Comparison of Different Battery Technologies

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General Electronics Battery Co. Ltd. devotes itself to Li-ion Battery, including $LiCoO_2$, $LiMn_2O_4$, $Li(NiCoMn)O_2$ and $LiFePO_4$. From the following, you can know our battery technology.

In the past decade, electric vehicles (EV) such as electric bicycles, electric scooters, electric motorcycles and electric cars, have become more and more attractive because of their environmental advantages such as zero emissions, low noise, high energy efficiency, and reduction of our dependence on imported oil. With the increasing demand for clean transportation tools, the governments, environment organizations and consumers around the world are demanding lower cost, higher safety and longer-ranging vehicles, all of which are determined by the performance of the battery that fuels the mobile equipments.

Lead-acid battery, Nickel Metal Hydride (Ni-MH) Battery and Lithium-ion Battery have been used as power packs in the electric vehicles. Among these three different technologies and products, Lithium-ion Battery is the best power solution for EV applications, because of its high energy density and long cycle life. Lead-acid Battery as an outdate technology has being used less and less for EV applications, due to its heavy weight, large size and non-environmental friendly for battery materials such as lead and sulfuric acid. Therefore, we are going to focus on two topics, comparison between Ni-MH Battery and Lithium-ion Battery, detail comparison among different lithium-ion battery technologies.

1. Comparison between Ni-MH Battery and Lithium-ion Battery

Electric performance comparisons for three types of batteries are given in the following table 1, using lead-acid battery as a reference.

Table 1: Comparison among three battery technologies

Items	Li-ion	Ni-MH	Lead-acid
Working voltage (V)	3.7	1.2	2.0
Gravimetric energy density (Wh/kg)	130~200	60~90	30~40
Volumetric energy density (Wh/L)	340~400	200~250	130~180
Cycle life (cycles)	500	400	300
Capacity self discharge rate (% per month)	5%	30%	10%
Memory effect	None	40%	None
Energy efficiency ($C_{discharge}/C_{charge}$)	99%	70%	75%
Weight comparison for the same capacity	1	2	4
Size comparison for the same capacity	1	1.8	3.5
Reliability	High	Low	High

It is clear to see the advantages of Li-ion Battery versus Ni-MH battery:

- Higher working voltage and higher reliability: Li-ion Battery has working voltage of 3.7V, three times higher than that of Ni-MH battery (1.2V). Battery packs for E-bicycles application request high voltage, 37V for example. That means that a Li-ion Battery Pack needs 10 cells in series connection, but a Ni-MH Battery Pack will need 30 cells in series connection. Power packs for E-bicycles must be highly reliable due to bumpy road and fast changes of temperature. The more cells in series connection are used in a battery pack, the more defects occur during usage, the lower reliability it has, according to statistic analysis and the past experiences.
- Higher energy density: The gravimetric energy density of Li-ion Battery is more than double than that of Ni-MH battery. Its volumetric energy density is also much higher than that of Ni-MH battery. Therefore, the weight and dimensions of Li-ion Battery Packs would be only 50% of that of Ni-MH Battery for the same energy.
- Longer riding distance range. Li-ion Battery would offer a rider with 2 times longer riding distance range than Ni-MH Battery for the same weight and size of power pack.
- Longer cycle life. Li-ion Battery has better cycle-ability, it would be running for longer life time.
- Smaller self-discharge rate. Among all battery systems, a Ni-MH Battery shows the highest self-discharge rate, for about 30% per month. That means the 30% energy loss during storage time for one month. When a rider needs to use the E-bicycles, he will have 30% less riding range one month after storage.
- Memory effect. All Ni-MH Batteries have memory effect for about 40%. Due to this memory effect, a Ni-MH power pack can not be fully recharged for 100%. The residual energy inside a Ni-MH battery would resist recharging energy during charging process. Therefore, a rider has to first fully discharge his power pack and then recharge it to reach 100% recharge energy. This process waits energy and recharging hours.
- Recharging energy efficiency. A Ni-MH Battery has very low energy efficiency, less than 70%, due to side chemical reaction during recharge process. For example, to get 1Wh energy from a Ni-MH power pack, you need to pump in more than 1.3Wh energy during recharge process. More than 30% energy is lost

during recharge through side chemical reaction, such as heat generation and gassing.

Because of above-mentioned issues, E-bicycle makers in China have been replacing lead-acid battery by Li-ion Battery. Nobody uses Ni-MH battery as power pack for E-bicycles.

2. Detail discussion about Li-ion Battery Technologies

It is no doubt that Lithium-ion Battery is the best power solution for EV applications and that it is a trend to use Li-ion Battery Pack in E-bicycles to replace lead-acid battery. However, there are some detail differences among Li-ion Battery chemistries, which are given in the table 2.

Table 2: Detail comparison among Li-ion Battery chemistries

Cathode materials	**$LiCoO_2$**	**$LiMn_2O_4$**	**$Li(NiCoMn)O_2$**	**$LiFePO_4$**
Reversible capacity (mAh/g)	140	100	150	145
Working voltage plateau (V)	3.7	3.8	3.6	3.2
Charge termination voltage (V)	4.25	4.35	4.3	3.7
Overcharge tolerance (V)	0.1	0.1	0.2	0.7
R.T. Cycle life (cycles)	400	300	400	1000
55℃ Cycle life (cycles)	300	100	300	800
Heat Flow by DSC (kJ/g)	650	150	600	10
Overcharge without PCB	4.9/3C Explosion	8V/3C Firing	8V/3C Firing	25V/3C Pass
Price (US$/kg)	30	15	22	12
Battery energy density (Wh/kg)	180	100	170	130

- Lithium cobalt oxide $LiCoO_2$ chemistry has been used for consumer electronics and digital applications, such as mobile phones and digital cameras, since 1993. $LiCoO_2$ battery offers very high energy density. However, this chemistry is not suitable to large format Lithium-ion Battery for E-bicycle applications, because that $LiCoO_2$ material is very expensive and unsafe. The element of cobalt Co in lithium cobalt oxide $LiCoO_2$ is a precious metal with very limit resource in our planet. Its price has been increased all the time like petroleum. The crystal structure of $LiCoO_2$ is unstable during recharging process. Slight overcharge to $LiCoO_2$ would cause its structure collapse, resulting in firing and explosion. Therefore, $LiCoO_2$ battery can not

be used for E-bicycles.

- The chemistry of lithium manganese oxide $LiMn_2O_4$ is not a good option for EV applications, because of its poor cycle life, especially at elevated temperature. In addition, the energy density of the battery with $LiMn_2O_4$ chemistry is the lowest one among all lithium-ion batteries, about 100 Wh/kg, similar to that of Ni-MH battery. Therefore, there is no advantage to use this chemistry in large format lithium-ion battery.
- New material of $Li(NiCoMn)O_2$ is a better candidate for large format lithium-ion battery. By using only one third of Co metal in the compound, its cost would be much lower than lithium cobalt oxide $LiCoO_2$. Its safety is fairly good. General Electronics Battery Co., Ltd. has been making its Li-ion Battery by using $Li(NiCoMn)O_2$ chemistry. GEB would provide you with power packs having better performance, higher safety and lower prices.
- Recently lithium iron phosphate $LiFePO_4$ has been becoming "best-choice" materials in commercial Li-ion Batteries for large capacity and high power applications, such as lap-top, power tools, e-wheel chair, E-bicycles, e-car and e-bus. A $LiFePO_4$ battery has hybrid characters: as safe as lead-acid battery and as powerful as lithium ion cells, with lower cost. The R&D team of General Electronics Battery Co., Ltd. has been working hard on this new chemistry. We will provide you with new technology in the near future.

General Electronics Battery Co., Ltd. did cost analysis and will push the product sales price down as road map shown in the following graph. In the near future, our customers around the world will have new generation of Li-ion Battery with better performance and lower prices.

Road Map for Cost Drop vs. Production Scale (24Ah/37V Battery pack)