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Statistics of plug-in electric cars sales in the world from 2011 to 2016 and overview of the evolution of their performances

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Abstract: *Between January and December of 2016, 774,384 electric cars have been sold in the world, representing a growth of 41.26% compared to 2015. Thus, by the end of the last year, more than 2 million plug-in electric cars have been deployed in the world. With 61,027 units sold since its introduction in the market in late 2010, the Nissan Leaf is the world best-selling electric vehicles. Likewise, with the diminution of the price of Lithium-ion batteries and the improvement of its performance, the global number of plug-in electric cars will reach 41 million by 2040. Besides, since the first sale of the first Lithium-ion battery in 1991, the energy density of this chemistry had always increased. It passed from 90Wh/kg to around 200Wh/kg today. So, full electric cars driving range had ameliorated to reach an average of 250km nowadays. However, this distance can still be increased, thus new batteries like Lithium-sulfur and Lithium-air are now developed by researchers. They have a high energy density compared to other chemistries, between 500Wh/kg and 1,000Wh/kg.*
Keywords - *Driving range, electric vehicles (EVs) sales, energy density, growth, Lithium-ion battery, plug-in electric cars.*

1. INTRODUCTION

The climate change is a phenomenon which currently worries the world. The consequences of this problem are already felt nowadays and will be even more important in the next decades if concrete measures will not be taken. To face this situation, cars manufacturers worldwide multiply their efforts in the development of cars more innovating like plug-in electric vehicles.

At the first time, this paper offers an overview of the evolution of electric vehicles markets (plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs)) between 2011 and 2016. It gives an estimation of electric vehicles worldwide stock by the end of 2016, and EVs sales in some countries and region for the six last years, then forecasts on plug-in electric cars sales in the next years will be presented. The second part of this work talks about the progress of BEVs performances since 2011. That concerns especially the improvement of the Lithium-ion battery energy density and the driving range of these all-electric cars.

2. STATISTICS OF PLUG-IN ELECTRIC VEHICLES

This first section gives global statistics about plug-in electrics cars for 2011 to 2016. These include the EVs stock in the world, EVs sales during the six last years in selected countries and region with an overview of most sold models, and forecast of EVs sales in the future.

2.1. Worldwide EVs stock in 2016

Since 2011, the number of light-duty plug-in electric vehicles in the world had always increased to surpass 2 million units in 2016 [1]. Thus, at the end of December 2016, worldwide EVs stock rose of 62.86%. For 2014 and 2015, the EVs global stock was respectively 706,770 and 1,256,900 units [2] and the growth was 84% and 77%.

Despite this rapid increase, plug-in electric vehicles represent only 0.1% of all cars in the world at the end of the last year.

By 2016, the United States and China are the two first countries where one can find the greatest number of electric vehicles on the road with respectively 563,229 units and 664,151 units [1]. More than 50% of EVs worldwide are localized on these two countries. Japan takes the third place with a stock of 148,775 units registered since 2009.

On the regional plan, Europe had over 500,000 EVs on the road in late 2016 [1]. With its 116,482 units, Norway is the first country in this continent that have the greatest number of electric cars. Afterwards, there is the Netherlands with 110,644 EVs deployed on its roads, the United Kingdom and France took the fourth and fifth places with respectively 88,953 and 88,864 units.

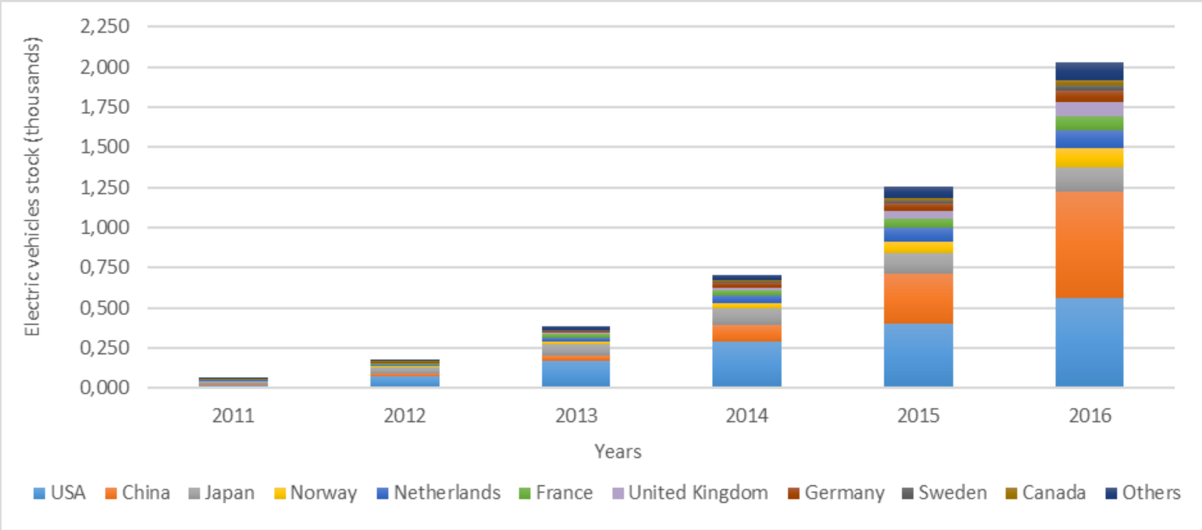

Fig. 1. Progress of the global electric vehicles stock from 2011 to 2016
(Sources: Data compiled from Global EV Outlook 2016, http://ev-sales.blogspot.com, http://insideevs.com)

2.2. Sales of plug-in electric vehicles by country and region from 2011 to 2016

After a slow start in 2011, sales of plug-in electric cars had always rose: 118,580 units in 2012, around 200,000 in 2013, about 323,680 in 2014, 550k in 2015 and 777,497 units at the end of 2016 [1]. Despite this growth, the global EVs share worldwide didn't reach yet the desired 1%, it is only 0.85%.

At the beginning of the modern age of plug-in electric vehicles in 2011, in one hand the United States, Europe and Japan had similar levels with respectively 17,763 – 14,160 and 12,600 units of EVs sold [3]. On the other hand, Chinese annual registration of new EVs was only at some 5,202 units [3]. However, since 2015, China was significantly ahead all other countries and became the largest EVs market in the world. After 2013 where 17,542 plug-in electric vehicles have been sold in this country, the number of new EVs increased very quickly every year: more than 234% in 2014, around 251% in 2015 and 69.67% in 2016 [1]. Consequently, last year, Chinese EVs share reached 1.4%, that's up 0.5% from the 2015. The main reasons for this situation are the generous incentives given by the Chinese government. EVs didn't pay acquisition and excise taxes. Purchasers of EVs enjoy of subsidies whose maximum value is 95,000 yuan or $14,240 [4] according to the local governments, engine displacement and price.

In Europe, 222,619 new plug-in electric cars have been registered last year [1], 15% over 2015. European market is led by Norway (45,662 units), followed by the United Kingdom (39,283 units) and France (34,574 units) [1]. With its 29%; Norway remains the country in the world where EV share is very high. Other European countries had also high market shares: Iceland (4.2%), Sweden (3.7%) and Finland (1.2%) [1]. Despite this global growth, some slowing markets should be noticed. Compared to 2015, significant decreases have been observed last year in the Netherlands (3.4% vs 9.3%) and Denmark (0.6% vs 2.3%) [1]. These sales slowdown is respectively caused by the policy incentive change applied on PHEVs and the application of a registration tax to new BEVs.

Since 2011, sales of plug-in electric cars in the United States grew during three years, but for the first time in 2015, it dropped 4%. This regression can be explained by a lack of new offerings and a perturbation in the procurement of some models which are very appreciated in the U.S. like the Chevrolet Volt, the Toyota Prius PHV or the Nissan Leaf. Consequently, the United States market have been overtaken by China and Europe. Fortunately, in 2016, sales of electric cars in the United States took back their increase and 158,455 units [1] have been registered at the end of this year, a growth of 37.37% compared to 2015.

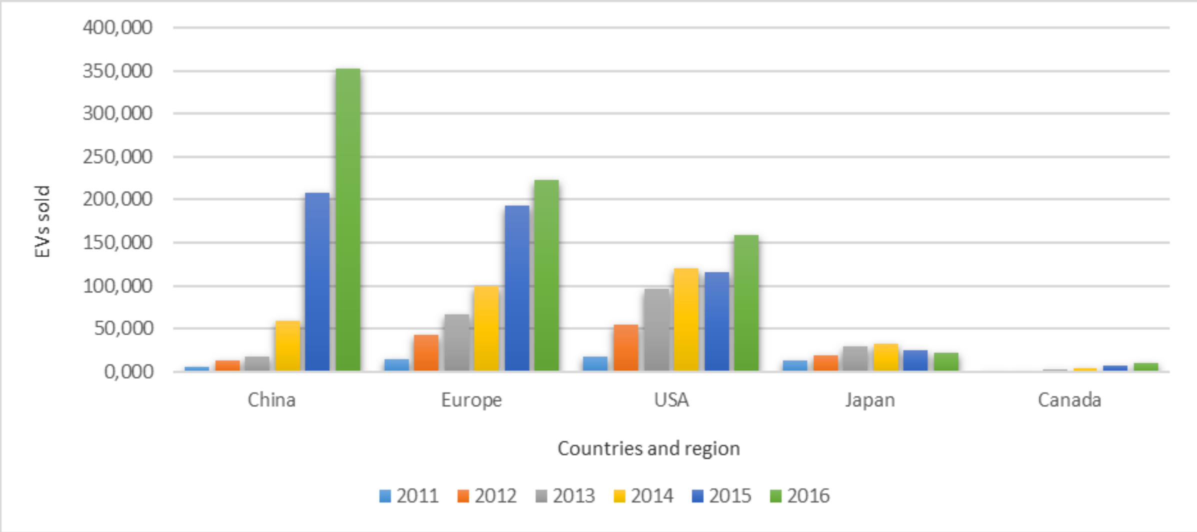

Fig.2. Evolution of EVs sales between 2011 and 2016 in some countries and region
(Source: Data compiled from http://ev-sales.blogspot.com and http://insideevs.com)

Meanwhile, Japanese annual sales have decreased significantly for the second time after 2015 to reach 22,375 units last year, 31% inferior to the 2014 peak where 32,418 new plug-in electric cars have been registered [1] and the EVs market share was 0.98%. So, since 2013, the number of EVs sold in Japan was widely falling behind China, Europe and the United States. This slowdown is mainly the consequence of the determination of the Japanese authority and some local carmakers to lean towards hydrogen fuel cell cars.

During the six last years, Canadian plug-in electric car sales still increased and reached in 2016 a volume of about 11,000 units [1]. One can noticed a growth of 56% compared to 2015.

2.3. Sales of plug-in electric cars by model between 2011 and 2016

The Nissan Leaf is the most sold plug-in electric car in the world since its introduction in the Japanese and U.S. markets in late 2010. More than 230,000 units have been sold in the world during six years [5]. In 2011 and 2012, this model dominated the EVs worldwide market with the Toyota Prius Plug-in (e) and the Chevrolet Volt which both are plug-in hybrid electric vehicles. Furthermore, with the dynamism of the European and the American markets in 2014, sales of the Nissan Leaf was exceptional. 61,027 units of this pure electric vehicle manufactured in Yokohama have been sold in the world this year [1], representing about 19% of the worldwide market share. However, the next year, for the first time, its sales dropped of 28.11%. Consequently, the Nissan's electric lost its first place and the Tesla Model S, an all-electric car introduced in the market in June 2012, became the EVs best-seller in 2015 with 50,366 units sold [1].

The last year have been marked by the race between the Nissan Leaf and the Model S for the first place. The Japanese pure electric vehicles was the winner with 51,882 units against 50,944 units for the Tesla [1]. The BYD Tang took the third position with 31,405 units. This Chinese PHEVs model jumped five positions over 2015. Only available in the United States, Canada and South Korea, the Chevrolet Volt was nevertheless ranked fourth (28,296 units), ahead another plug-in hybrid electric vehicle, the Mitsubishi Outlander (27,322 units). In 2016, sales of this Japanese mid-size crossover SUV decreased 37% compared to 2015 where it took the third place.

For the second consecutive year, China was the largest EVs market in the world in 2016 and produced by far more plug-in electric vehicles than any other country. The Chinese EVs production is led by the BYD Company [7]. Thereby, beyond the BYD Tang mentioned above, three other BYD models were last year present in the 20 EVs world best seller: the BYD Qin (#9 with 21,868 units), BYD e6 (#10 with 20,610 units) and BYD e5 (#17 with 15,639 units). Seven other Chinese models also appeared in this classification. They are the BAIC E-Series EV (#11), BAIC EU260 (#12), Geely Emgrand EV (#13), Zotye Cloud EV (#14), Chery eQ (#15), SAIC Roewe e550 (#18) and Zotye E200 (#20) [1].

After taking the third position in 2014 behind the Mitsubishi Outlander PHEV and the two second places in 2013 and 2015, the Renault Zoe obtained its first Gold medal in 2016 on the European market of EVs [3]. With 21,735 units registered last year in this region, sales of this French full-electric vehicle increased 17% regarding 2015. Even if this model was very appreciated in European countries, it was disappointed elsewhere.

Thus, the Renault Zoe was only ranked 8 on the EVs world market last year [1].

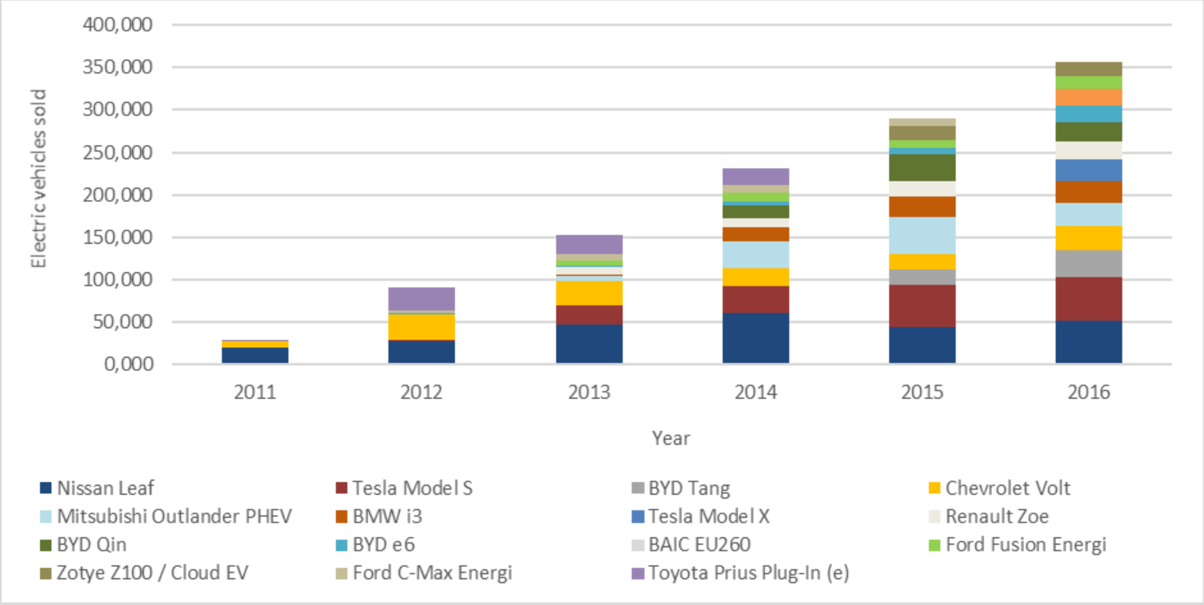

Fig.3. Sales of the most sold plug-in electric cars models between 2011 and 2016
(Source: http://www.greencarreports.com, http://ev-sales.blogspot.com)

2.4. Forecast of EVs sales

By 2022, some U.S. car manufacturers like General Motors and Tesla have fixed an ambitious target that batteries costs for pure electric vehicles will reach USD 100/kWh [2]. As the price of the battery represents 33% of the total cost of a pure electric vehicle and according to the Bloomberg new energy finance (BNEF) report [9], [10] published in April of the last year, plug-in electric cars will be as affordable as conventional cars in the next six years. Moreover, due to the improvement of energy density and lifetime of batteries, most of EVs will perform better than normal vehicles.

BNEF foresees that, after 2030, other battery chemistries will appear with cells materials more accessible with high-performance [9]. Other factors like the growing of tax breaks and incentives government policies, as well as the increase of oil price will drive to opt for electric mobility.

Between 2020 and 2030, costs of BEVs would be lower than normal cars price. By 2040, BNEF forecasts that a plug-in electric car would cost $ 22,000 (compared to the average of $30,000 in 2016 [9]). Thereby, by this year, plug-in electric cars market share in the world would be 35% and EVs stock worldwide would reach 41 million. China would remain the largest EVs market in the world with 35% share, followed by the United States (21%) and Europe (15%).

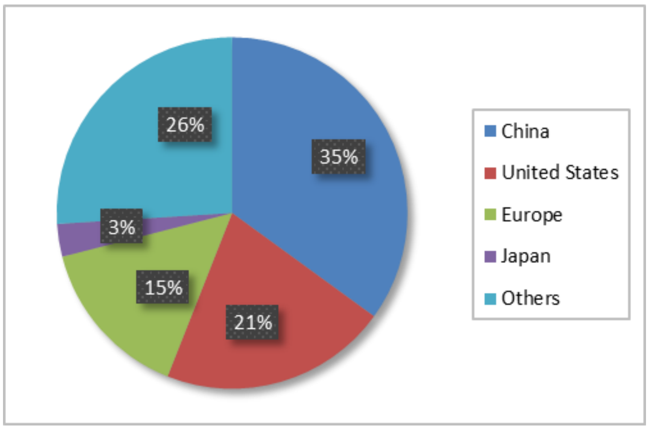

Fig.4. Distribution of plug-in electric cars by 2040.
(Source: http://www.bbhub.io/bnef/sites/4/2016/04/BNEF-Summit-Keynote-2016.pdf)

Moreover, the Electric Vehicles Initiative (EVI) has fixed a goal: 20 million plug-in electric cars [11] in the world by 2020. To reach this target, between 2009 and 2011, many countries had set their own deployment goals by 2020: China 5 million, France 2 million, Germany 1 million, Japan 800k, Netherlands 200k, Denmark 50k units [12].

3. PROGRESS OF BATTERY ELECTRIC CARS PERFORMANCES

EVs performances and costs, especially for pure electric vehicles, depend on the battery which is the main organ of these cars.

3.1. Evolution of the costs and performances of Li-ion battery for electric vehicles

Since 2010, the Lithium-ion batteries price decreased for about 65% and will pursue its descent by the next years [10]. The cost of Li-ion batteries was $350/kWh in 2015 and would be about $120/kWh after thirteen years [10]. According to the global EV Outlook 2020, this situation is mainly the result of battery packs optimization, the drop of prices of cells materials and the progress done on the fabrication process.

Since its first commercialization in 1991 by the Japanese Sony, Lithium-ion batteries performances had largely ameliorated. Among the parameters that can used to quantify the performance of a battery, there is the energy density. Very important especially in automotive applications, it represents the amount of energy stored per unit of mass of cell. This parameter defines the driving range of battery electric vehicles. Higher is the energy density, BEVs run time will be longer. Since 1991, the energy density of a Li-ion battery was increased from 80Wh/kg to around 200Wh/kg in 2008. One can deduce that this parameter gains an average of 6% per year.

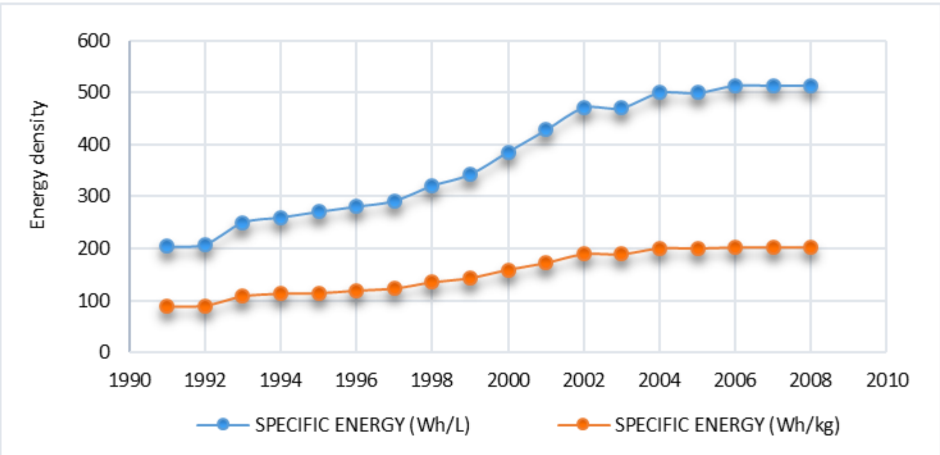

Fig.5. Evolution of the energy density of Lithium-ion batteries for 1991 to 2008
(Source: http://batteryuniversity.com/learn/archive/battery_statistics)

This improvement of the performance of a Li-ion battery is due to four main causes [15]. The first is the replacement of the initial hard carbon in the positive electrode by a graphite. Consequently, the capacity of the anode material rose from 200mAh/g to 280mAh/g. In the second time, there was the amelioration of the graphitization of this same electrode by the bringing of new electrolyte. The third reason is the amelioration of the battery pack. When this last had reached its limit, researchers turned over on the creation of new materials for the cathode. Thereby, there are today five main types of Lithium-ion chemistry that can be used in plug-in electric cars [14].

The next table provides the characteristics of 5 technologies of Lithium-ion batteries that equipped EVs today. The Lithium Cobalt Oxide or LCO also appears in this classification. Even if it equipped the pure electric car Tesla Roadster in 2008, it is nowadays mainly used in consumer products like smartphones, laptops and tablets. In spite of its high energy density (150 to 200Wh/kg), this chemistry would be maladjusted for electric vehicles because of problems of safety. Furthermore, it is not be able to charge and discharge at a high current (above its C-rating) whereas it is very important in automotive applications.

TABLE. Types of Lithium-ion battery available for EVs
(Source: http://batteryuniversity.com/learn/article/types_of_Lithium_ion)

Battery name	Year	Cathode material	Anode material	Nominal voltage (V)	Energy density (Wh/kg)	Cycle life	EV
LCO or Li-cobalt.	1991	Lithium Cobalt Oxide ($LiCoO_2$)	Graphite	3.6	150 - 200	500 – 1,000	
LMO or Li-manganese	1996	Lithium Manganese Oxide ($LiMn_2O_4$)	Graphite	3.8	100 - 150	300 - 700	Already in series car (e.g. Leaf, Volt, iMiEV)
LFP or Li-phosphate	1996	Lithium Iron Phosphate ($LiFePO_4$)	Graphite	3.3	90 - 120	1,000 – 2,000	Already in series car (e.g. Fisker EV)
NCA or Li-aluminum	1999	Lithium Nickel Cobalt Aluminum Oxide: ($LiNiCoAlO_2$)	Graphite	3.6	200 - 260	500	Already in series car (e.g. plug-in Prius)
NMC	2008	Lithium Nickel Manganese Cobalt Oxide ($LiNiMnCoO_2$)	Graphite	3.7	150 – 220	1,000 – 2000	Used in consumer goods and EV prototypes
LTO or Li-titanate	2008	Graphite	Lithium Titanate ($Li_4Ti_5O_{12}$)	2.4	70 -80	3,000 – 7,000	

As one can noticed, all the Lithium-ion chemistries presented in this table use graphite as anode material unless the LTO. In this chemistry, the graphite is replaced by a Lithium Titanate (Li4Ti5O12). This technology has the higher cycle life and safety level, but also the lower nominal voltage and energy density among the Lithium-ion batteries technologies.

An interesting remark is that a new battery chemistry finds its first utilization in electronic products. It must do its proof there before to be used in series electric cars, which takes at least five years. Thereby, ten to fifteen years are necessary for a successful laboratory battery chemistry to integrate automotive market [15].

3.2. Progress of BEVs performances

The first model of plug-in electric car produced in series between 2008 and 2012, and using a Lithium-ion battery pack was the Tesla Roadster. It was equipped with a Lithium cobalt oxide (LCO) having an energy density of about 117Wh/kg. Consequently, this pure electric car was able to travel a range of 394km between two recharges [17].

Nevertheless, the adoption of EVs by the consumers had really increased since 2011, few months after the introduction of the Nissan Leaf in the market. From this year, BEVs driving range had always risen, its average passed from 160 to 250km nowadays. Some electric vehicles of today like the Tesla Model S and the Tesla Model X are even able to travel a distance more than 400km before to be recharged [17]. This improvement of the driving range of battery electric cars is mainly due to the amelioration of the energy density and the storage capacity of the battery which average passed from 27kWh to 38kWh today. To have this growth of the storage capacity, battery manufacturers increase the number of cells in a battery pack.

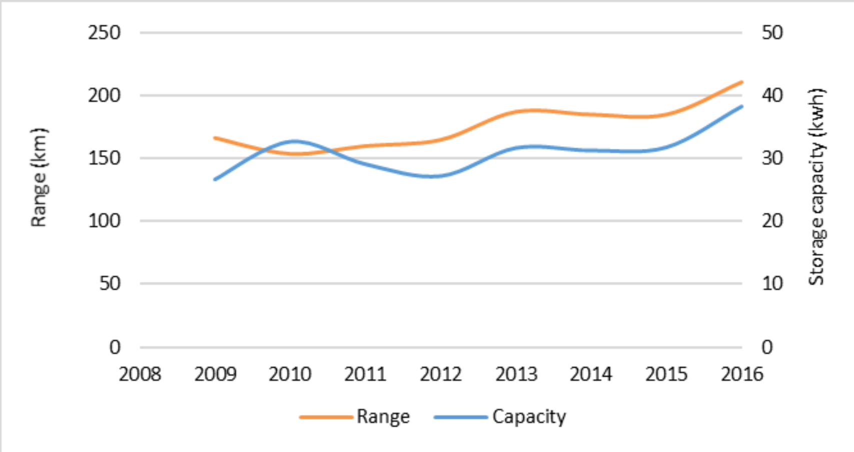

Fig.6. Evolution of BEVs driving range and the storage capacity of Li-ion batteries for 2009 to 2016 (Source: own compilation)

The graph above shows the evolution of the average of the driving range and the storage capacity of BEVs since 2009. One can explain the pic of the storage capacity in 2010 by the introduction in the market of the Nissan Leaf and the BYD e6 which has respectively a storage capacity of 24kWh and 75kWh.

3.3 Future batteries for plug-in electric vehicles

Future generation of batteries for plug-in electric cars must have higher energy density, so that full electric cars can travel a longer distance. BNEF foresees that other battery chemistries will appear with cells materials more accessible with high-performance. These elements will allow having packs lighter, less cumbersome and cheaper. Among these new technologies the Lithium-ion battery with nickel cobalt manganese and composite cathodes, and silicon anodes is very promising [15]. It will have an energy density around 300Wh/kg allowing to a BEV to have an average of driving range of about 400km in a single charge. It is forecasting that this battery will be available for EVs used by 2020.

The batteries under development today utilize a Lithium metallic in the negative electrode to have a higher energy density. Most of these systems are however for the moment unstable and have a cycle life that remains very weak. Among these new technologies, the Lithium-air is interesting. Unlike Li-ion batteries, the Li-air doesn't use oxide metallic in the positive electrode, it utilizes Lithium as anode material and a carbon which reacts to the air which encircles the cathode to produce electricity. According to academic predictions, this battery has a very high energy density that is between 500 and 1,000Wh/kg [15]. Its number of cycles of charge-discharge is however only 50 cycles.

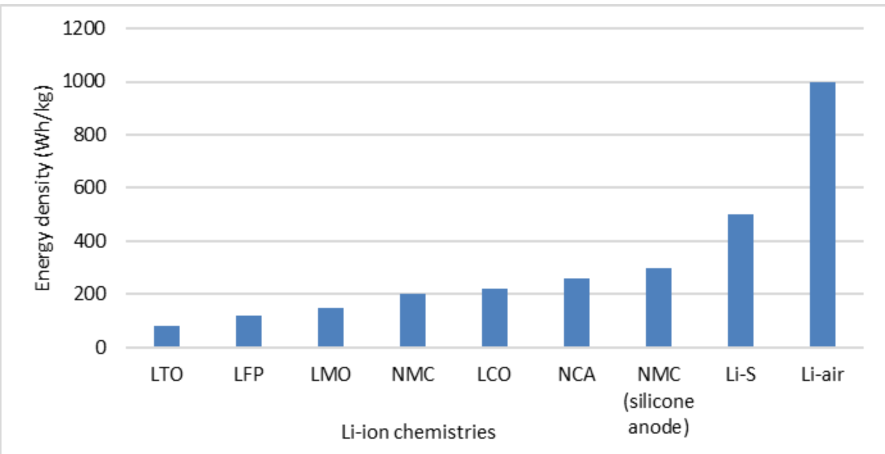

Fig.7. Comparison of the energy density of different technologies of Lithium batteries (Source: http://batteryuniversity.com)

Another encouraging technology is the Lithium-sulfur (Li-S) [15]. It gives an energy density that can reach 500Wh/kg and its specific power is 2,500W/kg. This technology uses a Lithium metal as electrode positive and a lighter sulfur in the other electrode. However, it suffers of a very weak cycle count (40 – 50 cycles) compared to standard Lithium-ion batteries. It is also unstable at a higher temperature.

4. CONCLUSION

This work provided statistics about sales of plug-in electric vehicles (BEVs and PHEVs) in the world for 2011 to 2016, and about global stock of these vehicles in December 2016. Thereby, last year, there was over two millions EVs on the world. More than half of these vehicles are located in two countries, the United States and China. At the end of December 2016, plug-in electric vehicles represent 0.1% of the total number of cars worldwide and its market share is only 0.85%. However, sales of these vehicles increased significantly since 2011 and will continue on it by the next years. Besides, we also saw in this paper the progress of Lithium-ion battery performance, especially its energy density, and consequently, the evolution of the driving range of all-electric cars since the introduction in the market of the Nissan Leaf in late 2010. Finally, other promising battery chemistries have been presented in the last section of this document. However, even if their energy density is high, many works remain to be done to have a battery as effective as gasoline and diesel.

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