

Review of Traction Battery Industrialization for Plug in Electric Vehicles in Chinese Market

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Summary

Developing plug-in electric vehicles (PEVs) has been taken as state strategy by Chinese government and series supporting policies have been introduced, leading to the rapid growth of PEVs industry of China. China ranks the first in PEVs output and ownership, and becomes the biggest traction battery production country with capacity exceeding 20GWh in 2015. The traction battery technologies roadmap is diversity for different kind of new energy vehicles in China. To review the characteristics of the revolution of traction battery technologies and industry is very necessary for Chinese government to re-evaluation the reasonability of the state research and development plan in next 10 years. In this research, a lot of survey of traction battery technology and industry is done. Based the detailed statistics, the rules the traction battery revolution has been found. The technology roadmap of various traction battery is clarified and the progress of traction battery industrialization is reviewed by models of new energy vehicles. Based on the analysis of traction battery technology and industry progress, the prospective of traction battery roadmap can be presented reasonable.

Keywords: electric vehicles, lithium battery, energy storage system, technology roadmap, installed capacity

1 Introduction

The Chinese automotive industry is facing severe challenges. With the ownership of vehicles sharply increasing, the issues of energy security are aggravated and sustainable development problems of transport section become one of urgent problems to be solved for China. Chinese vehicles ownership surpassed America in 2009, becoming the biggest vehicles production and output country and it has remained a rapid growth rate of above 6 %. In 2015, the output of vehicles of China is 24.59 million, including 21.14 million passenger cars and 3.45 million commercial vehicles[1], accordingly, the ownership of vehicles in China has been climbed to 172million, ownership of private cars being 124 million, and ownership of 100 household being 31. In megacity, such as Beijing, Chengdu, Shenzhen, ownership of private cars very 100 households is more than 60[2], indicating that China is stepping automotive society. The rapid increasing of vehicles ownership aggravates energy security issue. From 2009, Chinese foreign oil dependence exceed 50%, which is the security alarming value, and has been growing. In 2015, Chinese foreign oil dependence exceed 60.2%[3].

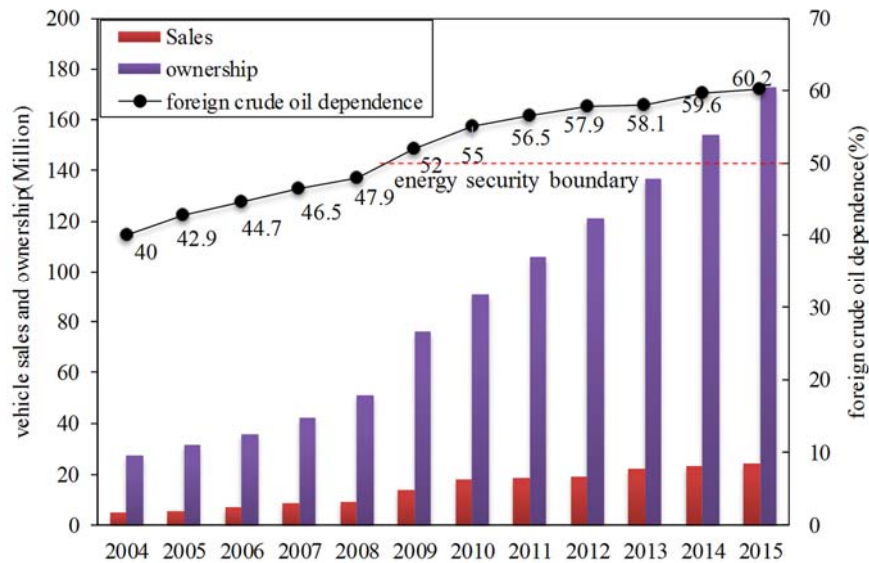


Figure1: automotive industry development with energy security

Secondly, the urban air pollution causing by tailpipe emission is becoming severe and the issue of PM2.5 is paid close attention by international, especially in typical city circles, such as Beijing, Tianjin and other cities[4, 5]. Relevant research shows that the tailpipe emission by vehicles is the main source of harmful emission to human health, such as PM2.5[6]. Chinese government has pay more importance on controlling the frog and series policies are introduced.

In addition, Chinese automotive industry are in the transition from big vehicle output country to advance in vehicles technologies. In internal combustion engine vehicle(ICE), China fall behind a lot on core technologies, such as engine control technologies. In term of the new energy vehicles, China start researching and industry fostering early, and the traction battery technologies and industry are at advanced level in the world, so it is expected to be the breakthrough point for China to become strong automotive country. Developing new energy vehicles is the only way for China being competitive in the automotive industry in the world[7].

The relevant research results show that the urban air pollution caused by tailpipe emission can be resolved by developing NEV effectively[8]. Long all electric range(AER) electric vehicles, including battery electric vehicles, plug-in hybrid electric vehicles and range extended electric vehicles, contribute to sustainable transportation, so Chinese government take developing NEVs as state strategy[7, 9-11]. State R&D key programs of NEVs are established in the 10th 5-year plan, 11st 5-year plan, 12nd 5-year plan and 13rd 5-year plan, funding 880 million RMB, 1.1 billion RMB, 2.8 billion RMB and 3.0 billion RMB respectively to support the technologies breakthrough and mass market penetration[12-17]. Developing electric vehicles has been taken as state strategy by Chinese government, there are concentrated supporting policies are issued continuously. The policy system taking fiscal incentive as core has been set up to push the comprehensive development of NEVs technologies and industry.

By the supporting of state incentive policies, the NEV industry grow rapidly. In 2014, China become the second big country of plug-in electric vehicles ownership and annual sales, exceeding Japan. By the end of 2015, the annual sales of NEVs is 397,000(normal hybrid electric vehicles are not included), including 39% battery electric cars, 24% battery electric buses, 17% plug-in hybrid electric cars, 13% plug-in hybrid electric buses and 7% battery electric special vehicles[18]. In 2015, the mark share of NEVs in new sale vehicles is increased to 1.5%, and China rand first in annual sale of NEVs, exceeding America(Annual sale is 114,000[19, 20]), and also rank first in NEVs ownership with 497,000[21].

2 Traction battery state developing plan

Chinese government has funded to research and develop traction battery from 2001, and the development of traction battery experience 3 stage in China:

The initial stage, the different kind of battery technology have been tried, and the NiMH and LiMn₂O₄(LMO) is the main energy storage system before 2005. From 2005, more funding has been placed on LiFePO₄(LFP)

battery research and development. From 2010-2015, the, it is a stage of transition for technology battery roadmap, Li(NiMnCo)O₂(NCM) type traction battery begin developing targeting to 180Wh/kg. The energy limit almost has been reached up to 140Wh/kg.

The state plan of electric vehicle developing has been introduced in succession. In the R&D project of EVS, the traction battery technology is in the most important position, and much funding is invested on it to support develop high performance power type traction battery for hybrid electric vehicles and energy type traction battery for battery electric vehicles. The state R&D objectives of traction battery is shown as figure 2.

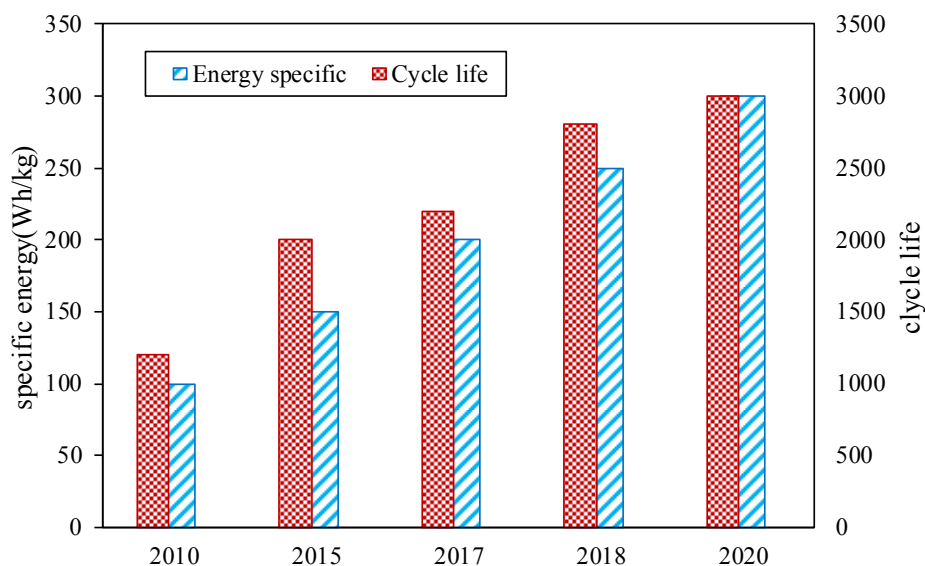


Figure2: Chinese traction battery target

In the state plan of 2016-2020, the traction battery performance is expected to increased greatly, and specific energy of cell will be increased to 300Wh/kg for large scale application, 400Wh/kg for small-scale application, and 500Wh/kg for new system battery material[22, 23]. The LFP anode material will be researched to develop composite material to improve the cell voltage, such as mixed with manganese material.

3 Progress on traction battery industrialization

The automatic production line has been used widely, replacing the previous semi-automatic production line of traction battery. The performance of mass production traction battery has been improved greatly. The specific energy of generally produced size of lithium battery cell with anode of LFP of 20Ah, 200Ah are 130Wh/kg and 135Wh/kg, and specific energy of lithium battery cell with anode of NCM of 2.6Ah is 180Wh/kg[24]. The warranty of traction battery pack is general 6 years or 100,000 km.

From 2009 to 2013, the industrialization of traction battery progress slowly (see figure 3), and accumulative installed traction battery capacity in five years only 2GWh, however in 2015 annual installed traction battery capacity on NEVs is more than 20GWh. The market share of battery for battery electric buses is 72%. From 2013, the electric vehicles industry progress rapidly to push the traction battery industry development and the technology updated. In 2015, the traction battery often is in short of supply, especially for high quality traction battery from the companies like CATL, Wangxiang, etc.

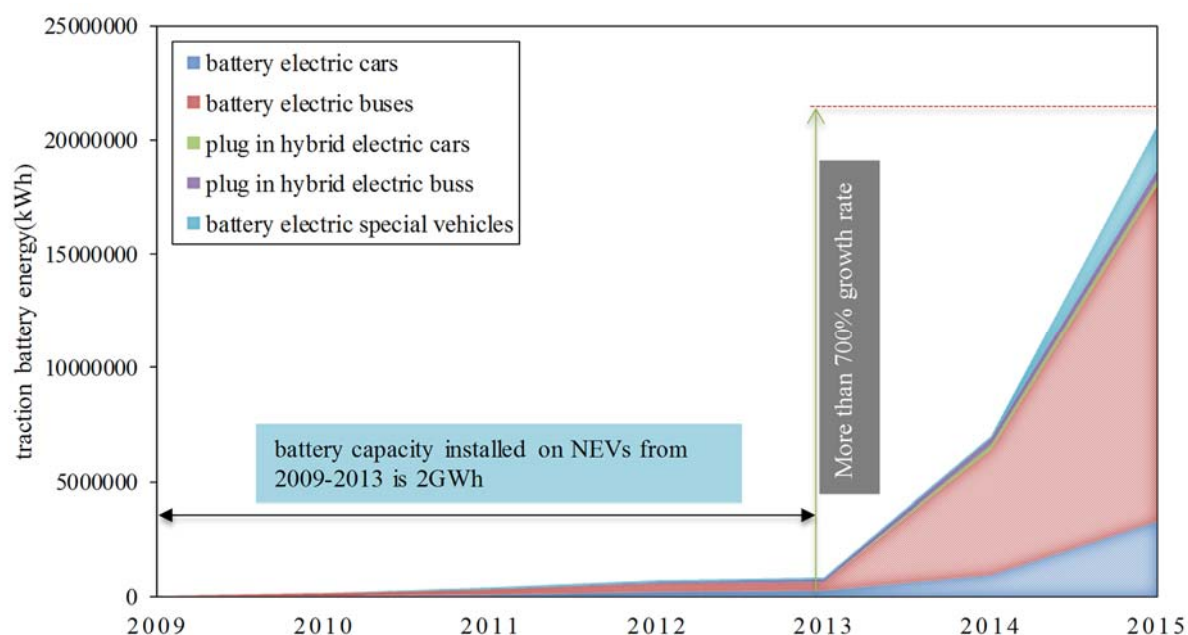


Figure3: the market shares of traction battery for different electric vehicles

The rapid development of NEV's industry promote the traction battery industry. In 2015, the installed battery on electric vehicles is increased to 20GWh, with 200% growth rate. The battery market shares of different electric vehicle are shown in figure 4. The battery applied in battery electric buses accounts for 72% market share, battery electric cars accounts for 16% and battery electric special vehicles accounts for 9% and battery of PHEV only accounts for 3%, so the energy type traction battery is the largest market share in Chinese market.

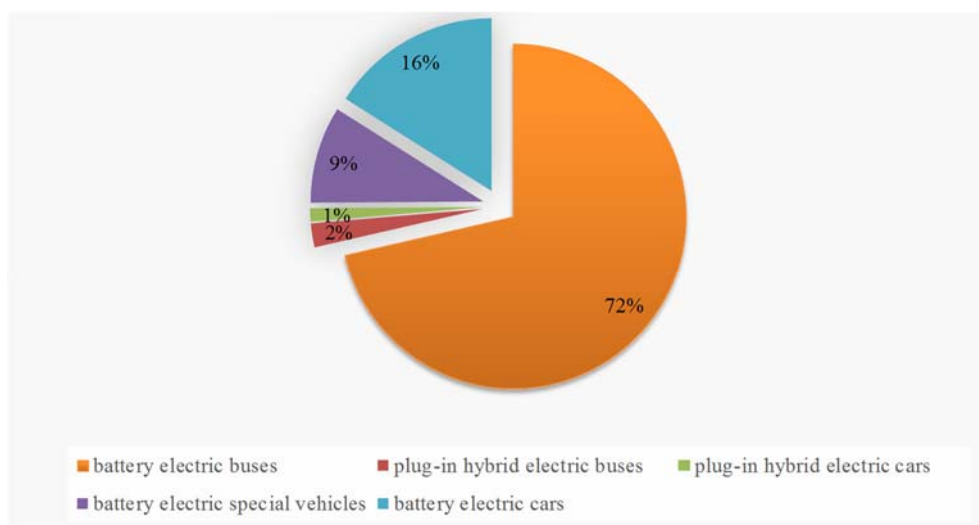


Figure 4: the market shares of traction battery for different electric vehicles in 2015

In terms of capacity market shares of the traction battery application the electric vehicle models, the progress can be seen clearly in figure 5. The battery electric buses rank first in traction battery installed capacity, accounting for more than 50% market share up to 80% except in 2013. The battery capacity of battery electric cars accounting for 10-30%. The two section in the main battery capacity usage fields.

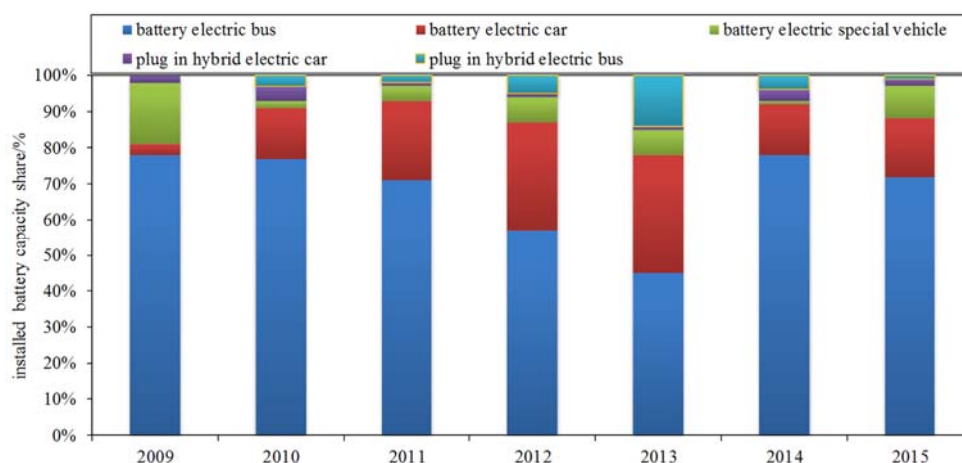


Figure5: the market shares of traction battery for different electric vehicles

The comparison between Chinese main battery companies with other international companies are shown in figure 6. The lithium battery cell is mainly steel shell type, and most products from Japanese companies and Korea companies is pouch type. In term of specific energy, Chinese local companies fall behind a little at cell level compared with advanced traction battery companies in the world, but fall a lot in the traction battery integrated and system technologies, so this point is the focus of next 5 years' state new energy vehicles plan.



Figure6: specific energy comparison with international companies

The 4 main traction battery industry clusters have been formed, including Pearl River Delta, Yangtze River Delta, Beijing and Tianjin and the Central Plains region. By incomplete statistics, there near 200 battery companies provide battery for electric vehicle. Annual output capacity has reached 30GWh, supporting the rapid development of Chinese electric vehicle industry. The main traction battery companies are competitive in the world, per annual capacity up to 16GWh by BYD (see Table1)[25-31]. The production capacity of China ranks the first in the world.

Table1: the production capacity of Chinese main traction battery companies

	company	2014 (GWh)	2015(GWh)
1	BYD	4	16
2	OptimumNano Energy	2.5	5
3	CATL	1.37	1.73
4	Lishen	1	1.68
5	Shandong Wina	1	1.6
6	Zhonghanglidian	0.8	1.5
7	Guoxuan	0.8	1.5
8	Guangyu	0.7	0.85
9	Wanxiang	0.7	0.7
10	MGL	0.36	0.5
11	Jiewei	0.1	0.2

4 Review of traction battery technology roadmap

4.1 Battery electric cars

From 2009 to 2015, the accumulative sale of battery electric cars has reached to 200,000, and the accumulative installed battery capacity of battery electric cars is 3.45 GWh, that of 2015 accounting for 95.5%, and the traction battery technology roadmap revolution is shown in figure 7.

The energy type traction battery is required by battery electric cars and battery electric buses. The traction battery installed on battery electric cars is mainly LFP before 2013, and after 2013 the application of NCM battery become more widely, especially on micro battery electric cars. The high temperature performance of LFP is better than NCM battery at present technology level, but low temperature performance is still not satisfying. In winter, Beijing for example, the AER is decreased sharply, even by 50% dropping.

The performance NCM battery for battery electric cars in increased apparently, especially in specific energy.

The specific energy of most NCM battery meeting the safety testing standards is about 180Wh/kg. The specific energy of 3.7V/38Ah battery provided by Wangxiang reached 170Wh/kg and specific power is 650W/kg, which has been installed on battery electric cars. The battery system technologies are as important as cell level, especially safety technologies, so the 2016-2020 the traction battery system technologies is assigned as one of focus to breakthrough. Accuracy of SOC estimation is no more than 8% for battery electric cars currently. From the statics in 2015, the market share of NCM battery is more than 60%, because in the micro and small size battery electric cars dominant the Chinese battery electric cars market, accounting for more than 70% in battery electric cars sales, and this kind of battery electric cars almost install NCM battery, especially for 18650 batteries. A typical kind of NCM battery applied widely on A0 class electric cars is shown as Table2. Performance of low temperature is better than that of LFP battery in operation.

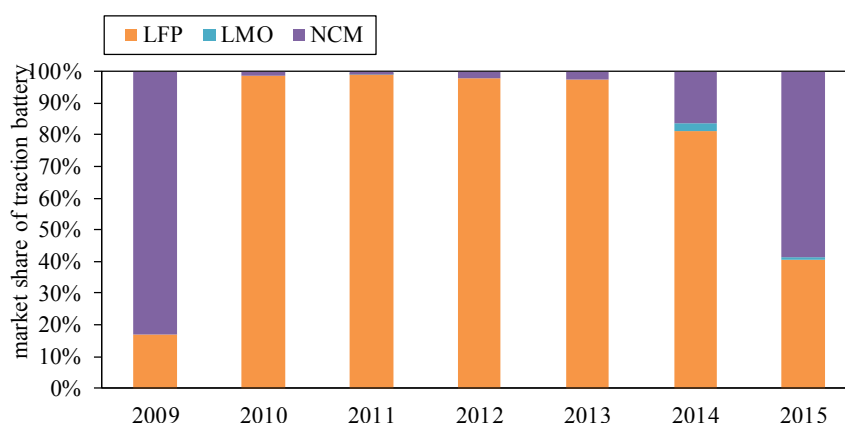


Figure 7: battery technology roadmap evolution in Chinese market

Table2: parameters of a typical NCM traction battery for battery electric cars application

Items	Testing results
Rated capacity(Ah)	25.0
Rated voltage(V)	3.8
Voltage range	3.0-4.2
Mass(kg)	600g
Specific energy(Wh/kg)	162
Operation temperature	-20℃～+55℃
Self-discharging current	25A/50A
-20℃ discharging capability	55℃/7Days: 3.05%.

4.2 Plug-in hybrid electric cars

From 2009 to 2015, the accumulative sale of plug in hybrid electric cars have reached 82,000, and the accumulative installed battery capacity of plug-in hybrid electric cars is 256MWh, that of 2015 accounting for 99.8%, and the traction battery technology roadmap revolution is shown in figure 7. It can be concluded that the main traction technology is LFP lithium battery, and before 2015 the market shares of LFP is 100%, being 97% in 2015. The NCM battery begin to be applied on plug in hybrid electric cars in 2015, the its market share is gradually increased.

The models of plug in hybrid electric cars in Chinese market are only 6, including 4 local models, 2 from BYD, 1 from SAIC, and 1 from GAC. The energy storage system almost is LFP, determined by the model of BYD, because of its market share being more than 80%. To improve the AER and decrease the battery cost, the NCM battery begin to be applied on plug in hybrid electric cars by BYD, such as the model of Yuan. The specific energy of LFP battery on plug in hybrid electric cars is up to 140Wh/kg, close to the limit of that kind of material system, and the cycle life has been increased to 4,000. The price has been decreased to a stable value as 2.5RMB/Wh.

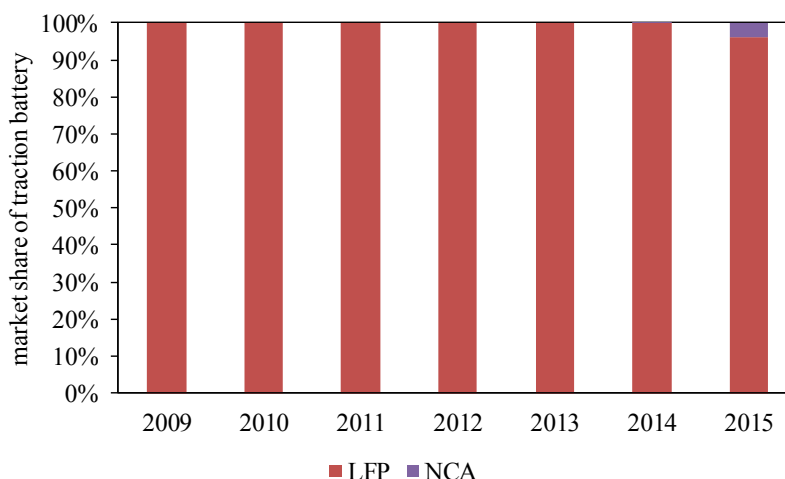


Figure 8: the battery technology roadmap revolution of plug in hybrid electric cars

4.3 Battery electric buses

From 2009 to 2015, the accumulative sale of battery electric buses has reached to 106,000, and the accumulative installed battery capacity of battery electric buses is 14.68GWh, that of 2015 accounting for 99.96%. The battery installed on battery electric buses accounting for most market share of all traction battery for electric vehicles, due to its high capacity pack installed on per vehicle, generally being more than 200kWh

for heavy duty buses. The traction battery technology roadmap revolution is shown in figure 8. Based on the statistics of battery capacity market share, LFP battery is dominant in battery electric buses. In 2015, the market share of NCM battery is increased greatly due to its application on 6 m, 7 m and 7 m length light duty electric buses. From a security perspective, the NCM battery is scarcely adopted by 10m to 12m length electric buses.

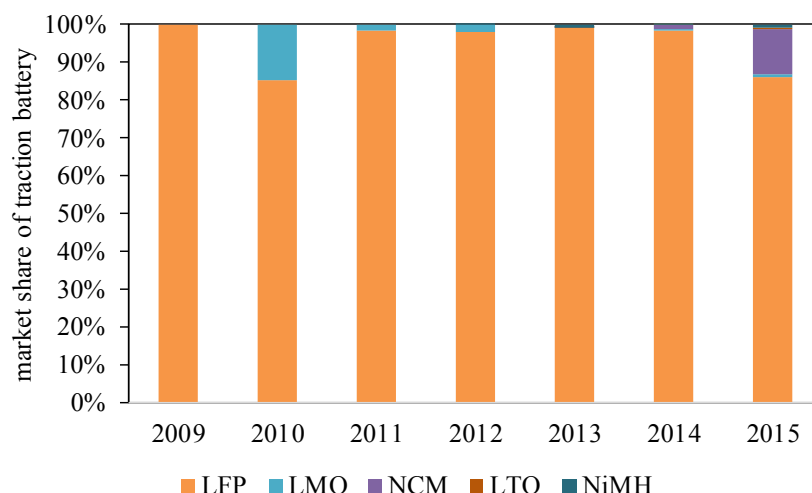


Figure 9: the battery technology roadmap revolution of battery electric buses

4.4 Plug-in hybrid electric buses

From 2009 to 2015, the accumulative sale of battery electric buses has reached to 106,000, and the accumulative installed battery capacity of battery electric buses is 513MWh, that of 2015 accounting for 89%.

From 2013, new subsidy policy was introduced, in which the normal hybrid electric bus was excluded and only large plug-in hybrid electric buses (length is over 10m) were qualified for getting subsidy of 25,000 RMB. In 2010 and 2011, 100% energy storage system is LFP of plug in hybrid electric buses (see figure9). In 2012, the fast charging pure electric bus is introduced by Hengtong Bus company, with LTO as cathode material. Cycle life of this kind traction battery is expected to 20,000 and maximum charging current can reach over 6C. The electric buses with LTO battery can be charged in 10 minutes to 50kWh energy at charging condition of 650V/500A, to drive the bus running 50km.

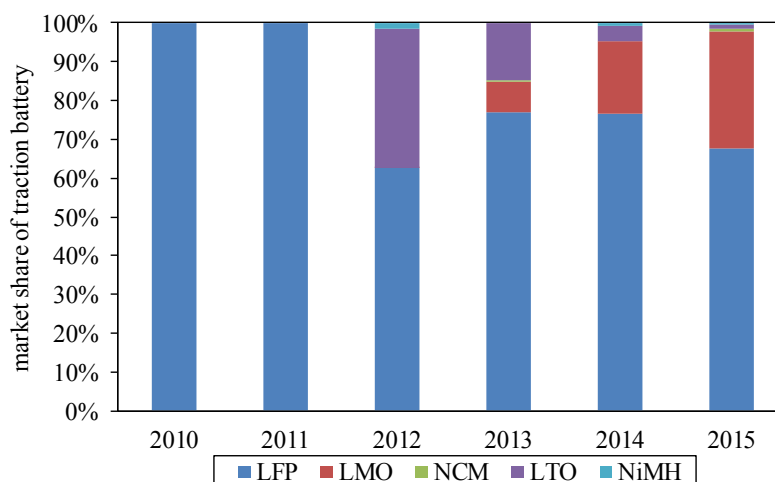


Figure10: the battery technology roadmap revolution of plug in hybrid electric buses

LMO battery is updated to meet the requirement of plug in hybrid electric buses, Ni being mixed in the anode material of LMO. The charging rate characteristics is excellent. When the battery is charged at 3C constant current, the temperature is only raised from 31°C to 37°C and from 31°C to 40°C at 4C charging. The battery capacity remains 80% after 2200 cycle at 1C charge/discharge and 25°C.

Table3: Typical power and energy type traction battery for PHEV application

Rated capacity(Ah)	35
Rated voltage(V)	3.6
AC resistance (mΩ)	0.42
Mass(g)	1004
Specific energy (Wh/kg)	135
Maximum continuous discharge current (A)	280 (8C)
Cycle life	≥1800 (1C 100%DOD, remaining capacity≥70%)
Operating temperature (°C)	-30~55
Storage temperature (°C)	-40~35

4.5 Battery electric special vehicles

From 2009 to 2015, the accumulative sale of battery electric buses has reached to 56,000, and the accumulative installed battery capacity of battery electric buses is 1.9G Wh, that of 2015 accounting for 98.8%. The traction battery technology roadmap revolution is shown in figure 10. The market share of LFO battery application on battery electric special vehicles is decreased gradually from 2010. From the statistics in 2015, it can be seen that the NCM is the dominant energy storage system for battery electric special vehicles, due to its low cost compared with LFP(see figure11). The battery electric special vehicles in China are mainly sanitation trucks before 2015. The battery electric special vehicles in China are mainly micro logistics vehicles in 2015, cost-effective is the main objective, so much traction battery is from the battery suppliers of low speed electric vehicles and electric bicycles. The price of the NCM battery for battery electric special vehicles is lower than 2 RMB/Wh, and the comprehensive performance is not well as that of battery electric cars. The 18650 cylindrical battery of NCM anode is applied widely.

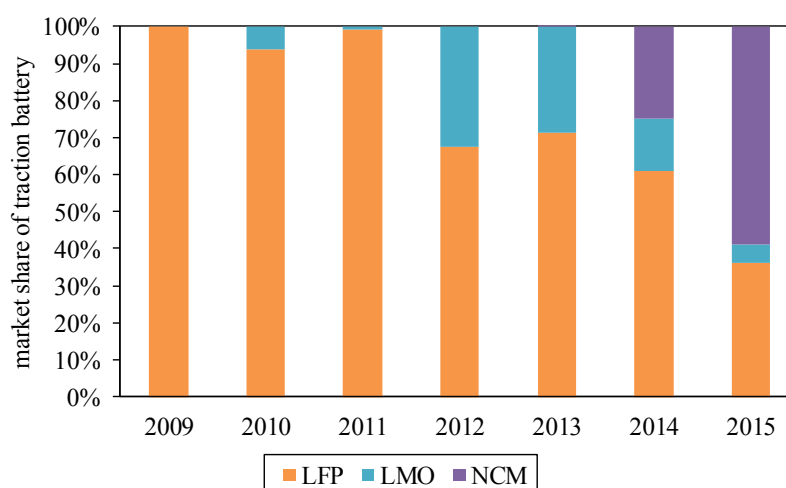


Figure11: he battery technology roadmap revolution of battery electric special vehicles

5 Conclusion and discussion

By analysis of the progress of the electric vehicle and traction battery industry of China, the main technologies roadmap is clarified as following:

- (1) The limit of LFP has been reached by most Chinese battery companies, the top specific energy being about 140Wh/kg, and new kind of anode material has been developed for passenger cars to improve the AER further.
- (2) The NCM is become the dominant technology of anode electric cars traction battery to reduce cost, improve AER and energy efficiency, the specific energy is 180Wh/kg generally, but the performance of safety and cycle life need to be improved further.
- (3) The NCM battery is the optimal choice for light duty buses for the cost-effective objective, and in next 5 years it will be the main energy storage of battery electric special vehicles.
- (4) For security reasons, the NCM battery still shouldn't be applied in heavy duty electric buses.
- (5) New type cathode, such as silicon-carbon composites material will be developed to improve the energy density further.
- (6) To improve the traction battery safety of conditions both in charging and operation, the battery system technologies must be focused besides improve the cell technology.
- (7) There too much lithium battery companies in China, and output of traction battery is overcapacity, but high quality traction is in shortage. The traction battery industry of China must be concentrated to foster large international enterprises with international competitiveness.

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References:

- [1] Analysis of Chinese Automotive Industry Situation in 2015, <http://www.caam.org.cn/zhengche/20160112/1605183563.html>, access on 2016-3-16
- [2] Ministry of Transport of the People's Republic of China, <http://www.mps.gov.cn/n16/n1252/n4386914/4990136.html>, access on 2016-3-10
- [3] cpcia, <http://www.cpcia.org.cn/html/13/20161/152634.html>, access on 2016-3-16
- [4] Ministry of Environmental Protection of the People's Republic of China, http://www.zhb.gov.cn/gkml/hbb/bwj/201407/t20140729_280610.htm, access on 2016-3-16
- [5] State council, http://www.gov.cn/xinwen/2015-12/06/content_5020614.htm, access on 2016-3-16
- [6] Beijing Government, <http://www.bjepb.gov.cn/bjepb/413526/331443/331937/333896/396191/index.html>, access on 2016-3-16
- [7] Xinhua NET, http://news.xinhuanet.com/2014-05/24/c_1110843312.htm, access on 2016-3-16
- [8] Huo H., Zheng B., Wang M., Zhang Q., He K.: Vehicular air pollutant emissions in China: evaluation of past control policies and future perspectives. *Mitigation and Adaptation Strategies for Global Change*. 20. 719 (2014). , access on 2016-3-16
- [9] State Council of China, http://www.gov.cn/zhengce/content/2014-07/21/content_8936.htm, access on 2016-3-16
- [10] State Council of China, http://www.gov.cn/zwgk/2012-07/20/content_2187770.htm, access on 2016-3-16
- [11] State Long-term Scientific and Technological Development Plan (Full Text), http://www.gov.cn/jrzq/2006-02/09/content_183787.htm, access on 2016-3-11
- [12] Ministry of Finance of the People's Republic of China,, http://www.gov.cn/gzdt/2012-10/12/content_2242395.htm, access on 2016-3-12
- [13] Ministry of Fiscal of People's Republic of China,, http://www.mof.gov.cn/zhengwuxinxi/caizhengwengao/2009niancaizhengbuwengao/caizhengwengao2009dierqi/200904/t20090413_132178.html, access on 2016-3-16
- [14] State Council of China, http://www.gov.cn/gzdt/2014-02/08/content_2581804.htm, access on 2016-3-16
- [15] Ministry of Finance of the People's Republic of China, http://jjs.mof.gov.cn/zhengwuxinxi/tongzhigonggao/201309/t20130916_989833.html, access on 2016-3-16
- [16] State Council of China, http://www.gov.cn/zwgk/2012-09/18/content_2227036.htm, access on 2016-3-16
- [17] Ministry of Science of Technology of the Peoples Republic of China. The Technology Report of Electric Vehicles State R&D Program in 11st 5-year plan. Beijing: MOST, 2012, 70 P.
- [18] Ministry of Industry and Information of People's Republic of China, <http://liulihua.miit.gov.cn/n1146312/n1146904/n1648362/n1648363/c4622444/content.html>
- [19] Monthly Plug-In Sales Scorecard, <http://insideevs.com/monthly-plug-in-sales-scorecard/>
- [20] Electric Drive Sales, <http://electricdrive.org/index.php?ht=d/sp/i/20952/pid/20952>, access on 2016-3-16
- [21] Ministry of Transport of the People's Republic of China , <http://www.mps.gov.cn/n16/n85753/n4449431/4473813.html>, access on 2016-3-16
- [22] Ministry of Science of Technology of the People's Republic of China, http://www.most.gov.cn/tztg/201502/t20150216_118251.htm, access on 2016-3-16
- [23] Tsinghua University, The developing strategy of new energy vehicles technology and industry in 2016-2020 of China. Beijing: MOST, 2015. , access on 2016-3-16
- [24] Ministry of Science of Technology of the Peoples Republic of China. The report of electric vehicles key

program in 12nd 5-year plan. Beijing: MOST, 2015.

- [25] Lishen battery company, http://www.lishen.com.cn/comcontent_detail_product/&FrontComContent_list01-1370586587730CurrentIds=5__23&comContentId=23.html, access on 2016-3-16
- [26] China ALT battery company, http://www.catlbattery.com/index.php/product_show-typeid-5.html, access on 2016-3-16
- [27] Shenzhen BAK battery company, <http://www.bak.com.cn/product/list.aspx?cateid=11529>, access on 2016-3-16
- [28] Shandong Wina battery company, <http://www.winabattery.com/>, access on 2016-3-8
- [29] Heifei Guoxuan battery company, <http://www.hfgxgk.com/>, access on 2016-3-6
- [30] CNCOSlight, <http://www.cncoslight.com/index.asp>, access on 2016-3-1
- [31] MGL, <http://www.mgldl.com.cn/>, access on 2016-3-16