically recharging vehicle into the smart electric grid of the future, which calls for automatic communication technologies, is another frontline of research. Advances in these areas will probably reduce the obstacles for battery powered EVs in near future.

In the last 30 years the batteries' energy density (Wh/kg) has increased by a factor of four in three very well distinctive development waves: i.e. the development in 1995 of Ni-Cd batteries (with about 70 Wh/kg), that of Ni-MH in 2000 (~100 Wh/kg) and the third wave with the development of Li-ion batteries in 2005 leading to currently about 200 Wh/kg. With the present battery's energy density a pure battery electric vehicle (BEV) can drive ca. 150 km with one charge, already opening the door for a substantial portion of series-produced EV models notably in urban environments. This already achievable all-electric range is larger than most of the daily average distance of city dwellers (in the USA about 90% of automobiles travel about 110 km daily and in Europe this distance is even smaller, as GPS-coupled monitoring analyses of ten-thousands of urban based cars have meanwhile proven also experimentally).

In any introduction of a new technology the role of stakeholders (public, commercial and private) is very important and their needs have to be understood and addressed. Because of the role of EVs in reducing the level of ambient pollution in urban conglomerations, this chapter will also look to different efforts and programs that some stakeholders as for instance different municipalities and regional and national governments, are setting up in order to actively support and stimulate the introduction of EVs.

Finally, the chapter will address how the above developments will support the introduction of EVs in the urban environment; it will also describe how reduced TCO will translate into more business cases and how this will impinge in a more general electrification of public transport with the consequent improvement of urban ambient air quality, noise levels, etc.

2. City vehicles

There is a very noticeable development effort on small city vehicles indicating that for the automobile industry (OEMs) the urban area represents the main niche in order to roll out the electrification of road transport. This effort is a globalised one with examples not only in Europe, but also in the US, China, Japan and India. In many cases demonstration is implemented by consortia of OEMs, or OEMs together with a university, or in public-private partnership.

Table 1 gives some examples of these cars besides the already launched ones in the market like, e.g. in Europe, the Smart for two Electric Drive, i-Miev, Peugeot-ION, Citroen C-Zero, Think City, etc..

We can conclude that OEM's are focusing on specific market segments within cities:

- The Smart for two for instance is part of a Car sharing project in Amsterdam;
- The HIRIKO will be used in Bilbao (Spain) to study the interest of the public for 'mobility on demand';
- The Renault Twizy is focused on very low purchase price and young customers;
- The VW Nils and the Audi concept are focused on individual transport.

It is noteworthy that for the city cars the OEMs are in particular concentrating in pure electric vehicles (BEV). Also hybridization of small cars is in development, and some technologies involved in hybridizing down-sized conventional engines, like capacitor banks of a few hundred Farad of capacity, might be cross-fertilizing the advent of advanced technologies also for pure electric solutions.

In the appendix further information on market share, number of BEVs per country and other data is presented.

3. Rechargeable Energy Storage Systems (RESS) for vehicles

Rechargeable Energy Storage Systems (RESS) in vehicles include a variety of technologies, each one providing different sizes and different levels of maturity/development. Among these technologies we can name: Electrochemical Storage (Batteries, capacitors and notably super capacitors), Fuel-cell (often containing also a buffer battery) electricity provision with e.g., a hydrogen or *on-board reformer* fuel storage system, and (more in a niche situation) Compressed Air Energy Storage (CAES), and Flywheels. It is noteworthy to indicate that whatever is the chosen RESS for *electrified* vehicles it will be a key enabling technology for the penetration of this class of vehicles, because it influences in a decisive way their weight, energy efficiency, maintenance complexity and thus longevity and usability – and thus generally their acceptance-level achievable in the market.

In figure 1 some RESS are presented. From this figure the benefits of a hybrid power pack can be seen. These packs combine a high power density of fuel cells and batteries with a high energy density of (super) capacitors. Also the flywheels can be located in this figure.

This section intends to give an overview on battery, super-capacitors and hybrid power-pack (batteries plus super capacitors) developments that in a near future will probably reduce the obstacles, questions and doubts that potential users might have, and thus helping to bridge the gap between early adopters of the technology and the public at large.

Model	Characteristics	View
Peugeot BB	Concept car, 4 seats, range of 120 km	
VW E-Up	4 seats and a range of 130 km (announced to come on the market in 2013)	
Toyota iQ FT-EV	Range 150 km (it will be in 2012 on the market)	
Gordon Murray T-27	Range up to 160 km, weight under 680 kg, now entering the investment phase	
Kia Pop	Range of 160 km, still a concept car	
HIRIKO	New concept of urban mobility, developed by MIT, it will be introduced in Bilbao in 2013	
VW Nils	One seater, light weight city car. It is a concept, for 2020	
Audi City Car	It is still a concept car	
Mahindra REVAi	Range of 80 km and a lead battery. It is a cheap car, coming soon to the EU market.	
Visio.M city EV (BMW & Daimler)	The aim is to develop a car with low price and low weight	
Renault Twizy	A low priced and low weight (500kg) city car. The battery is leased. The range is 100 km. The car is on the market since 2012.	

Table 1. Some examples of small city vehicles either in the process of being launched into the market or at concept stage

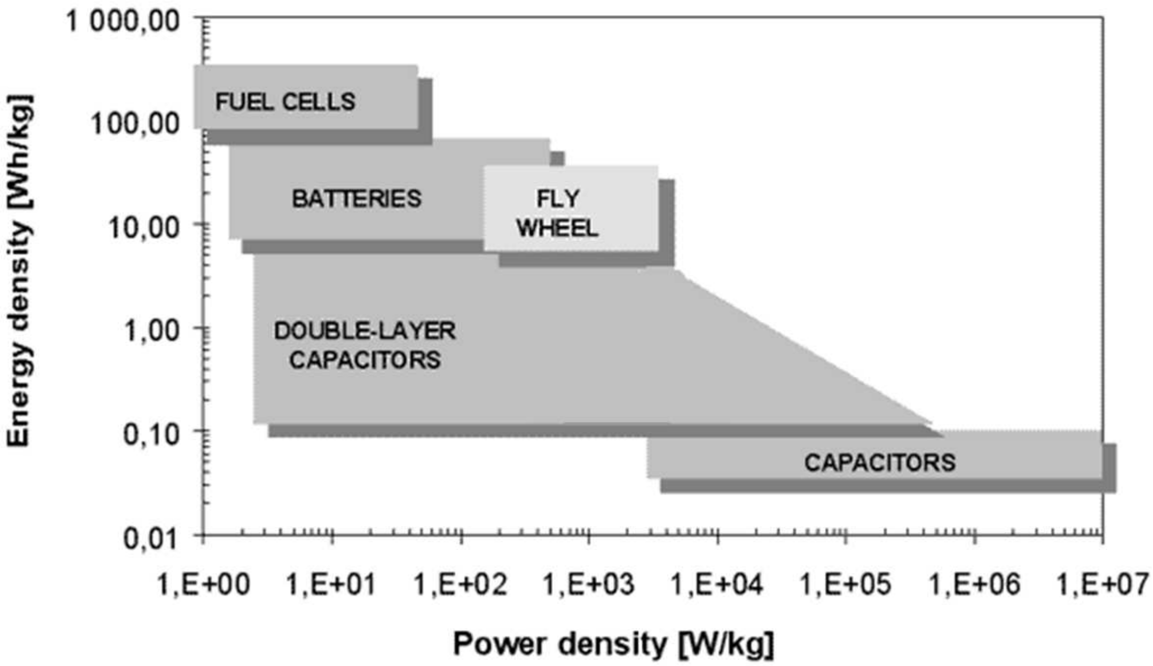

Figure 1. Energy density versus power density of different systems[3]

3.1. Batteries

There are many possible chemistries (battery technologies) that are considered as possible viable options to be used in an electrified vehicle (either BEV or HEV). They range from the very well-established, but comparatively heavy lead-acid batteries to others still in its research stage as Li-air, Al-air or Fe-air batteries passing through Li-ion batteries that represent currently the most used battery-type in commercial BEV.

It is not the intention of this chapter to give an exhaustive insight[4] on the chemistries of each of these batteries but rather to indicate the advantages and drawbacks as well as the possible gains in the future of new battery types still at the laboratory stage in terms of cost and specific energy/power, as these will strongly influence the viability of electrified vehicles.

Figure 2 shows a possible battery technology development roadmap indicating some characteristics of the here discussed batteries technologies.

3 http://www.mpoweruk.com/alternatives.htm

4 For a more exhaustive review of storage technologies see e.g.,: "Outlook of Energy Storage Technologies" (IP/A/ITRE/FWC/2006-087/Lot 4/C1/SC2) and "White Paper. Battery Energy Storage Solutions for Electro-mobility: An Analysis of Battery Systems and their Applications in Micro, Mild, Full, Plug-in HEVs and EVs" EUROBAT Automotive Battery Committee Report.

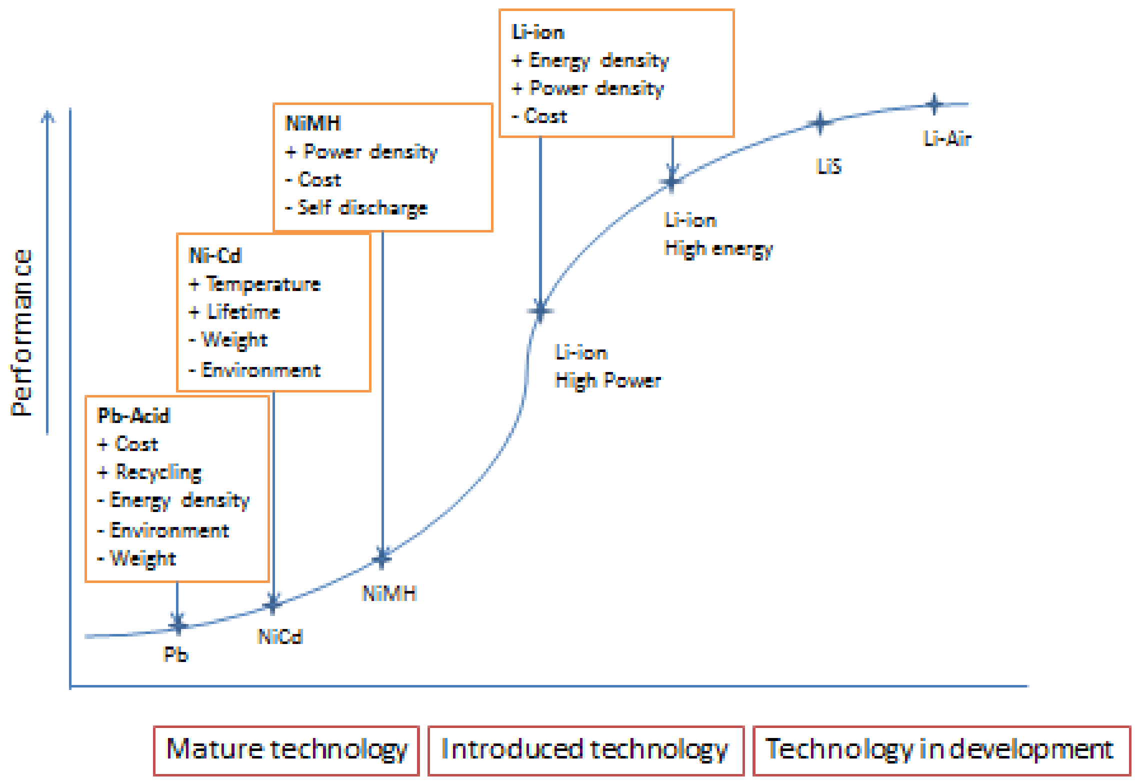

Figure 2. Battery technologies roadmap and characteristics

McKinsey argued in a paper that there are three important factors that could accelerate the development of electric vehicles. These are the manufacturing at (large industrial) scale, lower component prices, and boosting of battery capacity [1].

Table 2 shows some target performance parameters stated for batteries in electrified vehicles for the years 2015, 2020 and 2030 in a Technology Roadmap published by the IEA in 2009 [2].

	Energy density (Wh/kg)	Power density (W/kg)	Costs (Euro/kWh)
2010	100	1000 - 1500	1000 - 2000
2015	150	1000 - 1500	250 - 300
2020	200 - 250	1000 – 1500	150 - 200
2030	500	1000 - 1500	100

Table 2. Expectations on battery performances [2]

Table 2 indicates that the energy density is expected to improve by a factor 5 and that the costs are expected to be reduced by a factor 10 within the next 20 years. These two parameters (energy density and costs) are seen to be the limiting factors of today's BEV. By increasing the energy density the range an electric vehicle can drive will be extended substantially leading to fewer stops for recharging. This should boost EV usability especially in typical urban use. Decreasing the costs of the battery will lead to substantially cheaper electric vehicles, enabling more purchases by the public and fleet investors, due to more sound business cases for commercial use of BEVs.

The cycle-stability is an equally important parameter in applied battery chemistry. The attractiveness for automotive applications is not only dependent on the costs, the power density and the energy density of a battery, but also on the number of battery cycles that can be guaranteed.

3.1.1. Lead-acid batteries

The use of lead-acid batteries in electrified vehicles is mainly in industrial vehicles (e.g. forklifts, which must be heavy) because although at very affordable cost levels (100 – 150 $/kWh), the weight of lead representing about 60% of the weight of the battery translates into a low specific energy (30-50 Wh/kg), making this technology not competitive for most of electric road transport vehicles (even HEVs). It also suffers from a limited lifetime (3 – 5 years). It remains to be seen if lead-acid battery companies can substantially enter the market of micro-hybrid cars in view of small intermediate storage batteries as compared to the concurring battery technologies or modern, compact and lighter capacitor banks / supercapacitor units. At stake is a potential for growth of micro-hybridisation for small cars in the medium term (5-10 years).

3.1.2. Nickel-metal hydride batteries

The use of Nickel-metal hydride batteries (NiMH) had been considered a sufficiently good intermediate stage for application in electrified vehicles (see e.g., the more than one million Toyota Prius sold with NiMH technology, and ca. two million hybrid cars running on NiMH world-wide.) Clearly outperforming NiCd batteries, they were the choice as long as there were still concerns on the maturity, safety and cost of Li-ion batteries. As NiMHs' specific energy (< 100 Wh/kg) cannot meet the requirements for full electric vehicles, it has been mainly used in hybrid vehicles (both HEVs and PHEVs) of limited storage capacity requirements. For PHEVs, NiMH on-board storage capacity arrived at electrical ranges of typically 30 km. There exist concerns on the supply of rare earths (typically mischmetal) and nickel in their anode respectively, cathode. The relatively high content of Ni and possibly rising Ni prices limit further the prospects of reducing their cost and thus use in future EVs.

3.1.3. Lithium-ion batteries

These batteries represent the most actual, wide-spread application in new BEVs world-wide. Nowadays BEVs with ranges above 150 km have all in common that the on-board storage is provided by Li-ion battery packs, often containing some sort of thermal control devices. The name of Li-ion batteries covers a large number of chemistries; indeed, if only a small number of them are actually in use, the list of potential electrode materials is quite large. On the other hand, possible electrolytes range from the mostly used solutions of lithium salts in organic liquids to ionic conducting polymers or ceramics additions to polymers. The current advantage position for this technology is based on its relatively high specific energy (it has reached 160 Wh/kg respectively, 450 Wh/l) however, at present, cost is still a drawback (700 – 1000 $/kWh). The main efforts are thus directed to decrease its cost and to increase its performance level keeping the system safe. There seems to exist a trade-off between performance of the cathode material and its safety. While cathodes made of $LiFePO_4$ depict good safety records its performance in terms of specific energy is poorer than, for example, $LiCoO_2$. However, the latter has a worse safety performance. $LiFePO_4$ also have a comparatively high amount of useful charging cycles during their life-time.

Present research concentrates on the development of an advanced Li-ion batteries exploring the capacity limits of the system through the development of new cathode and anode materials in combination with higher voltage (up to 5V) which will require new electrolytes and binders. Breakthroughs are expected from the combination of so called 5V or high capacity (and then lower voltage) new positive electrode materials and intermetallic new anodes [3].

3.1.4. High temperature Na - β alumina batteries (Na-S and Na-$NiCl_2$)

The first prototypes of this battery type were introduced at the end of the 60s and contained sulphur as the positive electrode and the sodium β''-alumina as solid electrolyte. This material is an electronic insulator and exhibits sodium ion conductivity comparable to that of many aqueous electrolytes. However, to achieve enough electrochemical activity the Na-S battery operates between 300 and 350°C. Because of safety concerns, a derivative of this technology, based on the use of $NiCl_2$ instead of sulphur and termed ZEBRA battery [4], was later developed and evaluated for use in automotive applications. It has the advantage of being assembled in the discharged state and hence without the need of handling liquid sodium. As far as performance is concerned, its specific energy is relatively close to that of Li-ion batteries (115 Wh/kg), it has strongly improved its specific power (400 W/kg) and it has a relative low cost (600 $/kWh) although still between 4 to 6 time higher than the target set in many EV developing programs [5].

3.1.5. Other battery technologies

There are other battery technologies in the research stage that might in future meet the targets needed in electrification of road transport. We can mention among others Li-S [6], [7] and Li-air [8], [9] batteries (see figure 3). In particular they have demonstrated a specific energy[5] about 300 Wh/kg. However, other aspects as life-time, achievable cycles over lifetime and specific power still need further research to meet the challenge.

In the line of using ambient air (oxygen) as the cathode, other materials such as Zn, Al and Fe can be used instead of Li. However, those systems are still in their infancy and at different stages of development. Developments on their recharge ability, air electrodes (porous design) cycle stability and safety are among the areas to be addressed.

5 This value is at cell level (research object) as for a battery pack is expected to be lower due to the extra weight of materials used for packing and interconnection of the cells.

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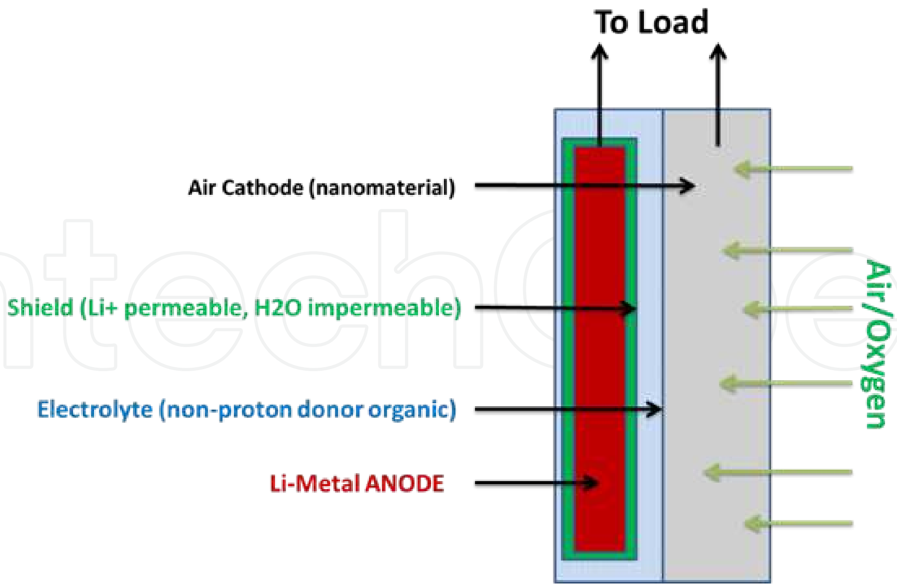

Figure 3. Scheme of a Li-air battery

3.2. Electrochemical capacitors

These devices are sometimes referred to as 'ultra-capacitors' or 'supercapacitors' but these latter are rather commercial names.

Electrochemical Double Layer Capacitors refer to devices that store electrical energy in the electric double layer (EDL), which is formed at the interface between an electron conducting surface and an electrolyte. The EDL may be considered as a capacitor with two electrodes; the capacitance is proportional to the area of the plates and is inversely proportional to the distance between them. Their capacitance is very large because the distance between the plates is very small (several angstroms). The energy stored by such capacitors may reach 5 Wh/kg but they are power systems which can deliver their storage energy in a few seconds (up to 5s). Therefore, they are intermediates between batteries (high energy, low power density) and conventional capacitors (high power low energy density) and thus, they are complementary to batteries and are not in competition with them.

Supercapacitors are already used in transportation applications. They have been announced to be used in the starter/alternator of micro-hybrid cars and are under study by many car manufacturers (Toyota, BMW, Renault, PSA). Recently Ford and Ricardo UK announced[6] the results of the HyBoost project, powering a small additional electric turbo-charging turbine for a down-sized thee-cylinder engine via such a fast ultracapacitor device of ca. 200 F capacity. Together with their outstanding cycle life, another key feature of EDLC systems is that, unlike Li-ion batteries, they can be recharged as fast as discharged. This is why they are used today in large-size applications for energy recovery in trams in Madrid, Paris, Mannheim and Cologne. There is hope, that a certain cross-fertilization in this area will happen

6 http://www.theengineer.co.uk/in-depth/analysis/hyboost-programme-promises-engine-efficiency/1010742.article.

between different improved road transport technologies, which may enable mass-production of EDLC systems sooner than later.

Supercapacitors (ultra-capacitors) have the ability to charge in a very short time however, its energy density is quite low and therefore by using only supercapacitors the electric range of an EV would not be sufficient. Consequently, the ideal situation would be combining both batteries and supercapacitors, which however requires a much more complicated voltage management.

3.3. Challenges

The performance of BEV and its competitiveness are closely linked to the performance of available battery systems in term of their specific power, efficiency and battery cost. In a recent paper Gerseen-Gondelach and Faaij [10] explored the performance of batteries for electric vehicles in the short and longer term. They review the different battery systems in term of performance and cost projection including sustainability aspects and learning curves. They concluded that well-to-wheel (WtW) energy consumption and emissions of BEVs are lowest for those with lithium-ion batteries, and that in the medium term only Li-ion batteries will have a specific power level of 400 W/kg or higher. Other battery systems like Li-S, Li-Air need efficiency improvements towards 90% to reach Well-to-Wheel (WtW) energy consumption of the BEV as low as found with Li-ion batteries. The author argued that already today, despite improvable efficiency levels, all batteries-types can enable similar or lower WtW energy consumption of BEVs compared to traditional internal combustion engine (ICE) vehicles: The WtW emissions are 20 – 55% lower using the EU electricity generation mix. Battery prices turned out to be of course the main parameter for improving the economics of BEVs e.g., if ZEBRA batteries attain a very low cost of 100 $ /kWh, such BEVs become cost competitive to diesel cars for driving ranges below 200 km. Such cost assumptions however were judged "unlikely" for the next and medium term.

With years of market introduction passing, an issue becoming provable will become battery ageing. With their use in extended time, batteries' performance can significantly reduce in terms of peak power capability, energy density and safety. Different auto manufacturers have set goals or targets for calendar life, deep cycle life, shallow cycle life and operating temperature range. However, it is still an issue of technological research to what extend current battery technologies can meet them.

Some examples of these targets are: for calendar life, the goals are typically for 15 years at a temperature of 35 ^{o}C, but current targets are for 10 years at which point a battery retains at least 80 per cent of its power and energy density. For deep cycle life, where the charge cycles go from 90 to 10 per cent of SOC[7], the goal is typically 5000 cycles, while the shallow cycle life expectation is 200,000 to 300,000 cycles. Goals for the temperature range as extreme as -40 to +66 ^{o}C can be found, such the question arises, whether batteries shall be specified for ambient conditions harsher than it has been done for any normal conventional ICE-vehicle. One extra difficulty that some of the results obtained on batteries performance are valid only for some specific

7 SOC means State of Charge

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charging and discharging rate and some specific range of ambient temperature exposure. It is still not clear if the test rates are more or less severe than the actual cycles a battery will be subjected to in an EV, and the interaction of ambient temperature with deep SOC cycling is also an unknown factor. A lot of pre-normative research is in front of us.

4. Cities are the natural environment to develop and to implement e-mobility

Cities are very important for the development and implementation of e-mobility, because the energetic and environmental benefits of BEVs replacing conventional vehicles are largest in city traffic. Moreover,

- About 70% of Europeans live in urban areas [11]. Most of the people live in cities with more than 50,000 inhabitants, and there are about 1,000 of such cities in Europe.
- Cities contribute substantially to the economics of Europe, 85% of European GDP is generated in cities [12].
- They contribute substantially to new knowledge (for instance from research being done on universities) and innovations by (high-tech) small and medium enterprises. Therefore cities have the potential to contribute to a better international competiveness of Europe.

The service sector is the most important source of employment in European urban economies. For example, in London, Paris, Berlin, Madrid and Rome the service sector accounts for between 80% and 90% of total employment. Examples of services are: government, telecommunication, healthcare/hospitals, waste disposal, education, insurance, financial services, legal services, consulting, information technology, news medias, tourism, and retail sales.

Providing and using these services lead to large transportation needs and activities of people and goods, and this, in turn, leads to a high use of energy and to the generation of anthropogenic emissions, like CO_2, NO_x, ozone, fine particles, noise, etc.

Let's focus in some of these aspects.

The energy consumption in European cities is high. About 80% of Europe's energy is used in cities [13]. It is expected [14] that this number will increase in future, because the urban population will grow and also the economic activities and the prosperity will grow.

We have about the same figures for CO_2. Cities are the largest emitters of CO_2. About 75% of the European's CO_2 is emitted in cities. On average the CO_2-emissions for European cities are in the neighbourhood of 1 ton CO_2 per capita per year [15]. Of course these emissions are dependent on the modalities of transportation which are used in the different cities. The higher the share in public transport, walking, cycling the lower the CO_2-emissions will be per capita.

Some examples: In Berlin [16], in 2008 32% of the people choose a car for transportation, 29% walked, 26% public transport and 13% took the bike. In London [17], in 2007 41% choose the car, 25% public transport, and 30% walked.

In some situations the concentration of NO_x and fine particles exceed the air quality limits. These situations are also called: hot spots. NO_x contributes to the formation of smog. Also acid rain can be formed out of NO_x.

Figure 4, depicts a street canyon in Copenhagen [18]. In many European cities the dispersion of air pollution is restricted by the geometry of buildings. This creates so-called street canyons. These canyons lead to elevated concentrations of local pollution, and therefore people living in (or in the neighbourhood of) these hot spots have a higher risk for getting ill.

Figure 5 depicts the concentration of NO_x in ambient air in a city (London) [19]. As can be seen from this picture the NO_x-concentrations exceed the maximum regulated value, which is 40 μg/m^3.

Figure 4. An example of a street canyon in Copenhagen [18]

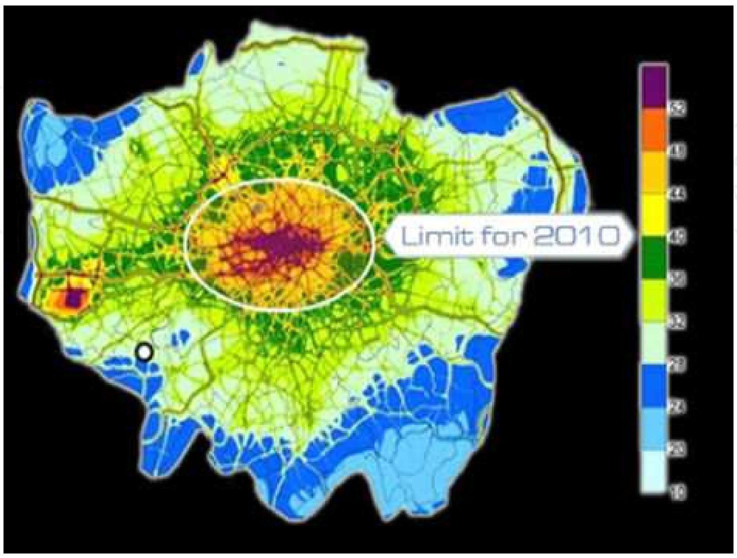

Figure 5. NO_x-emissions in the city of London [19]

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Figure 6 shows the NO_x-concentrations in European regions [19]. The intensively populated zones can be recognized easily. These are mainly cities and intensively used highways between the cities.

4.1. E-mobility can tackle these problems; many stakeholders are willing to contribute

The big advantage of e-mobility is that it gives direct results for improving ambient air quality. An electric vehicle does neither emit NO_x and PM, nor VOC (volatile organic compounds). So, when electric vehicles are introduced to replace conventional vehicles, these emissions decrease directly and ambient air quality will improve. Because ozone is formed by a photo-catalytic reaction between VOC and NO_x, also the ozone concentration will be reduced.

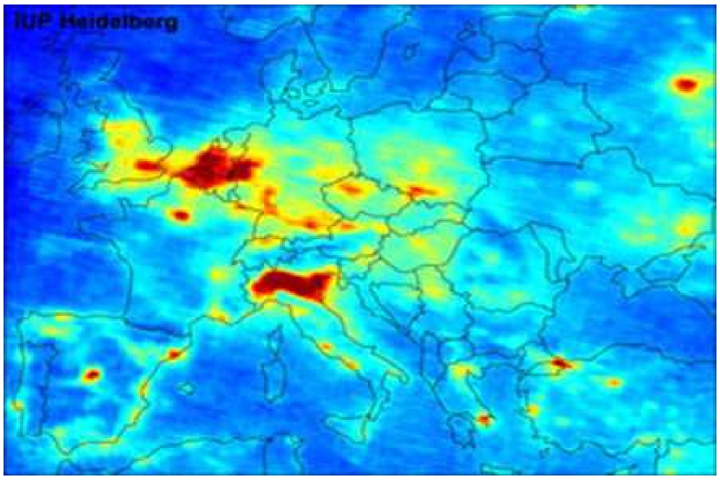

Figure 6. NO_x-emissions in Europe

A large number of stakeholders have parallel interests in the development and implementation of e-mobility in cities. The citizens want a clean city to live in. So, the ambient air quality needs to improve in several situations.

These ambient air problems are also a main driver for the politicians and administrations of cities to stimulate electro-mobility. The Covenant of Mayors which is signed on February 2009 is a good example of this. The main goal of this covenant, which now has about 4,000 signatories, is to increase energy efficiency and to use renewable energy sources. Within the framework of this covenant the Sustainable Energy Action Plans (SEAP) play a central role. A Sustainable Energy Action Plan (SEAP) is the key document in which the Covenant signatory outlines how it intends to reach its CO_2 reduction target by 2020. Already more than 1400 of these plans are submitted. A lot of these plans contain actions on the stimulation of electro-mobility in cities.

Also business leaders are major stakeholders. A first reason for that is that e-mobility can lead to sound Total Costs of Ownership (TCO). This means that economic activities can be done more cost effectively with e-mobility than with the petrol based vehicles. A second reason is that the spin-off of this technological development can be enormous. It is already stated that there are about 1,000 middle large cities in Europe. This is a big market for small and medium sized enterprises that develop new technologies for implementing e-mobility-systems.

4.2. Cities as living labs: some European experiences

Cities can be regarded as a living lab. This means that they have the possibility to test new concepts under real life circumstances. The behaviour of consumers working with new concepts can be studied, and the feedback of the consumer can be used by the supplier to modify and improve the concept. So, a cyclic process can be organized leading to the rapid development of new concepts. The administrations can take the lead in organizing these processes. They have all the ingredients to do so: the consumers, the suppliers, the infrastructure, and also the challenges and the solutions.

There are a lot of interesting projects going on in European cities on the development and implementation of electric vehicles. Some examples are the projects started within the European Green Cars Initiative [22].

Most of them concern electric mobility, for instance the Green eMotion project [23]. This project is supported by 43 partners from industry, the energy sector, electric vehicles manufacturers, municipalities as well as universities and research institutions. The goals of Green eMotion are:

- Connecting ongoing regional and national electro mobility initiatives;
- Comparing the different technology approaches to ensure the best solutions prevail for the European market;
- Creating a virtual marketplace to enable the different actors to interact;
- To demonstrate the integration of electro mobility into electrical networks (smart grids);
- Contribute to the improvement and development of new and existing standards for electro mobility interfaces.

In several projects ICT is introduced to facilitate the implementation of electromobility. One of these is the project MOBI.Europe [24]. In this project the users of electric vehicles are getting access to an interoperable charging infrastructure, independently from their energy utility and region. It is built on the e-mobility initiatives of Portugal, Ireland, the Spanish region of Galicia and the Dutch city of Amsterdam.

Another project is the smartCEM [24] project in which four European cities/regions are participating: Barcelona (ES), Gipuzkoa-San Sebastian (ES), Newcastle (UK) and Turin (IT). The goal of this project is to demonstrate the role of ICT[8] solutions in addressing shortcomings of e-mobility, by applying advanced mobility services, like EV-navigation, and EV-efficient driving.

8 ICT = Information and Communication Technologies

One part of the VIBRATe (VIenna BRATislava E-mobility) [25] project is to identify the possibilities of connecting two neighboring metropolitan areas—Bratislava (Slovakia) and Vienna (Austria) with a "green" highway. This highway will interconnect the two cities with a network of public charging stations for electric vehicles. In this project IBM is working together with Západoslovenská energetika, a.s. (ZSE) and the concerned municipalities.

Autolib [26] is an electric car-sharing program which is launched in Paris at the end of 2011. This program will start with 250 vehicles. The amount of vehicles will grow to 2,000 in the summer of 2012. This number will grow to 3,000 in the summer of 2013. In this car-sharing program the compact Blue car is introduced. This four-seat car is the result of a collaboration of the Italian car designer Pininfarina and the French conglomerate Groupe Bollore.

Car2Go [27] is a subsidiary of Daimler AG that provides car sharing services in several cities in Europe and North America. In November 2011 a fleet of 300 smart for two electric vehicles was deployed in Amsterdam.

In London the "Electric 10" is formed. This is an initiative of 10 companies that use electric commercial vehicles for their activities. The Electric 10 partnership was formed in autumn 2009, bringing together 10 major companies who are already using electric fleet vehicles on daily basis: Sainsbury's, Tesco's, Marks and Spencer, UPS, TNT Express, DHL, Amey, Go Ahead, Speedy, Royal Mail. The Municipality of London is working with these companies to learn from their experiences and encourage others to take their lead [28]. The use of electric vehicles for goods delivery not only benefits the environment, it also has a positive total cost of ownership (TCO).

4.3. Cities have the power to implement; and they are already doing so

City administrations have the possibility to develop new concepts under real life circumstances, as we have seen in paragraph 4.2. and to set projects to bring e-mobility to a reality. Of equal importance is that they also have the ability to implement using their legal instruments. Many cities are already doing this.

The instruments they use can be divided in three categories [29]:

Financial incentives

Examples of financial incentives are exemptions from vehicles registration taxes or license fees. Or exemptions from congestion charge. Another financial incentives are of operational nature e.g. the electric vehicle gets a discount on parking costs.

Non-financial incentives

There are cities which give non-financial incentives. For instance, free or discount cost for a parking place in the city centre. Or that the owner will get access to restricted highway lanes. An important incentive is also to get easy access to public charging facilities.

Their purchasing power

Municipalities are not only regulators. They also have a vehicle fleet and they give licenses to public transport systems. With these possibilities they also can stimulate the e-mobility.

They can buy electric vehicles for their municipal fleet and they can add hybrid buses to public transport systems. Municipalities can install charging stations on the public area, like: libraries, parking garages, city halls, or other public buildings.

4.4. Some remarks to this section

In paragraph 4.2 a total of 7 projects which are presently going on in Europe are described shortly. It should be stated that these are just illustrations. There are many more interesting projects on e-mobility. What we see is a steep increase in the amount of battery electric vehicles (BEV) in Europe [30]. In 2010 in total 765 BEVs were introduced on the EU-27-market, and in 2011 already ca. 9,000 BEVs. This took place predominantly in France, Germany, UK, the Netherlands, and Austria. The main BEVs types were Peugeot-ION, Mitsubishi-i-MIEV, Smart for two, Nissan-Leaf, and Citroen-C-Zero.

We expect that this steep increase will continue, because of the battery developments we described in the beginning of this chapter and also because of the strong efforts of stakeholders, like member states, municipalities, car manufacturers, and the EU. Indeed, in the 2011 Transport White Paper 'Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system' (COM (2011) 144 final), the European Commission proposes 10 goals for a competitive and resource efficient transport system which serve as benchmarks for achieving the 2050 60% GHG emission reduction target. One of these goals is to halve the use of 'conventionally-fuelled' cars in the urban transport sector by 2030 and to phase them out by 2050, thereby also reducing the transport system's dependence on oil.

5. Enabling technologies for the introduction of electricity in road transport

Another reason why electric vehicles are promising is because of the fact that it can contribute to the development and introduction of smart grids. With smart grids the share of green electricity by means of wind and solar can be better managed to increase. Electric vehicles can serve as storage for electricity (spinning reserves) in those times when the households don't need the amount of electricity produced at a certain moment, and the vehicles can deliver electricity to the grid in times when the households need more electricity than produced at that moment. The benefits are that with these smart grids the CO2 emissions will decrease as well as the use of fossil energy. The CO2 emissions will go down even more, because from well-to-wheel-analyses it can be seen that in most cases the CO2-performance of electric vehicles is better that petrol based vehicles [21].

It is generally considered that smart grid and V2X where X represents another vehicle (V2V), the grid (V2G) or sometime the user's home (V2H) are essential technologies for the early introduction of electrified vehicles as these provide an added value to the vehicle respectively, reduce its TCO.

5.1. What is a smart grid?

The concept of Smart Grid[9] was developed in 2006 by the European Technology Platform for Smart Grids, and concerns an electricity network that can intelligently integrate the actions of all actors connected to it - generators, consumers and those that do both - in order to efficiently deliver sustainable, economic and secure electricity supplies. Interoperability of EVs to Smart grids promises an increase of the EVs' overall energy efficiency and cost benefits.

Decentralized supply of electricity is growing. There are at least three types of decentralized supply options:

- More and more wind turbines are in operation;
- (micro) Combined Heat and Power (CHP) is up-coming.
- The generation by means of solar PV is increasing;

This development means that the fluctuations over time in the supply of electricity would be increasing in a near future with the consequent challenge to harmonize it with the demand of electricity.

There are some options to deal with this challenge. The first one is to influence the regulate the supply. When at a certain moment more wind and solar electricity is produced then the supply of electricity from fossil sources should be limited. To realize this real-time communication between consumers and producers should take place. This can be done by means of smart meters. To reduce the supply of electricity from fossil sources is, however, not always an easy task.

A second option is to realize a situation in which the fluctuations which might appear on the supply side will be match on the demand side. This can be realized by introducing fluctuating prices, which again can be realized by means of smart meters. So when the supply is high then the price will be low and then the smart meter can for instance start charging an electric vehicle or it can start other appliances e.g. the washing machine. And when the demand is high then the price will be high and then the electric vehicle will supply electricity to the house. Thus, by means of the price mechanism and the smart metering the supply and the demand can stay in balance, despite of the fluctuations occurring in the supply side.

A third option is by introducing a storage facility. This can be done by means of fly-wheels, ultra-capacitors, compressed air, and batteries. In this third option the batteries of the electric vehicles can play a role (see section 3).

A fourth option is that when there is an oversupply of electricity, it is used for the electrolysis of water and the formed hydrogen is either used directly or it is coupled with CO2 to produce methane. When there is a shortage of electricity the hydrogen and/or methane can be used to produce electricity by means of a Combined Heat and Power Plant (CHP). Of course the hydrogen can also be used to fuel a Fuel Cell Electric Vehicles (FCEV's).

Hence, with a smart grid it is possible to:

9 http://www.smartgrids.eu/documents/TRIPTICO%20SG.pdf

- Better facilitate the connection and operation of electrical generators of all sizes and technologies;
- Allow consumers to play a part in optimizing the operation of the system;
- Provide consumers with more information and options for choosing an energy supply;
- Significantly reduce the environmental impact of the whole electricity supply chain;
- Organize a symbiotic relation between the grid and the electric vehicle. The vehicle can be charged when the price is low, and the vehicle can contribute to the grid when electricity is needed there;
- Charge the electric vehicle with low-CO2-containing electricity, which contributes to low CO2-emissions when driving the vehicle;
- Maintain or improve the existing high levels of system reliability, quality and security of supply;
- Maintain or improve the efficiency of existing services;
- Foster the development of an integrated European market.

5.2. Some European efforts on a practical scale on smart grids including electric vehicles

There are considerable efforts in Europe (the same thing can be said on other developed markets; i.e. USA, Japan…) on smart grids[10] by supporting and carrying out many projects. In several of these projects electric vehicles are included and studied. Some examples are:

InovCity concept in Évora (Portugal)

The goal of this project is that the entire municipality of Évora will be connected to an intelligent electricity system which includes 30,000 customers.

Some characteristics of this project are:

- The project is initiated by EDP[11] Distribuição, with support from national partners in industry, technology and research (EDP Inovação; Lógica; Inesc Porto; Efacec; Janz and Contar);
- The electricity grid is provided with ICT, so that the grid can be controlled automatically. This is done by monitoring the grid in real time;
- Increase of renewable energies (PV solar cells, micro wind turbines) is facilitated by the intelligent electricity grid;
- The Energy Box plays a central role in this system. All consumers will have such a box, and this box connects the consumers to the intelligent grid. In the box the amount of electricity used and/or produced is recorded. And by means of the box the consumers can

10 A survey can be found on http://www.smartgridsprojects.eu/map.html

11 http://www.inovcity.pt/en/Pages/media-center.aspx

program devices, like washing machines, when the price of electricity is low. This process of programming devices can be automated fully;

- The electricity grid is also facilitating the charging and discharging of electric vehicles. The batteries of these vehicles will serve as a buffer when there is an oversupply and the batteries will serve as a producer of electricity when more electricity is needed in the homes.

Endesa's Smartcity Málaga Project (Spain)

The goals of SmartCity Málaga[12] are to implement and integrate distributed energy resources, energy storage, electric vehicle charging and discharging facilities, and intelligent public lighting devices.

The characteristics of the project are:

- Endesa in cooperation with 11 partners is rolling out state-of-the-art technologies in smart metering, communications and systems, network automation, generation and storage, and smart recharging infrastructure for e-vehicles;
- More than 17,000 smart meters are installed;
- 11 MW of renewable generation capacity which consist of solar PV, wind energy and co-generation;
- A storage facility consisting of batteries;
- A network of recharging points for vehicle-to-grid-technology;
- By means of ICT all these devices are connected to the Network Control Center, where these are monitored and controlled.

Harz.EE-Mobility (Germany) [13]

This project has been initiated by Siemens CT in cooperation with 14 partners – including research institutes, the Deutsche Bahn (German Railroad Company), and wireless provider Vodafone. The goal is to make Germany's Harz district a model region for electric mobility. Wind, solar, and other alternative energy sources already contribute more than half of the power generated in the Harz district. Sometimes in windy periods some wind turbines have to switch off. This problem could be solved using electric vehicles as small energy storage units allowing for useful demand shift.

The project focuses on Vehicle-to-grid-technology (V2G). Electric cars would recharge their batteries whenever winds are strong, especially at night. Conversely, during calm periods they could feed electricity back into the grid at higher prices. Ultimately, V2G aims at bidirectionality of both, car / grid communication and their energy flow.

In this project an energy management system is developed. All the 2,000 energy generation devices are connected and automatically controlled (PV, wind turbines, biogas, and

12 http://www.endesa.com/en/aboutEndesa/businessLines/principalesproyectos/Paginas/Malaga_SmartCity.aspx

13 *http://www.siemens.com/corporate-technology/en/research-cooperations/mobility.htm*

electric vehicles). The project also monitors and studies the movement profiles of electric vehicles. With this information is can be predicted how many electricity in what period is needed to recharge the vehicles. This will also be important control data for the electricity generation devices.

The above examples indicate the important role that information and communication technology play in an early uptake of electrical vehicles by their seamless integration in the electrical distribution and control network ("smart grid" of the future).

6. Discussion

This chapter has focussed on the technological requirements that electrical vehicles need in order to break into the (primarily urban) main stream as a valid personal or commercial transport means. However, their cost/price and environmental impact have not been addressed. This section intends to indicate some of the recent efforts that can be found in the open literature, both to forecast when this vehicle technology will become possibly a preference of the user and what policies could be put in place to better address the environmental benefit of increasingly electrifying road transport.

In a recent paper [31] Weiss *et al.* have forecasted the price for hybrid-electric and battery-electric vehicles using *ex-post* learning rates for HEVs and *ex-ante* price forecasts for HEVs and BEVs. They forecasted that price breakeven with these vehicles may only be achieved by 2026 and 2032, when 50 and 80 million BEVs, respectively, are expected to have been produced worldwide. They estimated that BEVs may require until then global learning investments of 100–150 billion € which is less than the global subsidies for fossil fuel consumption paid in 2009. Their findings suggested that HEVs, including plug-in HEVs, could become the dominant vehicle technology in the next two decades, while BEVs may require long-term policy support. In line with what it has been pointed out in this chapter, the authors indicated that the performance/cost ratio of batteries is critical for the production costs of both HEVs and BEVs. If current developments persist, vehicles with smaller, and thus less costly, batteries such as plug-in HEVs and short-range BEVs for city driving could present the economically most viable options for the electrification of passenger road transport until 2020.

More studies on specifically urban electrification of road transport might move the quantitative arguments to some extent, and show that there are several niches of earlier cost-effectiveness even for BEVs.

There is a debate on how to consider the environmental impact of this class of vehicles. Unlike their counterpart fossil-fuelled vehicles, the emissions generated by electrified vehicles are produced “upstream”, that is where the electricity is generated. Should they be considered to have GHG emissions of "0 g/km"? Lutsey and Sperling [32] argue that considering electric vehicles as 0 g/km and assuming 10% of cars sold by 2020 to be electric, this could result in a loss of 20% of the conventionally calculated benefit from USA regulations aimed at reducing vehicle GHG emissions – so one has to pay attention of what is summed up. They also found that if upstream emissions were included, an electric vehicle powered from the America electricity grid would on average emit about 56% less CO2 than their petrol counterpart (104 g/mile compared to 238 g/mile). It is clear that the exact amount will depend upon the particular electricity generation fuel mix and thus generation efficiency in the given State where the BEV was charged. These authors support the idea of using a full life-cycle analysis as regulatory option rather than the "0 g/km". This approach, although more complicated, would ensure that GHG regulations were scientifically rigorous and could accommodate future energy technology development.

7. Conclusions

In the 2011 Transport White Paper 'Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system' (COM (2011) 144 final), the European Commission proposes 10 goals for a competitive and resource efficient transport system which serve as benchmarks for achieving the 2050 60% GHG emission reduction target. One of these goals is to halve the use of 'conventionally-fuelled' cars in the urban transport sector by 2030 and to phase them out by 2050, thereby also reducing the transport system's dependence on oil. Among the possible options to support this target, the electrification of road transport seems to be a winning one - as we have indicated in this chapter. We have addressed the technological challenges that electrified vehicles have to face in order to overcome the present status quo. These are mainly due to the storage system on board of a BEV. There are promising technologies that can positively support the introduction of electric vehicles in our streets and roads (e.g. V2G and interoperability with smart grids through standardised communication). Finally, the areas of cost and environmental impact has been also addressed by commenting recent efforts in both forecasting the price reduction in the future and addressing full life-cycle analysis as possible policy options to include the full picture of the impact of vehicles in GHG emissions.

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