UNIVERSITY OF SOUTHERN CALIFORNIA

A comparative study of Lithium-Ion Batteries

By: Mehul Oswal, Jason Paul and Runhua Zhao

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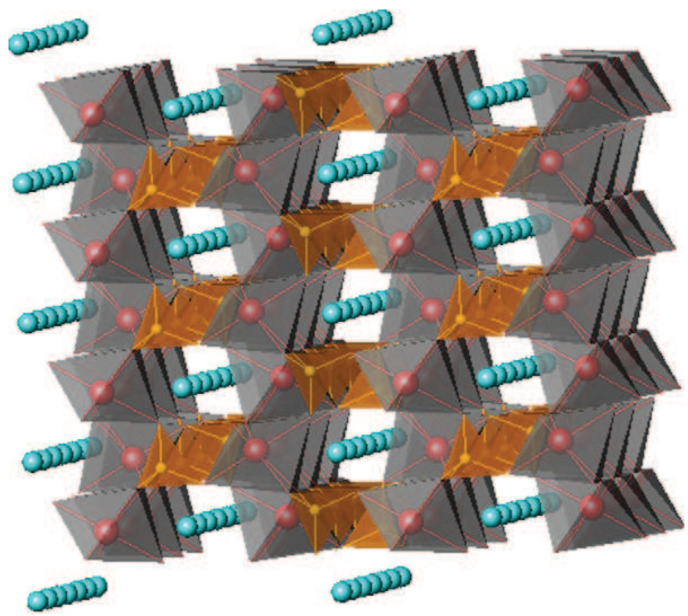

Abstract: Current lithium ion battery technology is ready to revolutionize hybrid vehicles. Lithium iron phosphate batteries produced by A123 offer almost twice the specific energy than that of nickel metal hydride batteries used in current hybrid vehicles. The batteries are also capable of enormous amounts of power, up to 3.3 kW/kg. This makes it possible for higher performance hybrids that are more appealing to the average consumer.

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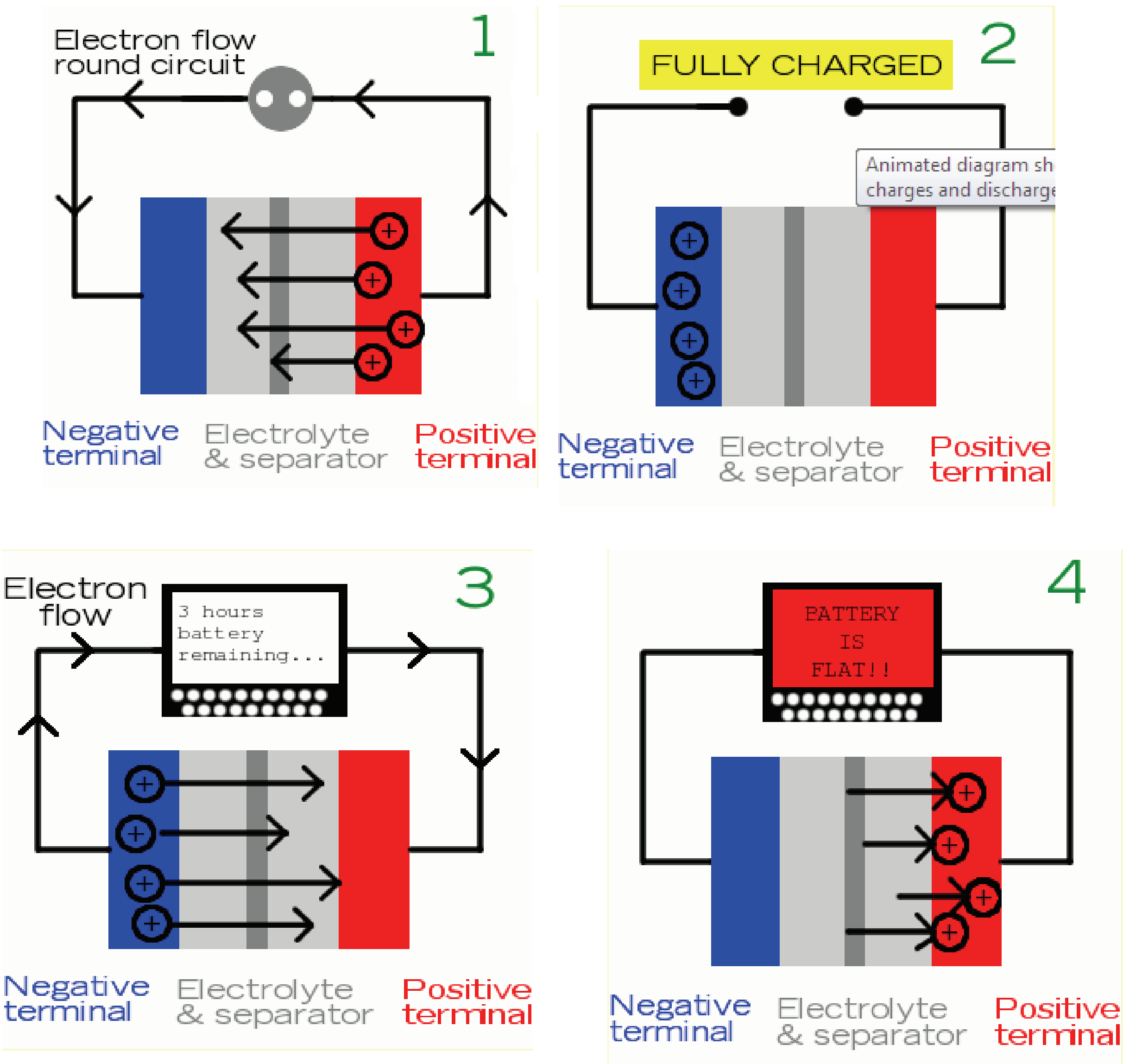
Introduction / By Mehul Oswa

Lead is a very heavy metal and therefore the research was done from many years to make better battery that is lighter in weight as well as it has improved power density. Then lithium became the logical choice to replace lead as it is the lightest metal available in the world. Lithium is not only light in weight but also highly reactive and for this reason pure lithium is never found in nature. Lithium metal is manufactured from lithium salts which are extracted from mining activities. In today's world Lithium Ion batteries are used in almost all gadgets including laptop, cell phone, camera, iPod and many more devices and hence they are very popular these days. They are one of the most energetic batteries available today which make them so popular. Our major concentration is on Lithium Iron phosphate batteries and Lithium Cobalt batteries. Lithium Iron phosphate batteries were developed by john good enough at the university of Texas. Although first commercialized by others, Lithium Ion batteries were very first manufactured by A123 by preparing doped nanophosphate lithium batteries in 2006. Today A123 has made good progress in its battery technology and manufactures batteries of wide range which serves the purpose for electric bikes to computer servers.

Big Challenge

Most of the electricity in the today's world is generated by consuming non renewable resources of fuel which is estimated to last till 40 to 70 years, hence there is a big challenge in front of this world to generate almost all the electricity by using some renewable sources of energy which would be convenient and cost efficient. In every day's life we are using a good percentage of non renewable resources of fuel in motor vehicles which have to be replaced by some renewable source of energy soon and this can be done in one way by generating electricity from non renewable sources of energy and storing them in to the batteries. We do have batteries which can store electricity and solve this problem but they are not good enough to replace the current technology to drive motor vehicles because to do this we would require very powerful batteries that can store enough electricity to drive large vehicles for at least 10 to 12 hours and can be recharged in 10 to 15 minutes. Research is being carried out on Lithium Ion batteries to improve the current technology so that we come closer to our goal.

Charging and discharging phenomena in Lithium Ion batteries:



1) During charging the battery, the lithium ions flow from the positive electrode to the negative electrode through the electrolyte. Electrons tend to flow in the opposite direction around the outer circuit.

2) When all the ions stop flowing, the battery is supposed to be fully charged and ready to use.

3) During discharging the battery, the ions flow back from the negative electrode to the positive electrode. Electrons tend to flow the opposite way through the outer circuit, powering our laptop.

Characteristics of Lithium-Ion Batteries / By Mehul Oswa

Figure1: Lithium-ion (Li-ion) batteries are less environmentally damaging than batteries containing heavy metals such as cadmium and mercury, but recycling them is still far preferable to incinerating them or sending them to landfill.

Lithium ion batteries are made up of one or more generating compartments called cells. Each cell is composed of three components: a positive electrode, negative electrode, and a chemical called an electrolyte in between them. The positive electrode is made from chemical compound named lithium cobalt oxide ($LiCoO2$) or lithium iron phosphate ($LiFePO4$). The negative electrode is made up of carbon (graphite) and the electrolyte varies from one type of battery to another. All lithium ion batteries more or less work in same manner. During charging the battery, lithium based positive electrode withdraws some of its lithium ions, which move through the electrolyte to reach to the negative electrode and remain there. The battery stores energy during this process. When the battery is discharging, the lithium ions move back across the electrolyte to the positive electrode, producing the energy that powers the battery. In both the cases electrons flow in the opposite direction to the ions around the outer circuits. Electrons do not flow through the electrolyte as it tends to be an effective insulating barrier, as far as electrons are concerned. The movement of ions (through the electrolyte) and electrons (around the external circuit, in the opposite direction) are interconnected processes and if any one of them stops and the other also stops. If ions stop moving through the electrolyte because the battery completely discharges and the electrons can't move through the outer circuit either, so the power is lost. Similarly we switch off whatever the battery was powering, the electron flow stops and so does the flow of ions and the battery stops discharging. Unlike other batteries lithium ion batteries have built in electronic controllers that regulate the charging and discharging in them. They prevent the overcharging and overheating that can cause lithium ion batteries to explode in some unusual circumstances.

Advantages of Lithium Ion Batteries:

1) Lithium Ion Batteries are light weight as compared to the other rechargeable batteries of the same weight.
2) Lithium Ion batteries have a very high energy density hence lot of energy can be stored in it and this is due to the fact that electrodes of lithium Ion batteries are made of lightweight lithium and carbon and lithium is highly reactive element.
3) Batteries made by lead-acid which weighs 6 kilograms can store the same amount of energy which a 1 kilogram lithium Ion battery can store.
4) Charge lost by lithium Ion batteries is as low as 5 percent per month as compared to NIMH batteries which has 20 percent charge loss per month.
5) Lithium Ion batteries do not need to be discharged completely, i.e. they do not have any memory effect which some other batteries have.
6) Hundreds of charge and discharge cycle can be handled by lithium Ion batteries.

Disadvantages of Lithium Ion Batteries:

1) Lithium Ion batteries have short life of 2 to 3 years from the date of manufacture no matter they are used or not.
2) They degrade much faster if they are exposed to heat as compared to the normal temperature exposure because they are extremely sensitive to high temperatures.
3) Lithium Ion batteries are ruined if they are completely discharged.
4) The cost of lithium Ion battery is high as compared to the other existing batteries.
5) There is small risk of lithium Ion batteries getting busted in to flames if it is not properly manufactured, though the risk is as low as 2 to 3 packs per million batteries produced may be defective.

Safety factor in Lithium Ion Phosphate Batteries /By Mehul Oswa

Battery safety is a matter of crucial importance to the lithium battery industry. In large size batteries the safety problems are more serious as compared to the small size batteries i.e. batteries for electric vehicle would have more risk of catching fire or explosion as compared to batteries for laptops and cell phones. When phosphate is used as cathode material in a lithium iron phosphate battery, we get very safe battery. Phosphates can withstand high temperatures and hence they are extremely stable in overcharge or short circuit conditions. Charging lithium ion batteries to above 4.6 V cell^(-1), when using lithium metal oxide cathodes and flammable liquid electrolyte cathodes can lead to unsafe events, possibly due to lithium deposition or to oxidation of solvents at these high potentials. Lithium iron phosphates may be safer as complete oxidation of this material occurs at a lower voltage (3.4), and the oxidation product of lithium iron phosphate is the stable material, ferric phosphate, according to the reaction:

$LiFePO_4 + 6C \rightarrow LiC_6 + FePO_4$.

In order to achieve battery safety without relying solely on external electronics, internal electronics within the cell have been used to provide overcharge and short circuit protection.
Various protection mechanisms are often employed with lithium-ion power systems. They range from internal cell safety separators to fuses, contractors, and carefully controlled charging algorithms and monitoring. But there is need for an inherently safe chemistry when batteries have to undergo through the harsh conditions or when they are placed in sensitive areas. Abuse conditions can always occur due to which a battery may be subjected to the condition in which the various safety mechanisms may not be able to prevent a thermal runway.

Phosphates are not prone to thermal runway and will not burn even though abuse occurs. Therefore lithium ion batteries made by phosphate as cathode are very safer as compared to other lithium ion batteries. Batteries made from LiFePo4 technology have good shelf life, long cycle life and is maintenance free. LiFePo4 batteries are environment friendly as compared to LiCoO2, LiMn2O4 and Li(NiCo)O2. LiFePo4 batteries can work in temperature range of -20C to 70C. LiFePo4 technology does not contain heavy metals and does not have the memory effect like nickel cadmium and nickel metal hydride batteries. Safety devices along with good electrode design can reduce the risk of fire or explosion.
Other safety features which are required for any lithium-ion batteries are as follows:

- Shut-down separator (To avoid over temperature)
- Tear-away tab (To avoid internal pressure)
- Vent (For pressure relief)
- Thermal interrupt (TO avoid Over current/ Overcharging)

Though these devices when attached to the cell occupy useful space inside the cells and reduce their reliability and permanently and irreversibly disable the cell when activated but they are necessary as anode produces heat during use, while the cathode may produce oxygen. By installing safety devices and implementing improved electrode designs we can greatly eliminate the risk of fire or explosion. Hence safety increases the cost of the lithium ion batteries compared to nickel hydride batteries, but at the same time it enhances the safe working of these cells.

Applications / By Mehul Oswa

Lithium Iron Phosphate has the wide range of characteristics due to which variety of different sizes of batteries can be produced and they found major areas of application:

1) Big electric vehicles: buses, electric cars, tour buses, hybrid vehicles and other attractions.

2) Light electric vehicles: Electric bikes, golf carts, small cars, forklifts, electric vehicle cleaning wheelchairs, etc.

3) Power tools: Lawn movers, electric saws, electric drills.

4) Remote control toys: cars, boats, planes, etc

5) Wind energy storage and solar equipment.

6) Warning lights, UPS, miner’s lamp, emergency lights, etc

7) Small medical equipment and portable instruments.

8) Laptops, cell phones, camcorders, IPods, etc.

9) Lightweight lithium ion batteries are used in a number of cutting edge electric cars including the pioneering Tesla Roadster. It takes around 3.5 hours for batteries of this vehicle to charge completely its 6831 lithium ion cells, which together weigh half a tone (1100lb). When these batteries are fully charged the can cover the distance more than 350 km (220 miles) In the left figure below yellow power lead is charging the batteries and in the right figure below batteries are in the large compartments directly above the back wheel.

Characteristics of Lithium Iron Phosphate batteries:

1) High Output performance with standard discharge for 2 to 5C and continuous discharge high current capacity of up to 10C and the instantaneous discharge pulse up to 20C.
2) Good performance is observed at high temperatures from 65 to 95 degree centigrade keeping the battery in good safe condition.
3) It shows excellent life cycles as after 500 cycles also it shows discharge capacity to be above 95%.
4) Even though during excessive discharge to zero volts there is no damage caused.
5) It gets quickly charged with very less time as compared to other batteries.
6) Cost is not very high and hence can be used for variety of applications.
7) It’s also environmental friendly battery which does not produce any waste.

Advanced HEV application:

Lithium Ion Phosphate batteries are installed in cars such as Plug-In Toyota Prius, Mercedes Hybrid S-Class and Saturn Vue Plug-In.

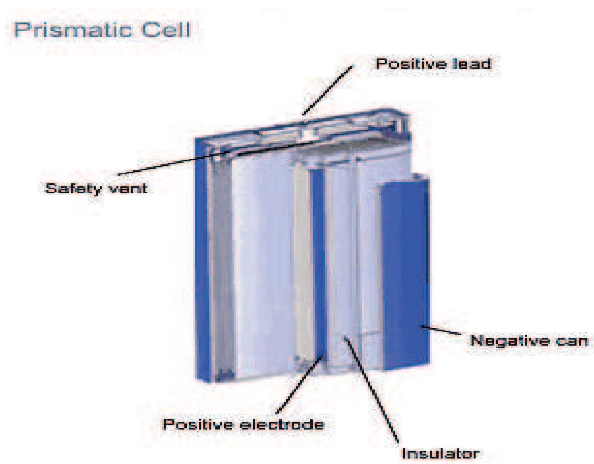
Manufacturers of Lithium Ion Batteries:

- A123 Systems
- BYD Company
- China Sun Group
- Lithium Technology Corporation
- ThunderSky
- Valence Technology
- K2 Energy

Lithium Ion Cobalt Batteries:

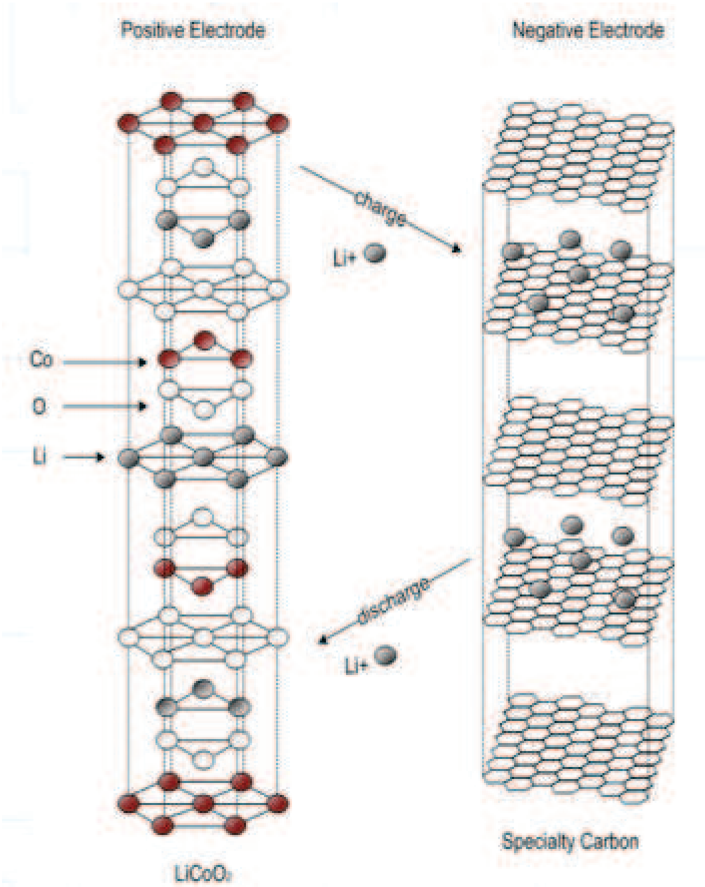
Lithium Ion batteries are leading edge battery technology. Most of the Lithium Ion batteries for portable applications are cobalt-based. Lithium Ion Cobalt batteries are also known as high-power lithium ion batteries because of their high energy density. The system consists of a cobalt oxide positive electrode as a cathode and a graphite carbon negative electrode as an anode. A typical Li-Ion cell is rated at 3.6V and this is three times more than the typical NICD or NIMH cell voltage (1.2V)

Structure / By Mehul Oswa



Lithium Ion cell has three layer structure. A positive electrode plate which is made up of Lithium cobalt oxide – cathode, a negative electrode plate is made up of Graphite carbon – anode and a separator layer. Also there exists an electrolyte which is a lithium salt in an organic solvent inside the battery.

Working Principle:



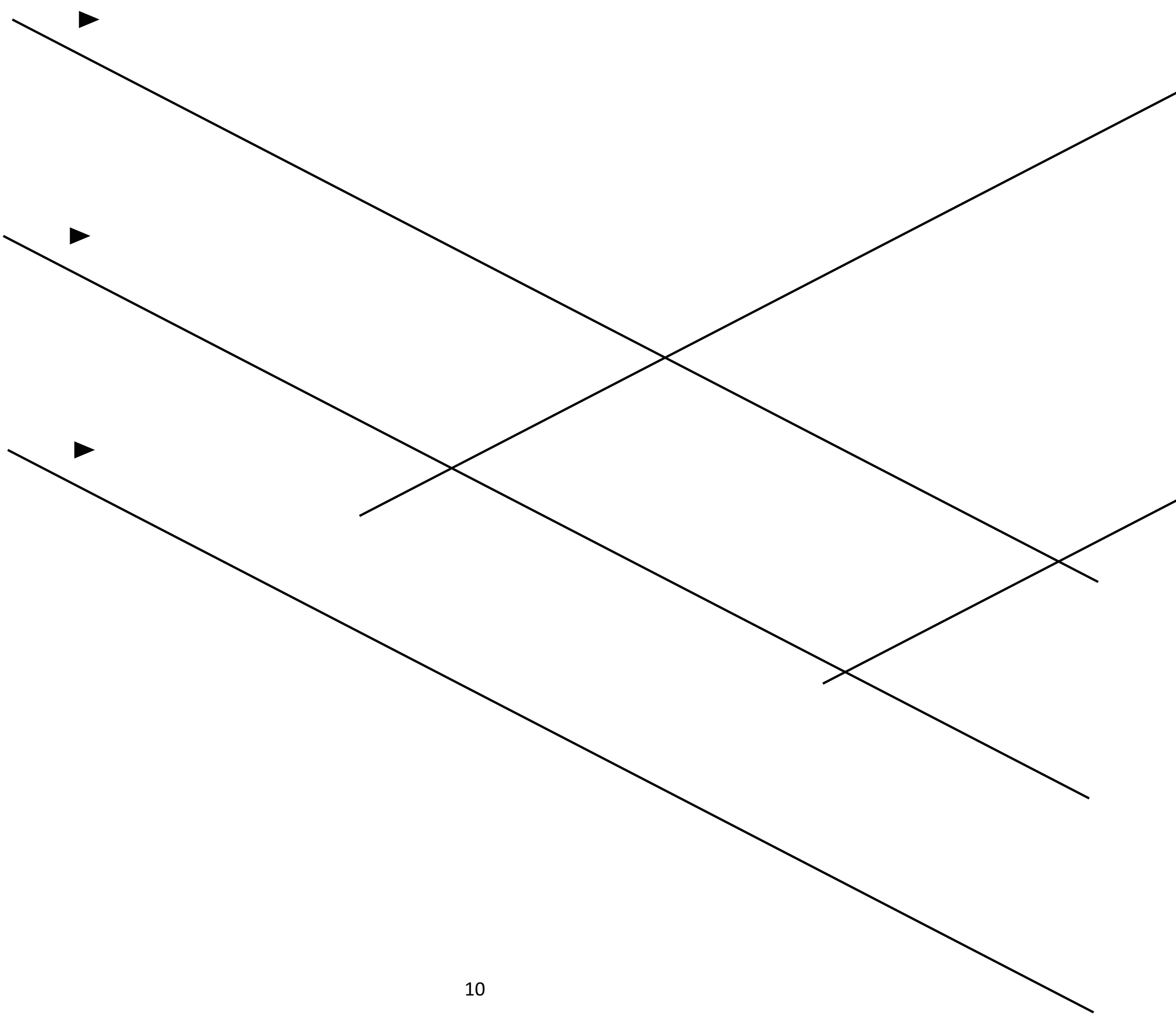
The chemical reaction that takes place during the charge and discharge, inside the battery is as follows:

$$LiCoO_2 + C_6 \underset{\text{discharge}}{\overset{\text{charge}}{\rightleftharpoons}} Li_{1-x}CoO_2 + C_6 L_x$$

The Main Principle behind the chemical reaction is the one where lithium, which acts as positive electrode material is ionized during charge and therefore it moves from layer to layer in the negative electrode.

Lithium Cobalt Oxide Manufacturing / By Jason Paul

Current manufacturing of lithium cobalt oxide batteries is highly automated. This is because speed and quality is desired, and because some of the chemicals used are either toxic or known carcinogens. The process starts by creating a cathode paste (LiCoO2+binders). This paste is thinly spread onto both sides of a sheet of aluminum foil. Similarly, an anode paste (graphite) is created and spread onto both sides of a sheet of copper foil. Next, a separator (polymer film) is sandwiched between the anode and cathode sheets. This sheet is then wound up and placed into a cylindrical housing. Then, the cell is filled with an electrolyte (lithium salt) and the cell contacts are connected. Finally, the cell is sealed. Usually, a circuit is attached to each cell to control charging and discharging. These circuits prevent discharge past a set voltage to prevent being discharged too deeply. Figure 2 summarizes the manufacturing process.



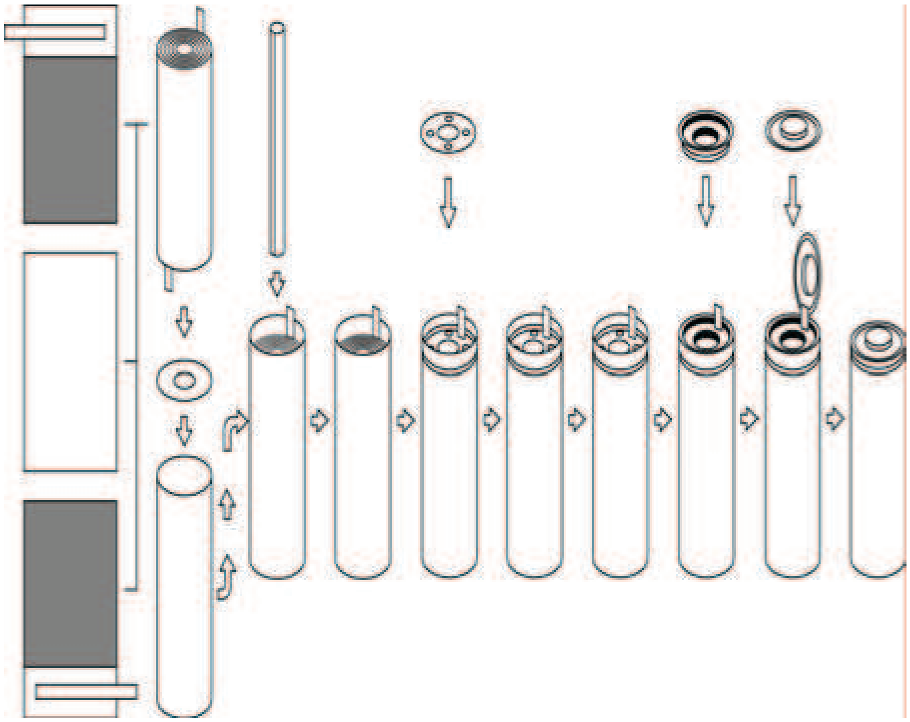


Figure 2: Summary of lithium cobalt oxide battery cell manufacturing.

Courtesy of Hohsen Corp., 1998 (via Argonne National Laboratory, 2000)

Energy and Power Density of Lithium Ion Batteries / By Jason Paul

Lithium cobalt oxide is the most common cathode material used in lithium-ion batteries. Electronic devices such as laptops, cell phones, digital cameras, and other low power draw applications all use cobalt oxide type lithium-ion batteries. They are used in such applications because lithium cobalt oxide's have relatively high energy density while having relatively low power density. This is in contrast to the iron phosphate type of lithium-ion batteries. This type of lithium-ion batteries are known for their tremendous power density while having moderate energy density. Unsurprisingly, they are used in such applications that require high power draw such as portable power tools and electric vehicle.

The real differences in performance between lithium cobalt oxide and lithium iron phosphate batteries can be seen by comparing batteries which are readily available for purchase. This can be accomplished by comparing Panasonic's CGR18650E and A123's 26650 batteries. The CGR18650E is a cylindrical type lithium cobalt oxide battery. It is readily available over the internet. A photograph of the cell is shown in Fig 3. The 26650 cell is a lithium iron phosphate battery also built in cylindrical form. A photograph of the 26650 cell is shown in Fig 3. A summary of specifications for both batteries is shown on Table 1.1.

Figure 3: Photograph of the Panasonic's CGR18650E Lithium Cobalt Oxide () Battery

Figure 4: Photograph of the A123's 26650 Lithium Iron Phosphate () Battery

Table 1.1: Summary of Battery Specifications

Cathode Chemistry	Manufacture/ Model	Price [$]	Volume [m3]	Mass [g]	Voltage [V]	Current [A]	Capacity [Ah]
Lithium Cobalt Oxide ()	Panasonic/ CGR18650E	11	1.77	47	3.7	4.9	2.55
Lithium Iron Phosphate ()	A123/ 26650	15	3.42	70	3.3	70.0	2.30

Each battery's energy capacity can be calculated using information from its specifications shown in Table 1.1 and Eq 1.1. Next, each battery's energy density and specific energy can be calculated using Eq 1.2 and Eq 1.3. Please note that the calculated values will only be rough estimates because batteries do not discharge current at a constant rate or at a constant voltage. A summary of the energy calculations is shown on Table 1.2

(1.1)

(1.2)

(1.3)

Table 1.2: Summary of Battery Energy Calculations for Each Battery Type

Cathode Chemistry	Energy [Wh]	Energy Density	Specific Energy
Lithium Cobalt Oxide ()	9.44	533	203
Lithium Iron Phosphate	7.59	222	108

()			

Each battery's power output can be calculated from the information listed in Table 1.1 and Eq 1.4. Calculating the power output of each battery then enables one to calculate its power density and specific power using Eq 1.5 and Eq 1.6 respectively. A summary of the power calculations is shown in Table 1.3

(1.4)

(1.5)

(1.6)

Table 1.3: Summary of Battery Power Calculations for Each Battery Type

Cathode Chemistry	Power [W]	Power Density	Power Energy
Lithium Cobalt Oxide ()	18	1023	390
Lithium Iron Phosphate ()	231	6756	3300

Finally, the cost per watt-hour for each battery can be calculated using Eq 1.7. This calculation is shown on Table 1.4.

(1.7)

Table 1.4: Cost per Watt-hour for Each Battery Type

Cathode Chemistry	Price per Wh
Lithium Cobalt Oxide ()	1.17
Lithium Iron Phosphate ()	1.98

It can be seen from Table 1.2 that the lithium cobalt oxide type lithium-ion battery have well over twice the energy density that is available from the lithium iron phosphate type battery. It also has very close to twice the specific energy that the lithium iron phosphate type batteries have. The story with power is completely different however. Table 1.3 shows that the lithium iron phosphate type lithium-ion battery has just over six and a half times more power density than the lithium cobalt oxide type does. Also, it has a tremendous 8.46 times greater specific power compared to the lithium cobalt oxide type battery. Table 1.4 shows that there is a noticeable difference in price between the two different types of lithium-ion batteries.

Hybrid and electric vehicles require both high energy density and high power density. Lithium cobalt oxide type batteries can offer high energy density but not high power density. This is reversed for lithium iron phosphate type batteries.

Capacity / By Runhua Zhao

The definition of battery capacity is a measure of how much energy the battery can store.

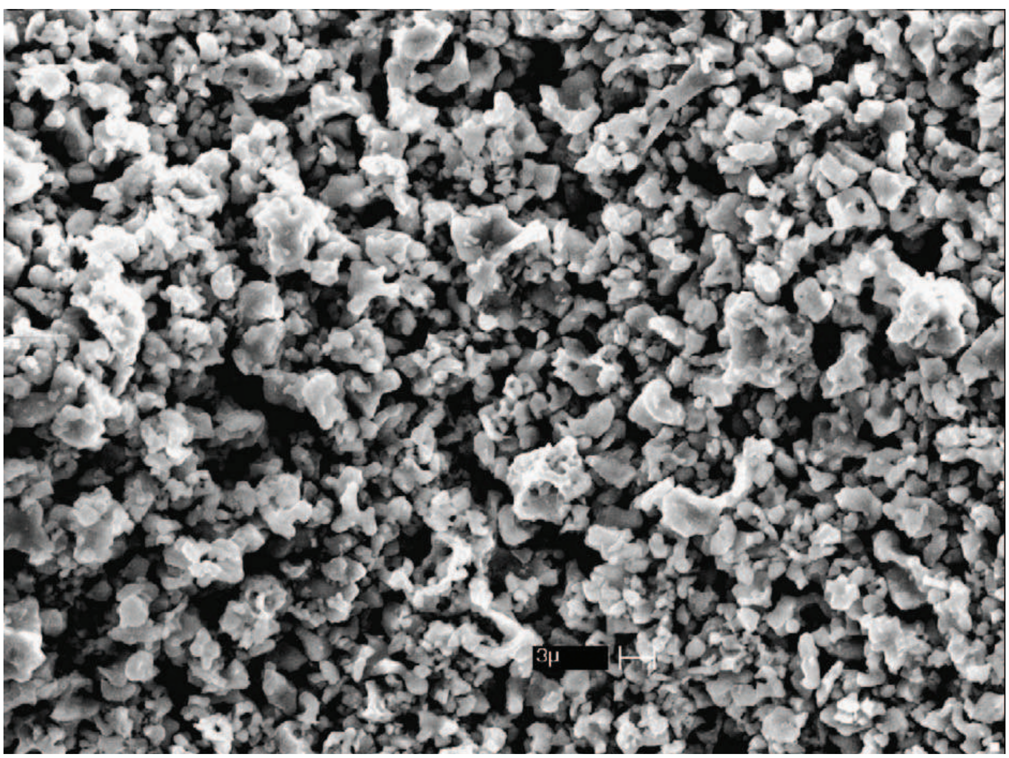
The amount of energy that can be extracted from a fully charged battery depends on temperature, the initial state of charge, discharge rate, cycles of charge and discharge and battery type. Therefore it is difficult to specify a battery's capacity with a single number.

Following is three major ways to quantify the capacity of certain battery.

i) Ampere-hour: The Ampere-hour (Ah) denotes the current at which a battery can discharge at a constant rate over a specified length of time. The standard is to specify Ampere-hours for a 20 hours discharge. This standard is denoted by the nomenclature of C/20. A 60 Ah C/20 battery will produce 60 Ah for a 20 hour discharge.

ii) Reserve Capacity: The reserve capacity denotes the length of time, in minutes, that a battery can produce a specified level of discharge.

iii) kWh Capacity: The kWh capacity metric is a measure of the energy (Volt * Amps * Time) required to fully charge a depleted battery.



SEM photo of LiFePO4 powders *(G.X. Wang et al. / Electrochimica Acta 50 (2004) 443–447)*

Peukert’s Law

The relationship between current, discharge time, and capacity for a traditional lead acid battery is approximated (over a certain range of current values) by Peukert's law:

$$t = \frac{Q_P}{I^k}$$

QP is the capacity when discharged at a rate of 1 amp.

I is the current drawn from battery (A).

t is the amount of time (in hours) that a battery can sustain.

k is a constant around 1.3.

The difference in performance of different battery at high current is tremendous. The real capacity for traditional battery at high current is exponentially decreased due to the Peukert Number while this number on Lithium ion batteries is closer to 1 compared with lead acid battery, which means the capacity is less current dependent which in turn indicates a better performance at high current.

This chart shows the Discharge curve of Lithium ion battery with the Peukert Number calculated as 1.016.

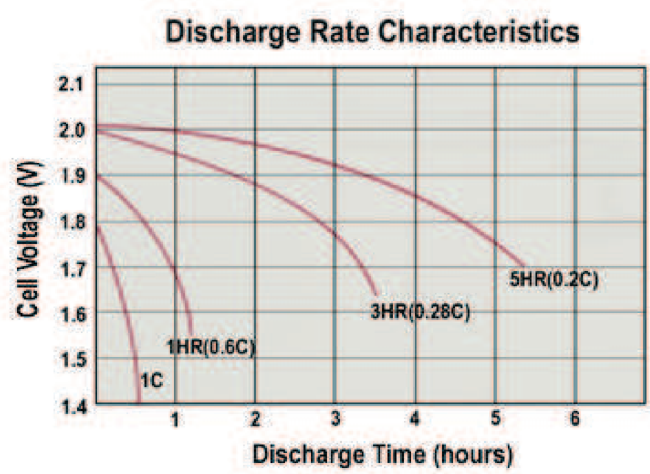
The Peukert number for different brands of Lithium ion batteries may vary.

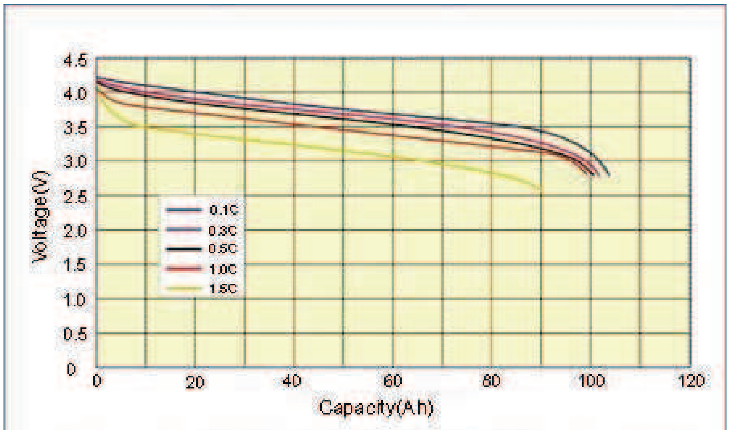
Source:

http://www.simon.richardson.net/electric/batteries/liion.html

This chart shows the Peukert effect on traditional lead acid battery.

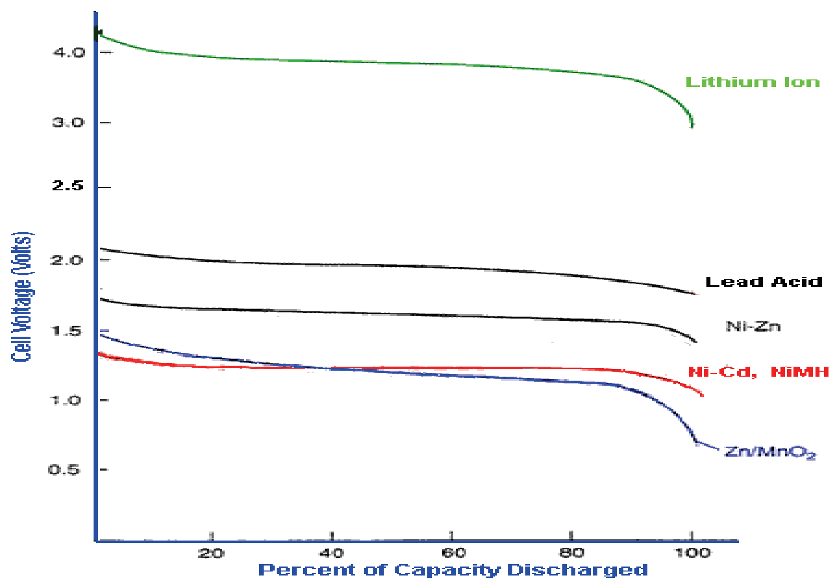
Source: www.batteryuniversity.com/partone-16a.htm





Discharge Curve under Different Current of Thunder Sky Power Batteries

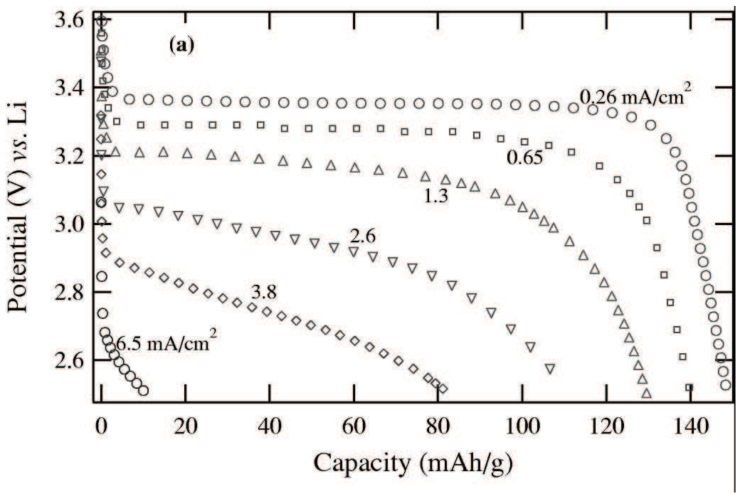
The graph below shows typical discharge curves for cells using a range of cell chemistries when discharged at 0.2C rate. Note that each battery has its own characteristic nominal voltage and discharge curve. Some chemistry such as Lithium Ion have a fairly flat discharge curve while others such as Lead acid have a pronounced slope.



Source: http://www.mpoweruk.com/performance.htm

For high performance application say electric vehicle, the discharge curve falls progressively throughout the discharge cycle by high Peukert number battery. On the contrary a flat discharge curve could offer a constant voltage output throughout the discharge cycle. So the lithium battery in this case is an ideal replacement for traditional lead acid battery for high current performance.

However the Lithium Iron Phosphate still has a peukert effect at extremely high current density. The following chart shows the constant-current density discharge curves of the iron-phosphate electrode at different densities. With the increasing current density, LiFePO4 may be affected by capacity loss due to diffusion-controlled kinetics of the electrochemical process.



Journal of The Electrochemical Society, 151 (10) A1517-A1529 ~2004

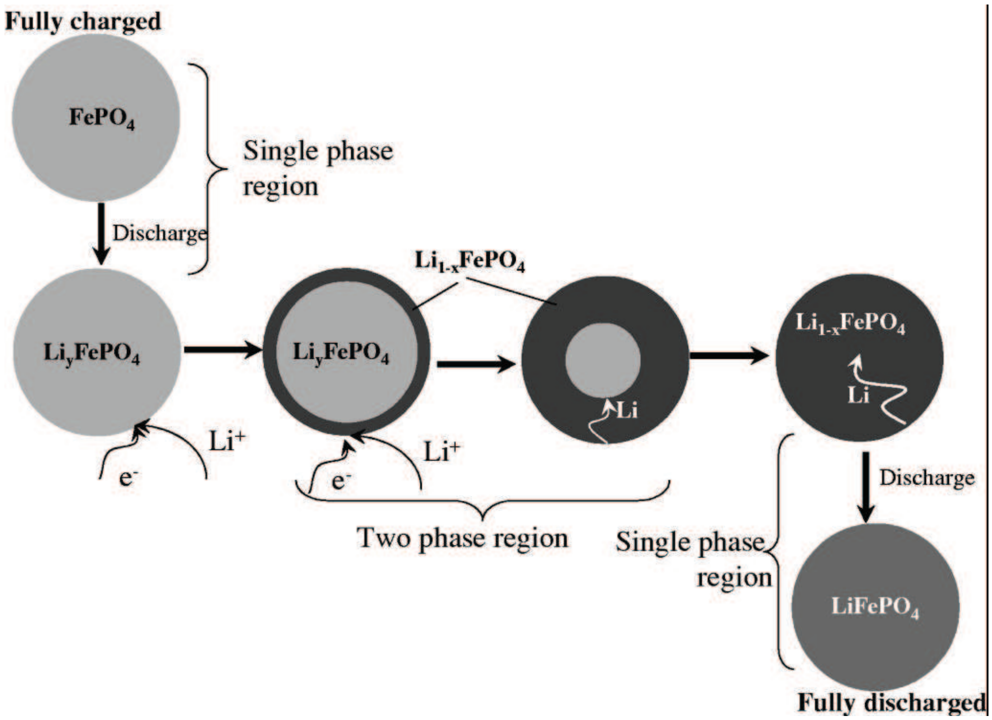
From the preliminary analysis of this chart, we notice the curve shape is similar to electrical potential to j0 plot in fuel cell battery. The voltage suffers a sudden drop and following a steady ohmic-loss slope. The initial steep drop in voltage is caused by the Lithium Iron Phosphate single-phase region. After that, the plot becomes flat which belongs to the two phase region. Also we could notice a slope gradient increasing with the increase of current density which is due to the transport limited process.

This special current density characteristic dominant and constrain the Lithium battery capacity. In order to minimize this dependence, doping method is introduced which include lattice doping and non-lattice doping method. Non-lattice doping metod helps the formation of LFP crystals by using the dopants as contact bridges while lattice doping method greatly improve the lattice electronic conductivity by selective doping with supervalent cation at Lithium site in crystals of LFP. Combination of these two methods is also developped which is called mix-doping method.

Special Characteristic of LFP Batteries

Beyond the above effect, there are some special property in LFP cathode material that also affect the Lithium ion cells power capability, including flat open circuit voltage characteristics, cycling history dependency of the internal resistance and long term load history dependence. In order to understand the capacity dependence on these characteristics we need to understand how Lithium battery works.

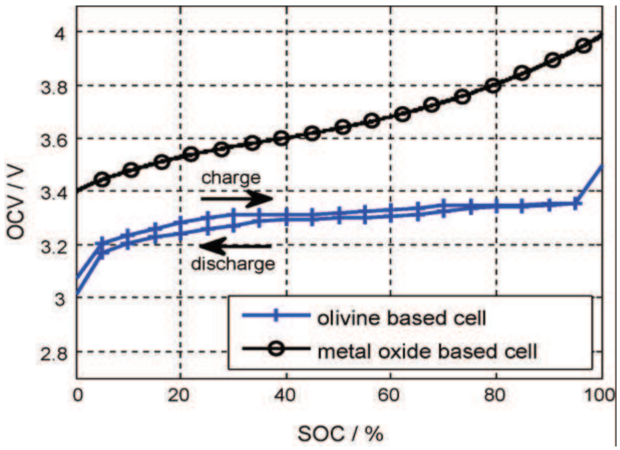
The following chart shows the conceptual discharge process of LFP.



During lithium insertion into a cathode particle the particles surface region becomes lithiated and two distinct phase regions (a lithiated phase and a delithiated phase region) emerge within the originally homogenous material. Between the two regions a phase barrier exists. One phase is transformed into its particular counterpart as lithium insertion proceeds and the barrier propagates from the particles surface towards the center. The lithium concentrations within each phase region remains constant. This two-phase transition continues until the particle is completely transformed. During lithium de-insertion the particles surface region becomes delithiated first and the phase barrier propagates towards the particles center again until the particle is completely delithiated. The phase separation in the two-phase state is stable over time. Hence, the phase barrier does not vanish through diffusion processes during longer rest periods.

The separated phase regions within the particles of electrode materials affect the electrical performance of Li-ion cells. The lithium has to overcome the distance through the shell region to the phase barrier to get inserted to the lattice, unless the surface phase region is delithiated then the lithium can be inserted into the host lattice at the particles surface. In the case of a delithiated shell phase the lithium has to overbear the distance from the lithiated core to the particles surface during discharge.

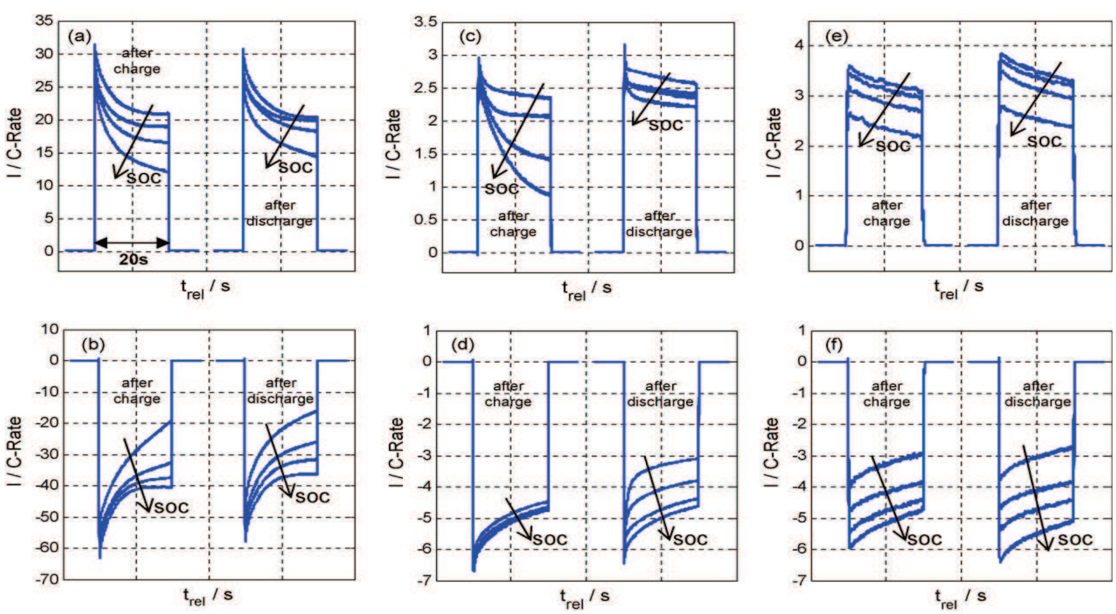
Impact of the two-phase transition on the internal resistance



OCV of olivine based (LiFePO4) and metal oxide based cells (3 h rest period at each SOC step).

During the two-phase transition the electrode potential shows a minor change in OCV which is due to the constant lithium concentrations within the phase regions. The surface region is lithiated during the whole insertion process. The incoming lithium leads only to a shift of the phase barrier. Hence, the electrode potential being associated to the Li concentration within the particles outermost phase regions remains constant. The surface region is delithiated during Li de-insertion. Therefore, the OCV curves of Li-ion cells based on a graphite anode and a LiFePO4 containing cathode are very flat since LiFePO4 as well as graphite show a two-phase transition behavior during Li insertion and de-insertion. On the contrast the metal oxide curves increases by 0.6V nearly linear from SOC = 0–100% without the two phase transition effect. As visible, the OCV of the olivine cell shows only slight changes with varying SOC.

Charge history dependent power capability

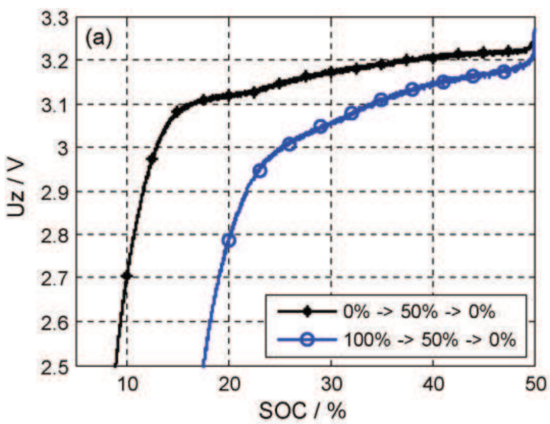


M.A. Roscher et al. / Journal of Power Sources 195 (2010) 3922–3927

The above plots show under various charge and discharge condition how the cells current over nominal capacity rate behave. The a,c,e plot represent the charge pulse condition and b,d,f represent the discharge pulse condition. Skipping the detailed analysis, we reach the conclusion that for Lithium Iron Phosphate (plot c and d) the available power strongly depends on the way the state of charge is reached. After charging the discharge current (plot c) is almost independent from state of charge while after discharge the discharge current significantly differ (plot d).

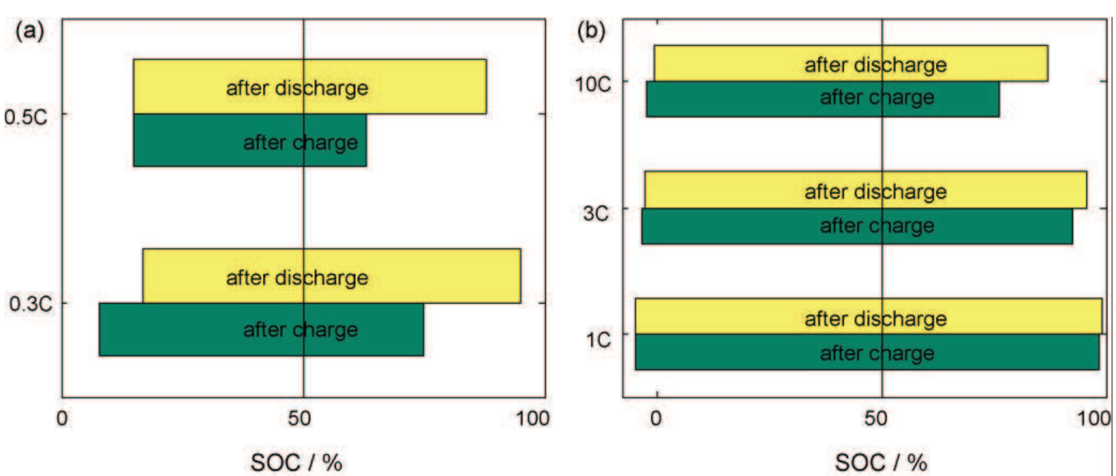
The available power of the metal oxide cells (assume Lithium Cobalt Oxide) is quite independent from the charge history but is closely correlated to the state of charge, which leads to the power capability decrease with voltage reserve.

Charge history dependent available discharge capacity



Voltage profiles during discharge of LFP (0.3 C-rate current) plotted vs. SOC, depending on the load history. M.A. Roscher et al. / Journal of Power Sources 195 (2010) 3922–3927

If the internal resistance varies according to the SOC adjustment, also an influence on the available capacity is assumed, due to the cutoff voltage value during charge/discharge cycling is expected to be reached earlier or even later, respectively. The above plot gives the typical cell voltage of the energy cells during a 0.3 C discharge. it is obvious that different initial state of charge could lead to a different internal resistance.



Typical SOC values when the cutoff voltages are reached at various current rates of LiFePO4 based energy cells (a) and power cells (b), depending on the SOC adjustment direction, starting at SOC = 50%. M.A. Roscher et al. / Journal of Power Sources 195 (2010) 3922–3927

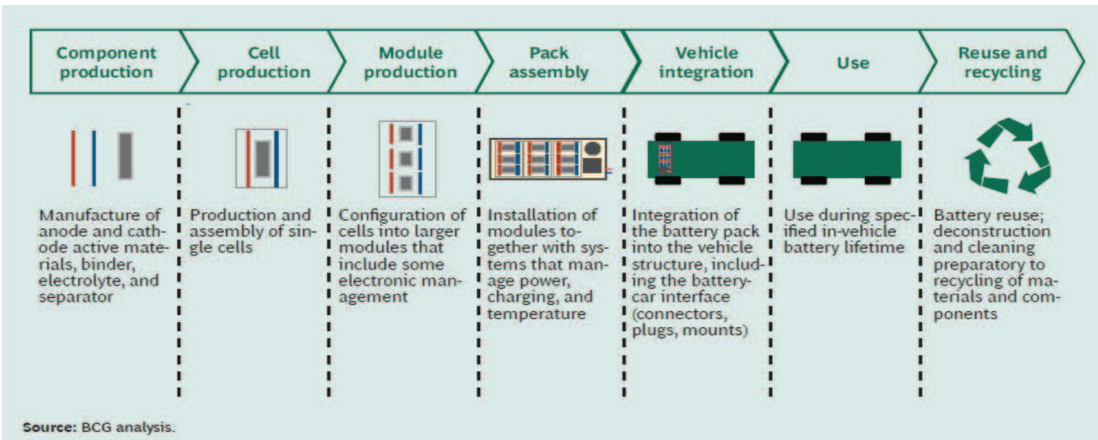
The above plots shows available charge and discharge capacities of LFP starting at SOC of 50%. The solution is that LFP battery has a much stronger state of charge dependency.

In sum, Lithium ion batteries have a less current dependence characteristic compared with traditional lead acid battery. Like other Lithium ion batteries, the capacity of LFP depends on current density under the circumstance without considering doping method. Meanwhile there are also some other special characteristics that also contribute to the way how LFP battery work.

The LFP shows a strong dependence on how state of charge is adjusted towards the power capability. Say, the discharge power capability is much higher after charge than discharge and state of charge is less relevant. And those characteristics offer LFP cathode materials a competitive role in market and promising future.

Cost Analysis / By Runhua Zhao

The cost for the package of one battery consists of material and production. One battery can be categorized from construction aspect as following: cathode, anode, separators, electrolyte, cell packaging and control circuits. In our case, the cathode material is LFP. Traditional cost analysis is not valid here since various new synthesis methods are under developing in the lab including hydrothermal processing, Sol-gel processing, precipitation method, emulsion-drying method and spray pyrolysis etc.. Many of which is only industrial feasible under massive production scale.

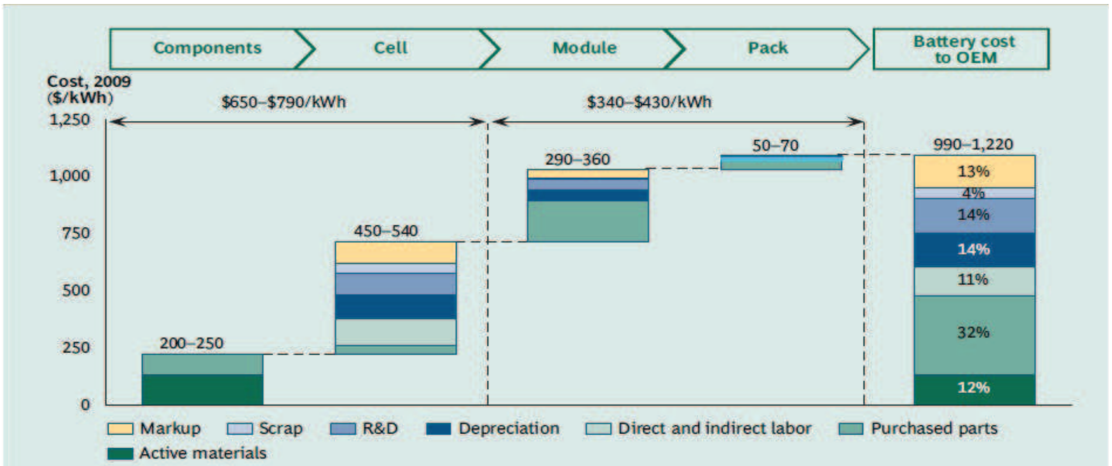


The above chart shows the decomposed seven steps for EV batteries value chain. Source: BCG analysis.

Given labor, scrap, depreciation and R&D cost, the customer purchase price is estimated 50% or even higher of the original battery manufacture cost due to the fact that advanced technology batteries are new products and still under development.

Current Cost:

Based on line-item model of individual component costs involved in making a battery in 2009, we could roughly estimate the cost for future LFP battery production.

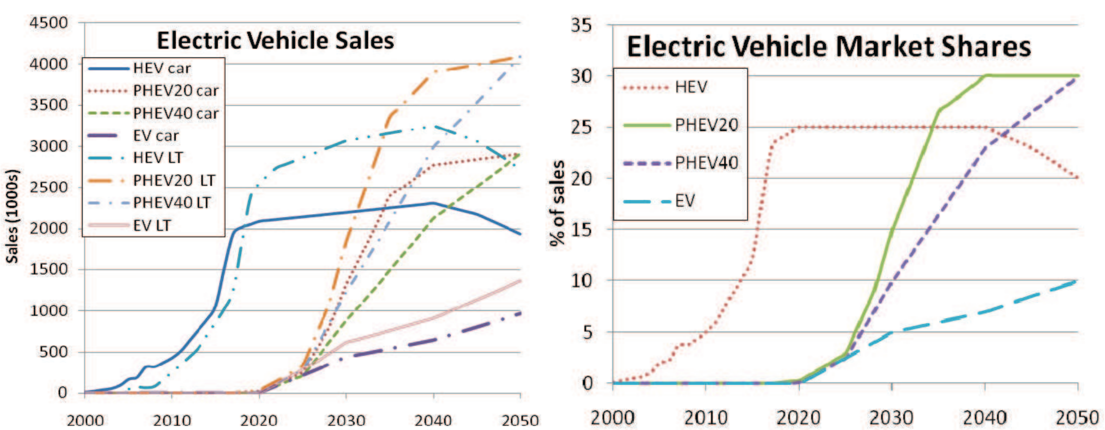


Sources: Interviews with component manufacturers, cell producers, tier one suppliers, OEMs, and academic experts; Argonne National Laboratory; BCG analysis.
Note: Exhibit shows the nominal capacity cost of a 15-kWh NCA battery and assumes annual production of 50,000 cells and 500 batteries, as well as a 10 percent scrap rate at the cell level and a 2 percent scrap rate at the module level. Numbers are rounded.

The above chart shows the complete pack-level bill of materials, direct and indirect plant labor, equipment depreciation, R&D, scrap rates and overhead markup for a NCA battery cost to OEM.

The price for LFP battery is pretty much at the same scale of NCA battery. Considering the fact that although LFP cathode material is half the price of NCA, LFP needs more materials in cathode and offset this price advantage. With increasing technologies, LFP could beat the competitor at last due to its high usable capacity. Thus the price will drop to meet the customers' needs.

Also notice that this OEM price is not final market price because the manufactures require roughly 50% scrap rate and the actual cost in the range of $1500 to $1900 per kWh.



Lithium-Ion batteries: Possible Materials Issues by Linda Gaines and Paul nelson Argonne national Laboratory

Future Cost

The battery costs will decline for sure as production volumes increase. The above chart shows optimistic HEV market expansion rate and scales. Based on the assumption that 14million cars will have electric or hybrid power trains by 2020, the customer price will fall to $570 to $700 and the battery price will drop to $270 to $330 per kWh respectively.

Lithium Ion Batteries and future ahead: / By Mehul Oswal

In today's world we can find the good amount of mix in the lithium iron phosphate and lithium cobalt batteries, with one (Lithium Cobalt) giving enormous power with longer life for performing heavy applications whereas another (Lithium Iron Phosphate) gives good safety with less power as compared to lithium cobalt batteries. Though lithium cobalt batteries are equipped with safety electronic devices along with the safety shell on its body, still they are not fully used in cars and other vehicles because of the safety concerns as they can catch fire or explode due to the extreme heat, overcharging or thermal runway, But we have very few cars which has started experimenting such batteries to power their vehicles up to certain extent whereas lithium iron phosphate batteries are widely used in all types of small devices including laptops, mobiles, IPods, digital cameras and many more and In some cases they are also used in HEV's and EV's. Technological research has made this possible that we have reached at the stage where researches are being carried out to find improved battery technology for electric vehicles and use them as a substitute for gas driven cars and other vehicles, If we continue to progress the way we have done in last 10 years in the field of battery technology advancement then In near future we would see the batteries of high potential which will require time to charge as less as it takes to refuel the car today, Also If we come up with such great technology then It would also help us to reduce the effect of global warming and would noise pollution.

Adding: /By Runhua Zhao

Apparently the price of HEV and EV is too high for ordinary family for now. As gasoline price launch to the mountain and overcome the price for HEV and EV in the future, people will eventually shift to use electricity and start to think about schedule their trip before head and have smaller vehicles, at least not that big. Because the battery capacity is finite even if the plug in Hybrid infrastructure is mature. The point is that one can't go wild and wherever they want since the price people pay for this road-freedom is too high and one day they can't afford it. We can foresee the mass transport system will come into play, more and more carpool happened on the street and people will better organize their trip. The energy spend on road transport per person will drop to rational value. Eventually the country on the wheel will change the way what it is today.

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