Current Status and Future of Energy Storage System for EV

C.C. Chan
University of Hong Kong, Pokfulam Road, Hong Kong
Tel (852)-2859 2709, Fax (852)-2559 8738

Liqing SUN
School of Mechanical and Vehicular Engineering, Beijing Institute of Technology
No.5 South Zhongguancun Street, Haidian district, Beijing, P.R. China
Tel: 86-10-86183862 68915205, Fax: 68915205

Ruchuan LIANG
School of Mechanical and Vehicular Engineering, Beijing Institute of Technology
No.5 South Zhongguancun Street, Haidian district, Beijing, P.R. China
Tel: +86-10-68911524 ext 8013

Qingcai WANG
School of Mechanical and Vehicular Engineering, Beijing Institute of Technology
No.5 South Zhongguancun Street, Haidian district, Beijing, P.R. China
Tel: +86-10-68911524 ext 8049

Abstract

The Energy Storage System(herein after referred as ESS) consists of batteries and/or ultra-capacitors and BMS. Different type of EVs need different ESS. ESS is the key to the future of EV including PEV and HEV. The paper will present the current status and the future of ESS for PEV and HEV separately.

Keywords: EV, HEV, FCEV, ESS , Battery, Ultra-capacitor

1 Background

The energy storage system is the key to success of EV, HEV and FCHV vehicles. With the progress of material technology, processing technology and the electronics, the performance of ESS has been improving for the complete commercialization of different kinds of EVs. The traction battery is the major part of the ESS. The successful commercialization of HEVs of Japan has proved that the ESS for HEVs has become mature enough. While the new trend in battery EV such like the REVA in Europe and North America gives us a new signal that the ESS for battery vehicle is entering a new era..

The Lead acid battery EES and Ni-Cd ESS are fading out with the more and more strict criteria on environmental friendly performance. The Ni-MH and Lithium batteries are the main streams of ESS for EV, HEV and FCHV vehicles today and for commercial ICE vehicle with larger and larger power of on-board electronic devices. Fuel cell is the future technology in view of commercialization as has been widely accepted.

2 Definition of Traction Battery

Traction battery is the key component of ESS, and it is a kind of energy storage system to drive motor by means of transforming chemical energy to mechanical energy with start current more than two times of that at normal working condition.

3 History of Traction Battery

The history of traction battery can be divided as four generations as listed in Table 1.

Table 1: The history of traction battery

Generation	I	II	III	IV
Main type	Lead acid battery	Alkaline battery	Lithium battery	Fuel Cell battery
Sample	VRLAB	Ni-Cd NiMH	LIB PLIB	PEMFC DMFC
Pollution	+++++	Ni-Cd +++++ NiMH+	+	Zero
Price	100%	200%	400%	800%
Mature	best	best	In batch	Not mature

4 Characteristic of Ideal Traction Battery

The characteristics of ideal traction battery are as follows, (1)High energy and power. (2) High power density and high energy density. (3)Long life cycle (over 10 years). (4) High Uniformity in internal resistance and voltage. (5)Wide working temperature range (-30-65°C).(6)No safety problem.(7)Monitored easily and accurately .(8)Maintenance free.(9)Low price .(10)No memory effect.(11)Long time reservation.(12)Reliability.(13)No pollution.

5 Current Status

5.1 ESS of Energy Type

5.1.1 Lead acid battery

The lead acid battery is the main type traction battery of ESS for EV today. Most light EVs(over 98% LEV in China) are powered by lead acid battery. The E-Car exported to USA and the REVA sold in UK are mostly powered by lead acid battery. Anyway, the ones powered by lithium battery have emerged on market. There are several companies in China who are experts in lead acid battery production such like Shanghai C&D Battery Co. Ltd., Tianhong Energy Technology, Dongbei Storage Battery, Beijing Powertronics Battery Co. Ltd., Zhejiang Tiannneg Battery Co. Ltd. and Shuangdeng Group Corporation. In Japan, GS-Yuasa has large capacity lead acid battery for traction application.

5.1.2 Ni-Cd Battery

The France is the largest consumer of Ni-Cd batteries for EVs. However, the Ni-Cd battery is fading out the market because of its bad environmental performance due to the use of Cd element.

5.1.3 Lithium Battery

The lithium battery for ESS for EVs can be divided into four kinds according to the anode materials. The comparisons of different anode materials are listed in Table 2.

Table 2: comparisons of different anode materials of lithium battery

Anode material	Discharge capacity(mAh/g)	Discharge Voltage(V)	Heat stability	Life Cycle	Safety	price
$LiCoO_2$	130-140	3.6	bad	good	bad	high
$LiMnO_2$	100-120	~4.0	bad	general	better	low
$LiFePO_4$	~140	3.4	best	best	better	low
$Li_3V_2(PO_4)_3$	>170	~4.0	best	best	better	lowest

It can be seen that the theoretical rated capacity of $Li_3V_2(PO4)_3$ is 197mAh/g and the inverse capacity can reach 170mAh/g and the discharge voltage is the same as that of $LiMnO_2$ while the price is lowest among them. Anyway the $LiFePO_4$ battery has been produced in batch and it taken as the most suitable for traction battery for ESS of battery EVs in view of commercialization at present. The most intensive competition in $LiFePO_4$ battery patents between Black & Decker, A123 Systems, Hydro-Quebec, Phostech Lithium, Good enough and Valence Technology in fact has given us a clear clue that the $LiFePO_4$ battery is the very battery for EVs today.

As studied, the technology level of lithium battery for ESS nowadays has partially reached the goal of the midterm of USABC(see Table 3) as shown in Figure 1.

Table 3 Performance Targets of EV Battery (USABC)

	Lowest Target for Market	Long-term Target
Power density W/L	460	600
Rated power(Discharge, 80%DOD, 30s) W/kg	300	400
Rated power(charge, 20%DOD, 10s) W/kg	150	200
Energy density Wh/L	230	300
Energy density Wh/kg	150	200
Life Cycle(80%DOD)	1000	1000
Operation temperature	-40~ 50 Capacity loss by Less than 20%	-40~ 85
High rate charge	20-70%SOC 150 W/kg(30min)	40-80%SOC (15min)

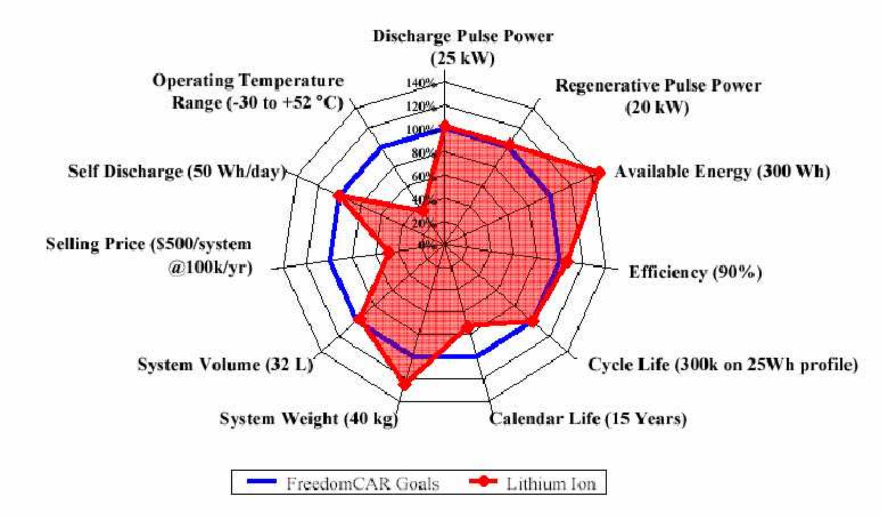

Figure 1 USABC Battery Target and Curent Battery technology Level

The representative companies in Lithium battery circle are MGL, Xingheng, Green Power, BYD, STL , Voltix, Thunder-sky and Huanyu. The main battery type produced by MGL and Xingheng is $LiMnO_2$, For the other companies is $LiFePO_4$.The Nano Chem Systems(Suzhou) is $Li_3V_2(PO4)_3$. The main batteries and their applications are shown in Figure 2 to Figure 5. Valence Technology, Inc., Electrovaya, Mitsubishi, Century Zinctech Ltd. and Pihsiang Energy technology Co. Ltd. also developed several kinds of lithium battery. Valence Technology, Inc. has successfully been the OEM suppliers for Segway. Coslight and Wangxiang also developed lithium battery and Wangxiang has used the battery on hybrid E-touring vehicles and battery buses as well as electric cars.

Figure 2 $LiMnO_2$ Battery of MGL and the battery bus for Beijing Olympic Games

Figure 3 $LiFePO_4$ Battery of Xingheng

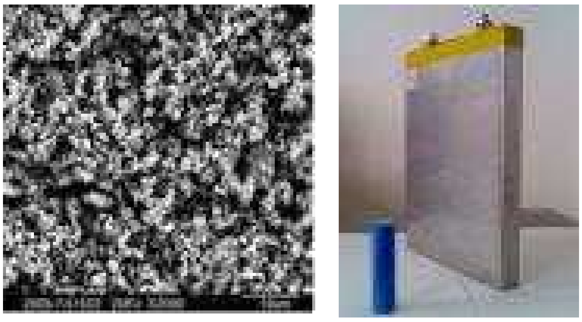

Figure 4 $LiFePO_4$ Material and Battery of STL, Tianjin, China

Figure 5 $LiFePO_4$ Battery of Voltix and Its Applications

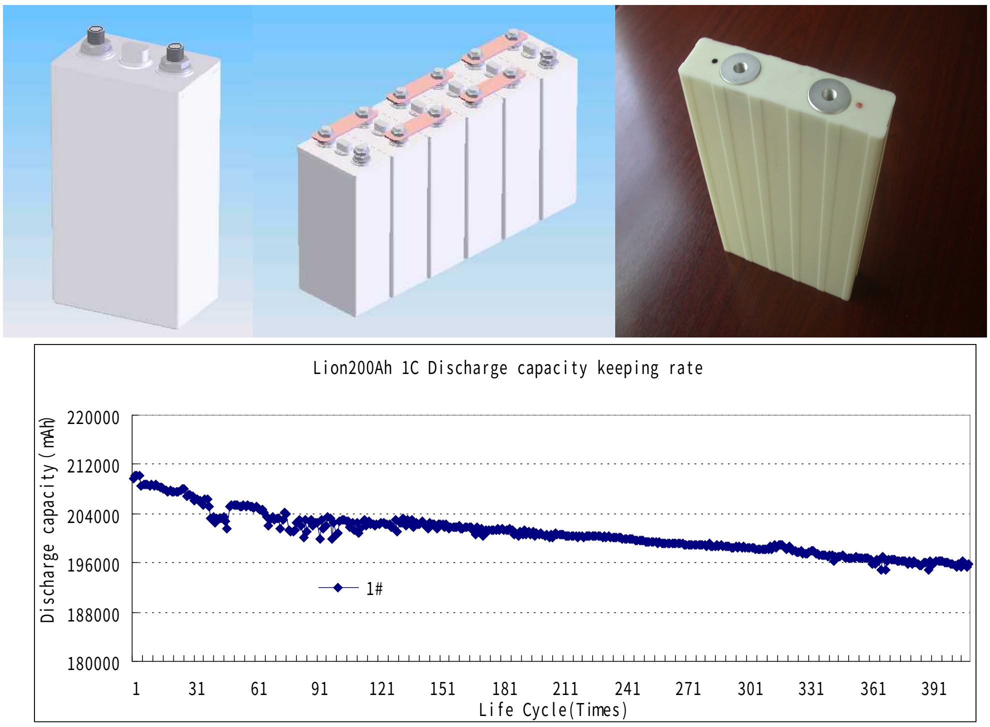

Figure 6 $LiFePO_4$ Battery of Huanyu and Its Life Performance

Figure 7 $LiFePO_4$ Battery of BYD and The E-car F3e

Figure 8 Li Battery of Thunder-sky and the EVs

Thunder-sky focuses on energy battery for EVs and other applications with large capacity battery of 10000Ah. Lately, thunder-sky announced its cooperation with FAW on a battery industry park of investment of RMB3.3 billion in Liaoyuan, Jilin Province, China. As reported, the company will head for a clear mobility era. The annual products consist of traction battery of 15 billion Ah and anode material of 6000 tons.

Figure 9 Li Battery of Lantian Double-cycle Tech Co Ltd and E-Car by Qingyuan EV

5.1.4 Ultra capacitor

Jurong, Shuangdeng and Aowei in China develop energy type UC for UC electric vehicle applications. An UC bus fleet has begun the commercial operation since last year. The UC and UC bus are shown in Figure 10.

Figure 10 Energy type UC and UCEVs by Aowei

5.1.4 Others

There are more than 3 units in China who focus on Zinc air battery development such like the Powerzinc, Shanghai, Changli Union, Beijing and a company in Guizhou Province. There also a Zinc Bromine battery company in Beijing, it used to develop a battery bus and now heads for E-bike applications. The Zebra's $NaNiCl_2$ battery also emerged and has been used for ESS for battery EVs.

Table 4 Comparison of ESS for Battery EV

	Lead Acid	NiMH	$LiMn_2O_4$	$LiFePO_4$	Ultra Capacitor
Rated Voltage(V)	388.8	388.8	388.8	390.4	600-300
Capacity	400 Ah	400 Ah	400 Ah	400 Ah	0.055F
Energy(kWh)	155.52	155.52	155.52	156.16	8-10
Weight(Kg)	4000	2625	1167	1500	1070
Price(RMB10000)	15	65	50	60	30
Operation Expense (RMB/Kwh)	1.67	2.68	6.25	6.25	1.67
Price ratio	160%	347%	374%	374%	100%

5.2 ESS of Power Type

5.2.1 Lead Acid

Besides lead acid energy type traction battery and lithium type, Yuasa also provides the high power type lead acid battery for hybrid vehicles.

5.2.2 NiMH power battery

The saft JCS developed high power Cylindrical NiMH of both NR6 with capacity of 6 Ah and 6NP7 with capacity of 7 Ah for Hybrid applications. GS Yuasa has developed P6A with capacity of 6.5 Ah NiMH high power battery for ESS of hybrids. The well-known Panasonic

EV Energy has high performance NiMH high power battery technology that has been commercially operated worldwide as shown in Figure 11.

Figure 11 High Power Pack for Hybrids of Panasonic EV Energy

Chunlan, Shenzhou and Peacbay have developed high power type NiMH battery and used them on Hybrids under the frame of 863 Key EV project as shown in Figure 12.

Figure 12 NiMH battery by Chunlan(left), Shenzhou(middle) and Peacebay(right)

5.2.3 Lithium power battery

The saft JCS developed high power Cylindrical Lithium of Both VLM with capacity of 27 and 41Ah and VLP with capacity of 20 and 30 Ah for Hybrid applications. GS Yuasa has developed P6A with capacity of 6.5 Ah NiMH high power battery for ESS of hybrids. GS Yuasa has developed EH6 with capacity of 6 Ah lithium high power batteries for ESS of hybrids. Xingheng, MGL and Green Power have developed high power type lithium battery for hybrid vehicles. Figure 13 is the battery of Xingheng, which has been adopted by hybrid cars. Panasonic EV Energy is developing the high power type lithium battery. The adoption by Prius hybrid car has been postponed to 2010.

Figure 13 High power lithium batteries of Xingheng

Figure 14 High power lithium batteries of Saft JCS

5.2.4 Power Type Capacity

Jurong, Shuangdeng and Aowei also have the power type large capacity UC for hybrids. Nissan Diesel, ECaSS Nichicon, Advanced Capacitor Technologies, Meiden, Suzuki and Nisshinbo in Japan announced their development of power ultra-capacitors on EVS22, Yokohama. The Maxwell, Esma and Nesscap also developed and lead the development. Anyway, Japan has a great research plan on UC and its application on EVs as well as conventional ICE vehicles.

Figure 15 Power Type Capacity by Companies in Japan

Table 5 Comparison of UCs of China with those outside of China

Company	Maxwell	Esma	Nesscap	Jurong	Aowei
Capacity(F)	>2600	>130000	>5000	>10000	>150000
Energy Density(Wh/Kg)	>4	>12	>6	5-12	>12
Power Density(W/Kg)	2000	800	2500	2500-3000	2000
Internal Resistance(mΩ)	<0.7	<0.4	<0.4	<1.0-1.5	<0.3
Life Cycle	10 years	10000 times	50000 times	20000 times	8-10 years
Price(RMB/Wh)	300-350	100-120	260-280	50-80	50-80

5.3 Capacity Battery

Nippon Chem-con EcaSS and Hitachi are developing a kind of battery with performance of both ultra-capacitor and energy type traction battery, which is taken as the next generation of ESS for both EVs and ICE vehicles.

Figure 16 Capacity Battery by Nippon Chem-con and EcaSS

5.4 Combined ESS

The combination of different batteries at present is feasible and practical ESS for EVs today. The typical combination categories are shown in Table 6.

Tab.3 Comparison of cost of hybrid power source

Indices	UC+Lead acid		UC+NiMH		UC+Lithium	
	UC	Lead acid	UC	NiMH	UC	Li
Total Energy(kWh)	1	155	1	155	1	155
Price(/Wh)	200	1.5	200	7	200	10
Ave. price(RMB10k)	20	23.2	20	108.5	20	155
Total Price(RMB10k)	43.2		128.5		175	

6 BMS of ESS

BMS is necessary for effective and reliable ESS. It should function at least as follows,

Capacity evaluation

Temperature Voltage and Current monitor

Equalization

CAN communication

The ideal ESS is that all battery cells has absolute uniformities. The BMS will not needed while ESS working. The price of ESS will be cut down.

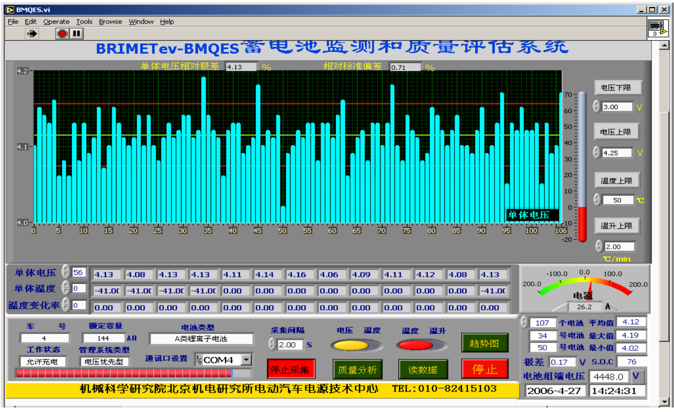

Figure 17 The BMS of ESS by Brimet for battery bus

7 Future of ESS

(1) The lead acid battery still will cover a considerable sector in years because of price factor.

(2) The advantages of $LiFePO_4$ is obvious, it will gradually substitute the lead acid ones in energy type.

(3) Capacity battery will become mature and replace the power type batteries for hybrids.

(4) Study results shows that the price decrease is less than 30% for lithium batteries. Anyway, with the large number of packs to be used on LEVs, it will become the main stream for ESS.

8 Reference

[1] http://news.sina.com.cn/c/2007-09-05/061512510863s.shtml

[2] http://www.jl.xinhuanet.com/jlzw/2007-09/14/content_11148542.htm

[3] International Forum on Lithium Power Battery'2006, The First Epoch City, Xianghe, China

[4] International Forum on Lithium Power Battery'2007, The First Epoch City, Xianghe, China

[5] Battery technology life verification test manual 2004(Advanced technology development program for lithium-ion batteries, Idaho national engineering and environmental laboratory)

[6] USABC electrochemical storage system abuse test procedure manual 1999

[7] Electric vehicle battery test procedures manual 1996(USABC)

[8] http://www.cngpower.com/Chinese/about.asp

[9] www.peacebay.com.cn

[10] http://www.xici.net/b390989/d57632484.htm

[11] http://club.battery.com.cn/showbbs_p1_36_37780_1.html

[12] http://www.xingheng.com.cn/beijing/docc/cpjs.htm

[13] www.thunsder-sky.com.cn

[14] www.shuangdeng.com.cn
[15] ww.cn-tn.com
[16] www.powertronics.com
[17] www.zjthny.com.cn
[18] www.saft.johnsoncontrols.com
[19] www.gs-yuasa.com
[20] www.zinctech.com
[21] www.phet.com.tw
[22] www.pues.co.jp
[23] www.valence.com
[24] www.electrovaya.com
[25] www.cnpower.com
[26] www.showa-aircraft.co.jp
[27] www.panasonic.co.jp
[28] www.chunlan.com
[29] www.szbatt.com
[30] www.act.jp
[31] www.nissan.co.jp
[32] http://ecass-forum.org
[33] www.nichicon.co.jp
[34] www.meidensha.co.jp
[35] www.nippon.chemi-con.co.jp
[36] www.nisshinbo.co.jp/seihin/rd/capacitor/index.html
[37] www.jrc.co.jp/product/ capacitor/index.html
[38] www.suzuki.co.jp
[39] www.nesscap.com
[40] www.esma.com
[41] www.coslight.com.cn/xdcgs.asp
[42] WWW.chinaev.org
[43] Electric Vehicle Research and Development, No.144-160, CES EV Institution, 2006-2007

10 Authors

Prof. C.C. Chan

Fellow, Royal Academy of Engineering,UK. , Academician, Chinese Academy of Engineering., President, Asian Electric Vehicles Society., Honorary Director, International Research Center for Electric Vehicles., Advisor and Director, Electric Vehicles Association of Asia Pacific (EVAAP)., Advisor to the President, Wuhan University. Distinguished Professor, Harbin Institute of Technology. Honorary Professor, University of Hong Kong, Pokfulam Road, Hong Kong

Tel (852)-2859 2709, Fax (852)-2559 8738 E-mail : ccchan@eee.hku.hk

Liqing SUN, **Assocaite Professor, Dr.-Ing,** School of Mechanical and Vehicular Engineering, Beijing Institute of Technology, No.5 South Zhongguancun Street, Haidian district, Beijing, P.R. China Tel: 86-10-86183862 68915205, Fax: 68915205 Email: slq_ev@163.com or sunlq@bit.eud.cn or slq_ev1@yahoo.com.cn

He is Deputy Secretary General of Special Committee of EV, China Electrotechnical Society, Co-editor of Journal of Asian Electric Vehicles and consultant of several EV related High-tech Corporations. His research interest is mainly in hybrid vehicles and fuel cell vehicle technology. He is mainly engaged in R & D of hybrid vehicles.

Ruchuan LIANG, Master candidate**,** School of Mechanical and Vehicular Engineering, Beijing Institute of Technology, No.5 South Zhongguancun Street, Haidian district, Beijing, P.R. China. Tel: +86-10-68911524 ext 8013, Email: liangruchuan@yahoo.com.cn

His research interest is mainly in hybrid vehicles and fuel cell vehicle technology.

Qingcai WANG Master candidate**,** School of Mechanical and Vehicular Engineering, Beijing Institute of Technology, No.5 South Zhongguancun Street, Haidian district, Beijing, P.R. China.

Tel: 010-68911524 Ext. 8049 Email: wangqingcai2003@163.com