Fundamentals of Electric Vehicles: Technology and Economics
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Lecture 22
Why Lithium Ion Battery - Part 2

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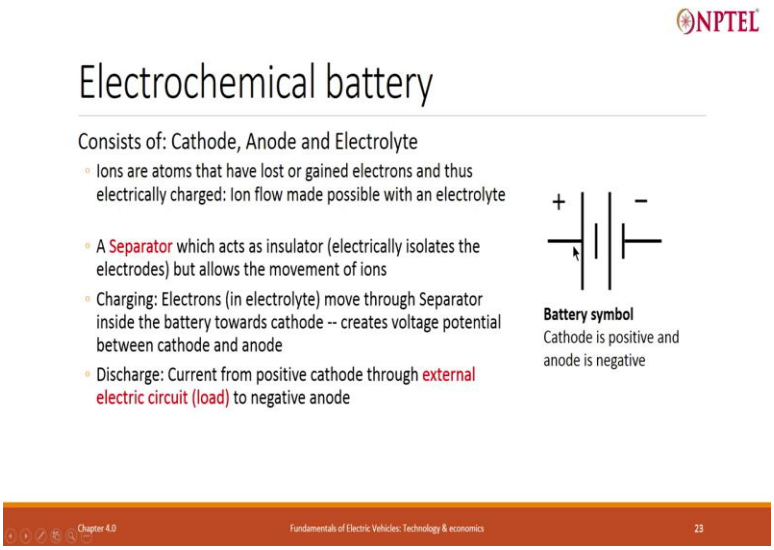

Let us look a little bit more at the battery. It consists of three elements cathode, anode and electrolyte in between. Cathode is a positive, anode is a negative and there is electrolyte. Ions are atoms that have lost or gained electrons these are all ions either one less then what in a neutral state it is negative charge, if there was a one more positively charged and these ions actually flow in a battery.

So, there is a separator which separates out the positively charged cathode and negatively charged anode. So, in charging electrons move through separator inside the battery to cathode and then it gets positively charged. During discharge the positive current will flow from here to here, electrons will flow from here to here. So, that is what happens. This is the way electrochemical battery goes.

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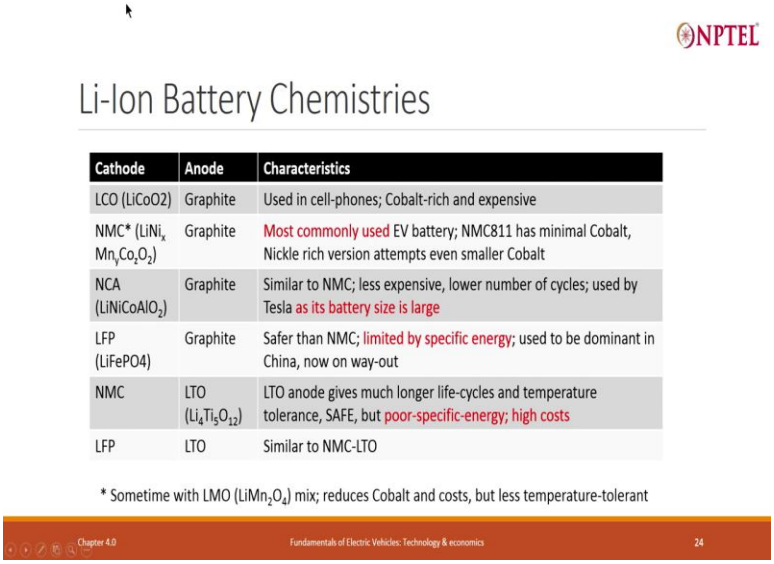

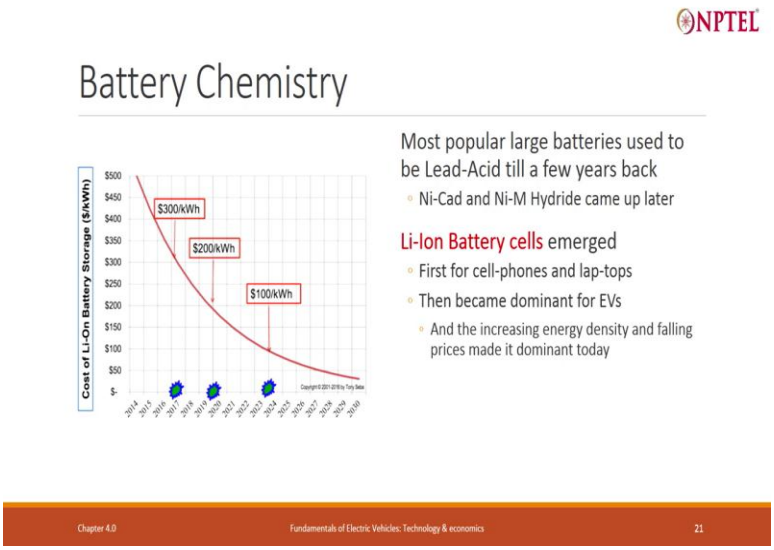

A lithium ion battery chemistry. It some there are a large number of lithium ion battery chemistry. It has been evolving then at least 1, 2, 3, 3 6 major chemistries. The battery called LCO lithium cobalt oxide. This is the main battery today, which is used in cell phone. It is cobalt rich and cobalt is a raw material, which is extremely expensive available only in a few countries China and there is a country called Chad in Africa or another country I am making a mistake and that has a lot of cobalt, cobalt is raw material which is not as easily found. But this is what the battery was used good density reliable battery.

And then the battery came NMC lithium manganese cobalt oxide. This is the battery which is most commonly used today NMC. It gives you a good energy density and NMC itself it ask a question how much of nickel, how much of manganese and how much of cobalt oxide. So, XYZ NMC811 basically 80 percent is nickel, 10 percent is manganese and 10 percent is cobalt dioxide. NMC111 basically means equal quantity as NMC111 moves towards NMC811 in between there is a 622, there is a 433, you will find more nickel and less of cobalt which reduces the cost and increases the energy density.

Today after you have reached NMC811 there are attempt to make it they add more nickel and less cobalt that increases energy density reduces cost. The other commonly used battery is NCA. In fact, NMC and NCA are more or less similar quality we will get into it little later, but they are both more or less equal NCA is used by Tesla for its batteries, very similar behaviour NMC and NCA. Now you look at it (NM) NCA has one advantage it does not have cobalt and therefore can be less expensive.

The disadvantage is it has lower number of cycles and NMC has higher number of cycles. So Tesla still prefers it, you will say, why if it is low remember cycle why is Tesla preferring it? Because Tesla has designed a large battery which lasts 600 kilo meters, which means if it has only 1000 cycles it is a 600 1000 kilo meters.

Now, vehicle is life does not go more than 300, 400, 1000 cycles. So, 1000 cycle more than enough. But if you have a 100 kilo meter range battery and if you have only 1000 cycles let us say 100 1000 cycles you have to keep on replacing maybe every alternate year. Then you want a 2000 cycles.

So, that is the reason in NMC will be preferred. There are two 1 other battery call LFPO LFP cathode, anode is graphite all these at graphite anode. It is a battery which is safer than NMC. It used to be, it was a Chinese I would do not know the Chinese invention but China dominated LFP and for a long time said this is the battery that we must use till 3, 3 and half years back. It was figured out that LFPO battery cannot go beyond 160 watt hour per kg.

Remember that watt hour kg that I talked about. So, it cannot go beyond 160 watt hour per kg which basically means at 160 watt per kg it costs, the material cost itself will be closer to 200 dollars, 250 dollars, it cannot go in this direction. When China realized that it decided to dump

LFP battery saying get rid of these factories start making a NMC batteries. It started only about 2 2 and half years back but dumping can also mean that you can export the factory. So, if India does not understand this very simple thing that LFPs life is over, it will say oh give us the factory at low-cost.

Except you are taking the battery is it factory which battery will have no future because that has 150 watt hour per kg or no more, you have already reach 300 watt hour kg China has it is China, which is Chinese company CATL which has crossed 300 watt hour per kg and tomorrow it will cross 400 watt hour kg. There is 150 watt hour kg will be two and half times more expensive who will buy that. But very often in India we do not understand that, we land up into trouble.

There is the other alternative there is alternative called NMCLTO it is called LTO battery. It is actually a battery which has a lower energy density but can charge discharge at a very high C rate and can withstand very high temperature. LTO battery it is called commonly it is called LTO battery. It has a, it, you can have a 10,000 cycles but almost two and a half times more expensive than NMC.

Now, what do you do with 10000 cycle or 15000 cycle and costly is about two and a half three times and if you are going to put in a large upfront investment and if your interest rate is not very low you are stuck with the battery. So the invest where the interest rate is very low. It may still have life in India it has a very limited usage. There is also LFP LTO not commonly used there is some something these are the battery. The important thing is a battery that we have to really focus on is number 1 this and number 2 this both batteries are good. If you ask me to choose I will not be able to, it depends on the application these are two batteries.

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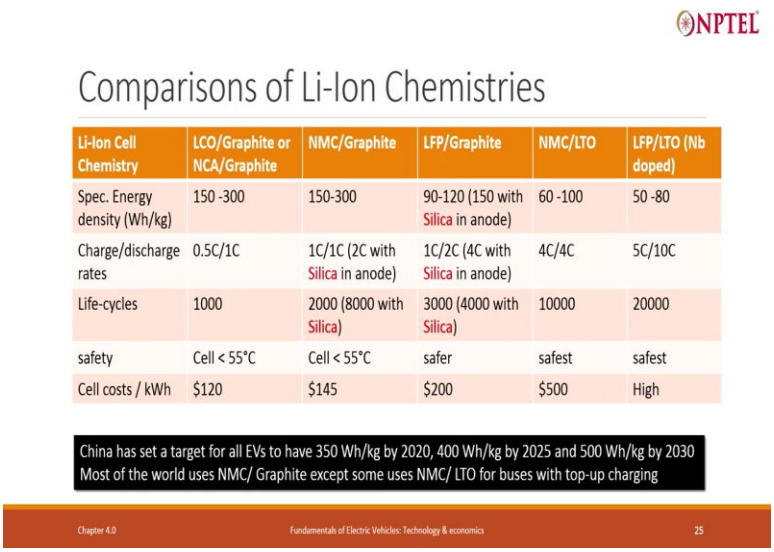

Now, comparison now just this is the same thing that I talked about if I look at NMC you can go 300 cycles, NCA also you can go 300 cycles, sorry 300 watt hour kg, 300 watt hour kg whereas LFP is 120, 150, 60 to 100, 50 to 80 this is what determines everything. This is also brings down the cost you can charge discharge at 0.5C 1C 1C 1C this you can charge discharge little faster 2C but again, what is a use you will limited by the energy density. Life cycle these had a slightly higher life cycle. But this also 2000 are there now and with silica you are looking at 8000 cycles.

So, this also fairly good. Cell temperature has to be 55 degree centigrade, LFP is safer. We must understand the why is it safer, it has less energy density, anything which is less energy density will be safer than anything with higher energy density. So you have to actually make use higher energy density because will cost low, less weight and make it safe. Cell cost of course you are seeing 100 dollars already on this. If you look at only safety, I will say NMC LTO is extremely safe. But energy density is only 80 watt hour per kg what you do cost is extremely high.

So, you must understand for what usage you are going to use what. China for example declare a policy that by 2020 all (vehicle) batteries should be 350 watt hour per kg. They are not, they are going to fall behind, they will not reach 350 but they have reached 300 that is important thing. They are saying if it is less than 350, you will not provide subsidy I think they are that modifying that, they this is the way they push technology, they declared it about three and a half years back.

India declared we will use LFP which is less than 150, but did not understand at all. I will say we will keep them on power, China realize that it has to get rid of LFP and LFP cannot go above 150 everybody so used to LFP, Chinese company will dump LFP in China, they say well you will not get subsidy if you use it and since subsidy still plays a major role it has able to force Chinese company to move towards NMC and NCA. This is the way Chinese policies are done. We may have our differences with China, we may not like China but at least they are clear that they want to technologically advanced.

So, now by enlarge there is a consensus in the world that has NMC NCA, but for a few years there was a lot of, lack of, the confusion (()) (12:22). For example, MNR in India still says you have to use only LFP battery. How this decision was taken? How did the Chinese influence them? I leave it. But the decision today is you can only use LFP we are making things solar packs with NMC battery this you cannot use it. So, what are they eight ask of a battery.

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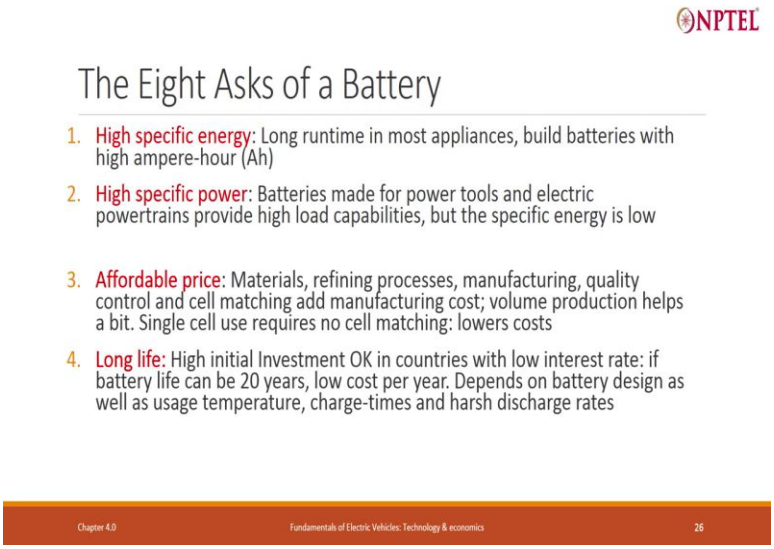

First as I talked of you high specific energy or gravitational energy density. Number 2 high specific power can I run at 2C, 2.5C, 3C at times discharge at least even charge at times. So, specific power, specific energy. Affordable price, very important, very important; long life can I get more number of cycles, price and life cycles have to you cope together, we want affordable price low price for reasonably good number of cycles.

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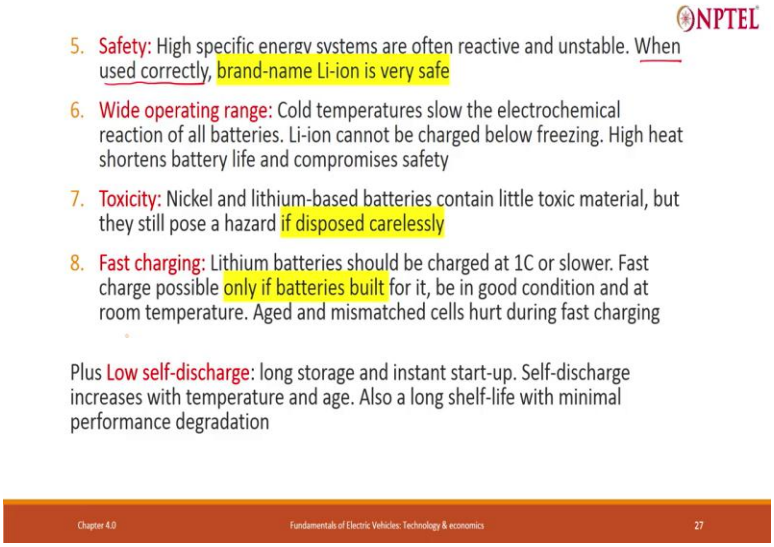

Fifth is safety of course, it has to be safe, well make it safe. But you know must remember that a brand name of lithium ion is safe as opposed to lead acid and all that. When use correctly if you do a bad design it will be unsafe, when used correctly the brand name is safe. Wide operating temperature you want to be able to operate in low temperature cold temperature at 45, 48 this is a difficult one but we this is our asks I am telling you what are the ask, 6th one. Seventh one, low toxicity it is not bad but it has to disposed of well, and then fast charging fast charging is actually related to the C rate that I talked about earlier.

Normally lithium battery should be charged once you are lower but can I charge occasionally fast charge. Now specific kind of battery you can, otherwise you impact the life very badly. So, these are 8 ask. Finally, a very important ask is also low self-discharge, should I charge it come back after 3 days 20 percent gone that is no good. Now fortunately lithium ion batteries have decent self-life.

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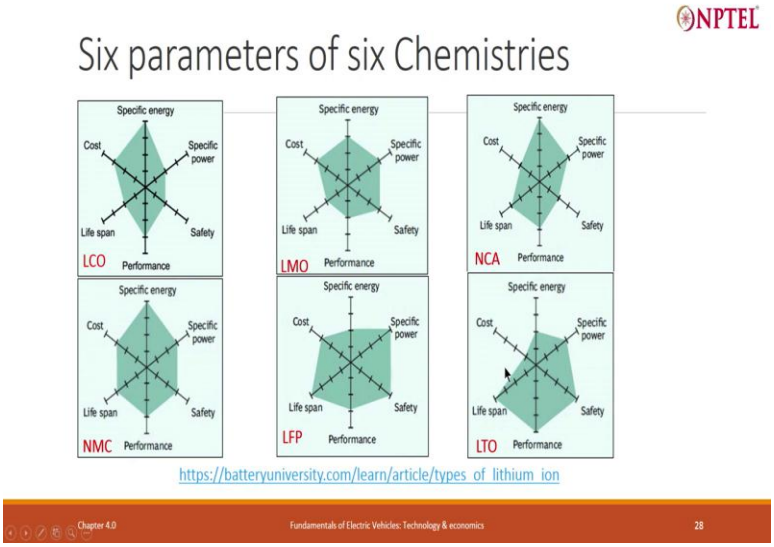

There is a very interesting where things are representing a battery chemistry is represented by a kind of a six axis curve, six axis curve specific energy, specific power, safety, performance, life span and cost. Life span, number of cycles, cost, performance to some extent C rate, safety, total power that you can draw, specific energy. This so if you look at it this LCO battery used in cell phones is very good specific energy, low cost, ideal load have been lower, power moderate not very good large power, but then so C rate is low, but that does not matter because cell phone draws very little current, safety good safety, performance overall performance of the battery is good and life span is decent.

If compared to this, I will look at a battery call NMC, NMC is the, if you look at it it is a more even it is all it is a moving towards hexagon. So, the weakness of (())(16:37) it has enhanced safety, specific power has gone up, it can do better than that, cost is roughly the same, lifespan has gone up. So, overall this has is a slightly, specific energy has gone up significantly. If I look at the LMO there is another chemistry and today sometime LMO is mixed with NMC its cost is lower, specific energy, specific power, safety, life span is also lower. So, when you mix things, you have to really worry about it.

LFP the specific energy is where it loses look at this. One say, this is much higher, this is bad. Cost is decent slightly higher because of the lower this thing. Power it can do better than even NMC, safety is better than an NMC, performance not that great, lifespan better than NMC but it

is this is the most important parameter, this and cost related. So, this is the angle that you have to really worry about.

Look at the NCA almost similar to NMC except if you see cost is even lower. But lifespan is, life span is less should have shown up more life span is less. Safety somewhat less but it is okay. LTO on the other hand very low specific energy, very high-cost, this is, this is not cost low, sorry I think I making mistake unless cost, cost wise it is very bad this tells you how good it is, so cost is cost is so sorry even in NCA the cost is higher then, so how good it is a goodness in all this.

So, this is a higher cost lifespan is good, very good, specific power also can be very good, performance can be very good, safety can be very good. So, this is a very good diagram I have taken this from a website called battery university. In fact, much of the material in this chapter has been taken from the battery university. It is a good description of these things.

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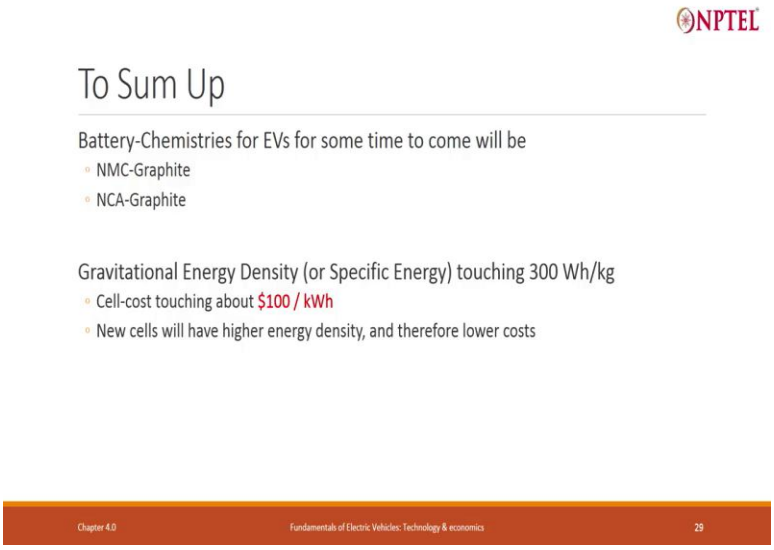

So, to sum up battery chemistries for electric vehicles for some time to come is NMC graphite and NCA graphite. I will look at the future battery in a short while. Gravitational energy density is touching 300 watt hour per kg, cost is going down to 100 per hour dollar 100 per kilo watt hour. New cells will have higher energy density and therefore lower costs.

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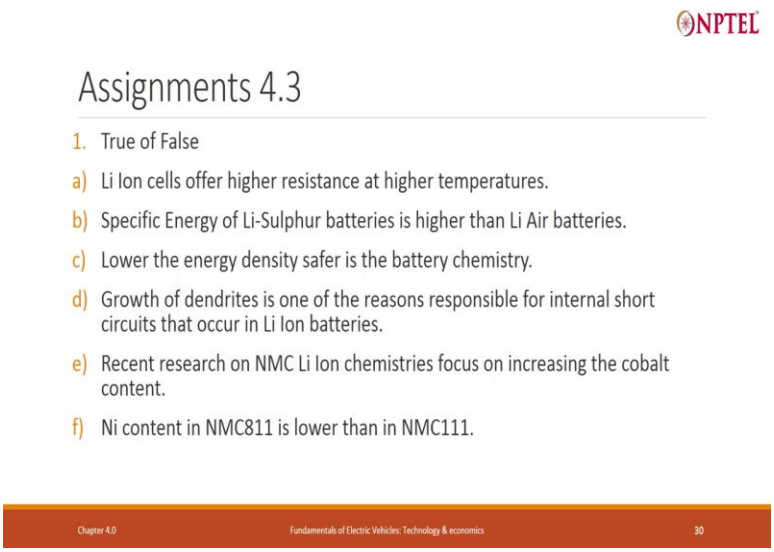

There are assignments that I am giving you, very simple assignment true or false. You have to just keep marking that and then we will come to batteries in future. Thank you.