Current Status and Future Trends of Energy Storage System for Electric Vehicles

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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 as 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.

4. CHARACTERISYIC OF IDEAL TRACTION BATTERY
The characteristics of ideal traction battery are as follows. [USABC, 1996, 1999]
(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 (-30-60°C).
(6) No safety problem.
(7) Monitored easily and accurately.
(8) Maintenance free.
(9) Lowprice.

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

(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

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.

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. [IFLPB, 2006, 2007]

As studied, the technology level of lithium battery for ESS nowadays has partially reached the goal of the mid-term of USABC (see Table 3) as shown in Figure 1. [USABC, 1996, 1999]

The representative companies in Lithium battery circle are MGL, Xingheng, Green Power, BYD, STL , Voltix,

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

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°C Capacity loss by Less than 20%	-40～85°C
High rate charge	20-70%SOC 150 W/kg (30min)	40-80%SOC (15min)

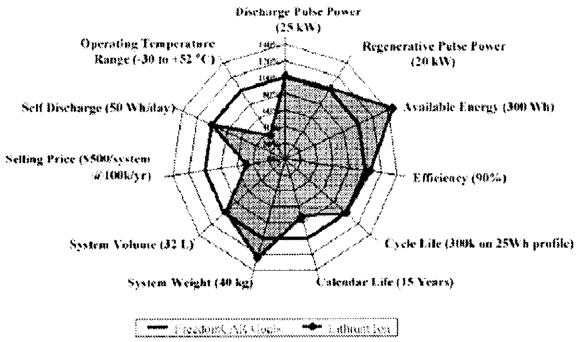

Fig. 1 USABC battery target and curent battery technology level [USABC, 1999]

Thunder-sky and Huanyu. [CES, 2007] 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.

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.

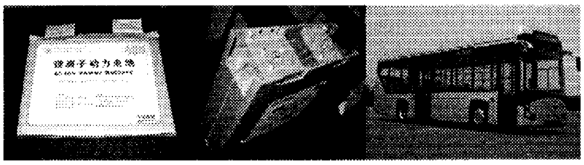

Fig. 2 $LiMnO_2$ battery of MGL and the battery bus for Beijing Olympic Games

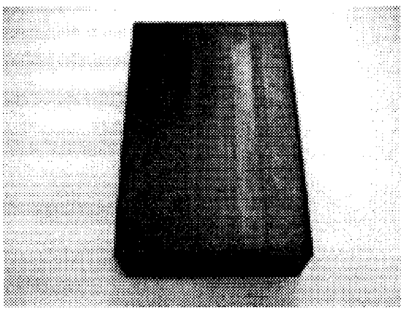

Fig. 3 $LiFePO_4$ battery of Xingheng

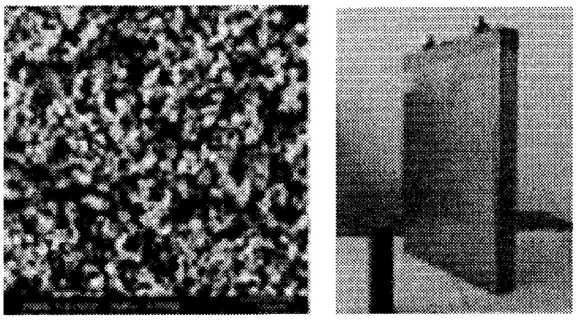

Fig. 4 $LiFePO_4$ material and battery of STL

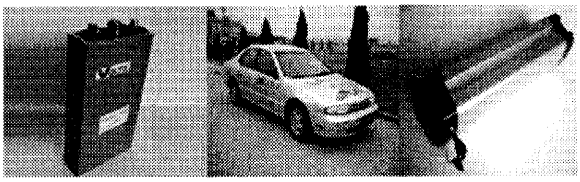

Fig. 5 $LiFePO_4$ battery of Voltix and its applications

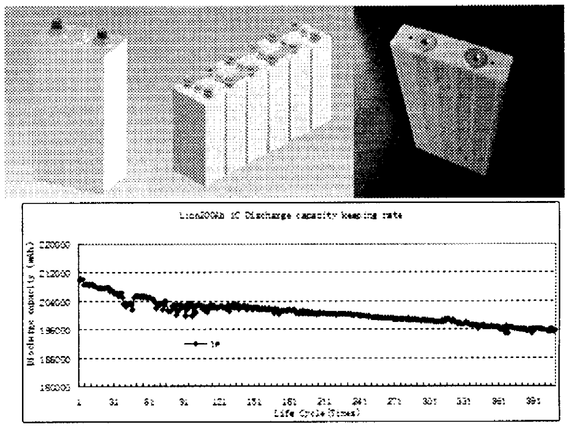

Fig. 6 $LiFePO_4$ battery of Huanyu and its life performance

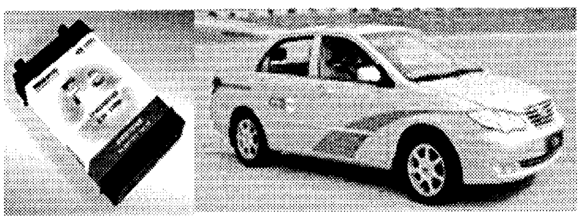

Fig. 7 $LiFePO_4$ battery of BYD and the E-car F3e

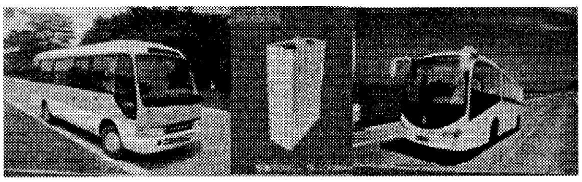

Fig. 8 Li battery of Thunder-sky and the EVs

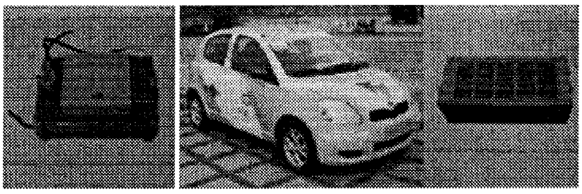

Fig. 9 Li battery of Lantian Double-cycle Tech and E-car by Qingyuan EV

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.

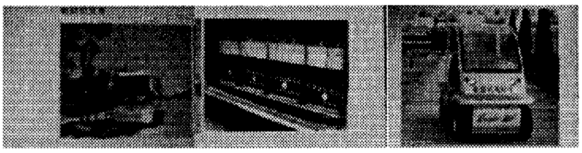

Fig. 10 Energy type UC and UCEVs by Aowei

5.1.5 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.

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 ca-

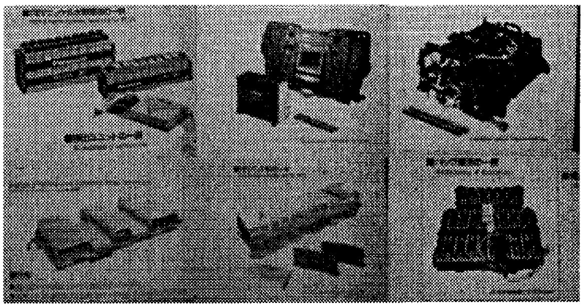

Fig. 11 High power pack for hybrids of Panasonic EV energy

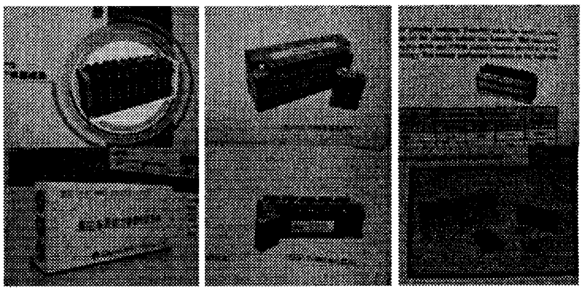

Fig. 12 NiMH battery by Chunlan (left), Shenzhou (middle), and Peacebay (right)

pacity 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.

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.

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.

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%

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.

Fig. 13 High power lithium batteries of Xingheng

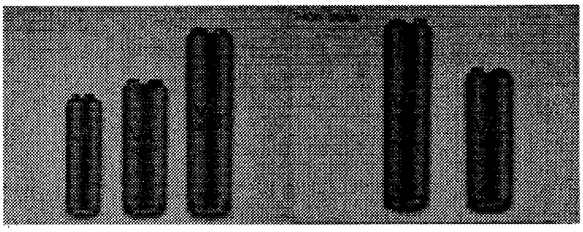

Fig. 14 High power lithium batteries of Saft JCS

5.2.4 Power type capacitor

Jurong, Shuangdeng and Aowei also have the power type large capacity UC for hybrids. Nissan Diesel, ECaSS Nichicon, Advanced Capacitor Technologies, Meiden,

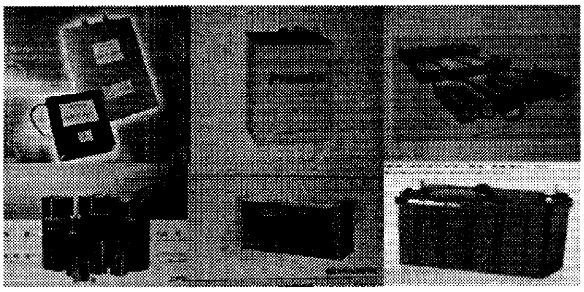

Fig. 15 Power type capacity by companies in Japan

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.

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.

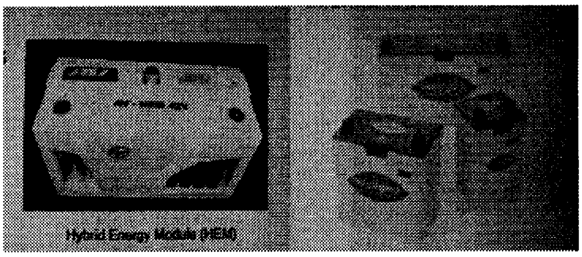

Fig. 16 Capacity battery by Nippon Chem-con and EcaSS

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.

6. BMS OF ESS

BMS is necessary for effective and reliable ESS. It should function at least as follows. [INCEL, 2004; CES, 2007]

(1) Capacity evaluation
(2) Temperature Voltage and Current monitor
(3) Equalization
(4) 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.

Table 5 Specifications of recent capacitors

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

Tabble 6 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 (yuan/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	

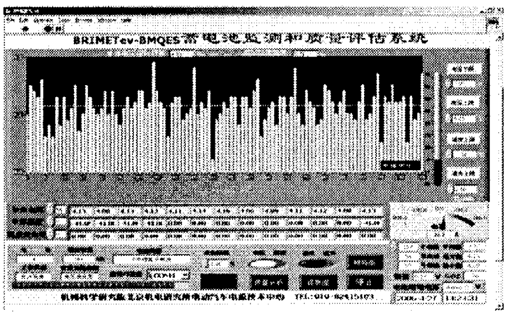

Fig. 17 The BMS of ESS by Brimet for battery bus

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 $LFePO_4$ 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.

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(Received September 3, 2007; accepted October 20, 2007)