Fundamentals of Electric Vehicles: Technology and Economics
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Lecture 20
Introduction to Battery Parameters – Part 2

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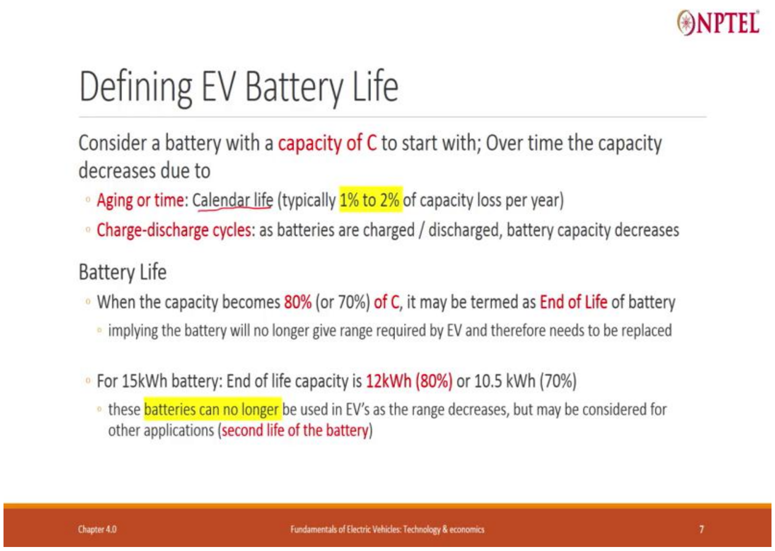

The next important parameter I want to define for the electric vehicle is, if a battery start with a capacity C, it is a new battery, it has a capacity C. Over the time the capacity decreases, I have pointed this out several time, it decreases due to two reasons one is aging or time you leave it in the shelf it get to deteriorate, it is a slow deterioration could be 1 percent a year, could be 1.5 percent year but slowly it will deteriorate.

So, you cannot say that you will come back 7 years down the line is you will have the same capacity, no, there is a it is called aging or also called calendar life of the battery, calendar life of the battery, so you have to worry about that. Of course, however it is small so and calendar life is large so you do not have to, impact is small, so you do not have to worry as much, but you have to take that into account finally.

The second capacity decreases due to charging and discharging, every time you charge and discharge you lost a, some capacity, charge and discharge you lost a capacity that is called charge discharge cycles, number of charge discharge cycles it supports that battery will go from

100 percent capacity to 80 percent capacity, if I define 80 percent capacity is end of life, that is the effective charge discharge cycles that I can use.

So, charge discharge cycles defined between 100 percent and a certain end of life, now you have to define what the end of life is, that is the number of charge discharge cycles, you can do so many charge discharge cycles is a rechargeable battery after that it is not useful and every time you are charging discharging your capacity is going down. Is that clear?

So, this becomes an important parameter. So, battery life is 80 percent or 70 percent of C it may be termed end of life, I had defined that, implying that battery will no longer be useful for EV, it does not mean the battery has gone it has still 70 percent capacity or 85 80 percent capacity you can still use it for something else. For a 15 kilowatt hour end of life if it is 80 percent that means a 12 kilowatt hour is end of life, if it is a 70 percent end of life it is a 10.5 kilowatt hour end of life, I am again pointing out these batteries can no longer be used for EV’s as the range decreases to 80 percent or 70 percent.

But it can be considered for what is called for other applications often called second life of the battery, for example, I do not have a weight or volume constraint and I do not have a range issue if I use it as a power back up in my office, so I can always take that battery out and use it for power backup. Typically, from 80 percent to around 50 percent you can have a second life. But remember the battery does not behave as well in the second life as in the first life.

First life 100 percent to 80 percent pays very well after that it pays all right from 80 percent to 50 percent, but that can be the second life, beyond 50 percent battery behaviour become erratic, not that it cannot be used, could I not use a storage up till it goes to 30 percent? Yes, but you never know at it may certainly fail at 40 percent. So, generally it does not work as a good battery, reliability itself goes down beyond 50 percent.

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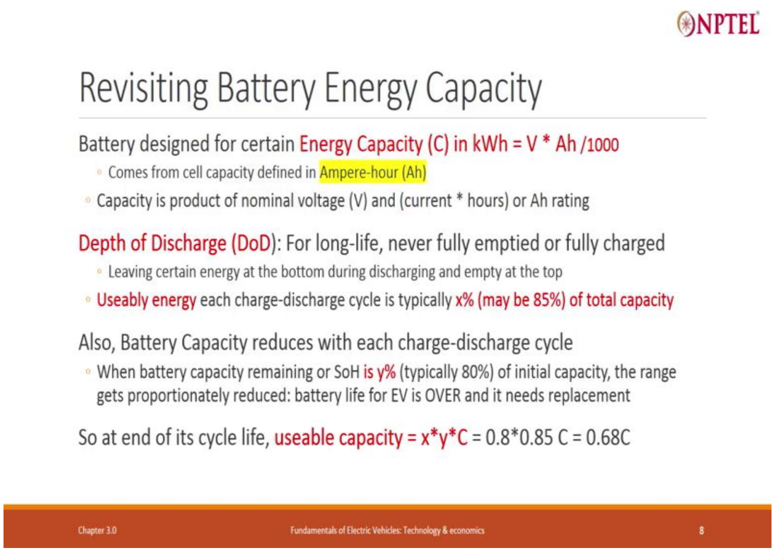

So, battery design for certain capacity as I told you voltage into ampere-hour this is something that I had already done capacity is a product of voltage and ampere hour, depth of discharge I had talked about, for long life the batteries never fully emptied, you leave certain energy, this is something that I had done in the previous chapter, usable energy is X percent or 85 percent of the total capacity and that comes from depth of discharge.

Also battery reduces with each charge discharge cycle, when battery reaches certain end of life, let us say y percent of initial capacity, range gets proportionately reduced, so battery life of for EV is over and it needs placement and therefore if it is 80 percent end of life and 85 0.85 85 percent depth of discharge the battery at end of life usable batteries as low as 0.68 C. Keep this in mind this is a slide that I had borrowed from previous chapter and brought it here to just define it again.

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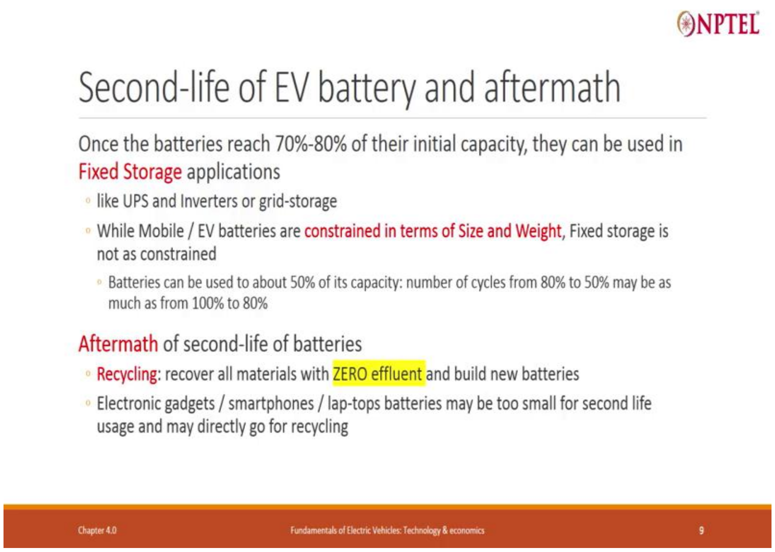

Second life for the battery, once the battery reaches 70 to 80 percent of the initial capacity it can be used for fixed storage, weight is not a constraint, volume is not a constraint, like UPS or inverter or grid storage. Electric vehicle is always constrained in terms of size and weight and whereas fixed storage is not.

So, you will not like using electric vehicles because it has a limited size and weight possible and it is giving you a low range, as I told you battery can be used to up to 50 percent capacity, number of cycles from 80 percent to 50 percent, well it will depend on the cells used, but roughly could be similar to a 100 percent to 80 percent, maybe less.

What do you do after its second life? When you as a pointed as you can continue to use it, instead of 50 percent can use it 40 percent or 30 percent, but if it becomes unreliable you do not want to use it, because when you need it power it will not give you power, so then a very important task that you can actually do is what is called recycling, particularly well for all batteries but for lithium ion particular, you can recycle the battery. What do you mean? You take the battery and extract the raw materials.

Now, when you extract the raw material it is a dirty job. So, is it going to give you harmful gases? Will it give you liquid which is will not know where to dispose? Will it give you solid which will be a problematic in disposal? These are called effluents, whenever you recycle you recover the material and then there is effluent, the whole idea is in today’s world we will have to do the recycling process with what is called zero effluent, no solid, no liquid, no gaseous effluent.

You actually convert it back into usable material, that is a ideal recycling and fortunately there are people who are shown that this can be done for lithium ion batteries. A lithium ion batteries are not there just for electric vehicles, it is the same batteries which is there in every cell phone, it is there in laptops and today you can start recycling.

And the batteries in cell phone and laptops are too small you cannot even use it for fixed storage, for office and things like that. For electric vehicles a large, if it is a 15 kilowatt hour battery you can use it, the batteries in cell phones and laptops are much smaller, so it generally goes straight for recycling, so recycling industry will start first with laptop and cell phone batteries, over time electric vehicle batteries. This is something that I wanted to get your picture.

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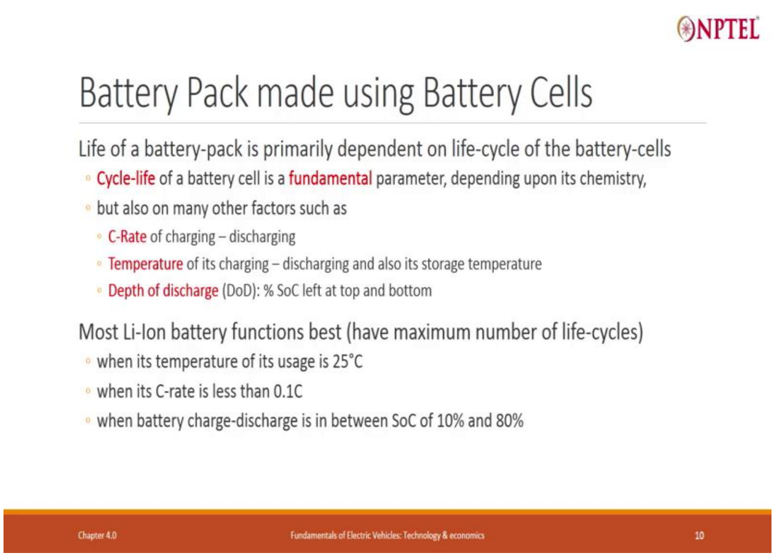

We will get to the next important thing how do you make a battery pack, battery pack is used is made using battery cells, these are lithium ion cells and life of a battery pack is very much related to life of a cells like of those cells, what will later on show you if one cell fails battery may become unusable, it depends on how the battery is designed or its capacity can considerably come down, we will later on talk about what is called serial and parallel.

So, depending on what cell is failure you may either completely battery becomes useless or its capacity can considerably come down, we will discuss this later on, its voltage can come down which may make it unusable. So, we have to understand the life of a cell to understand the life of a battery and therefore let me start with the life of cell. Cycle life of battery is a fundamental parameter, it comes from its chemistry and it comes from the cell manufacturer you cannot improve that, if cell has a certain life you can only do worse than that, at best you can reach the battery pack will have the same life as the cell life.

It depends on battery chemistry and exactly the process used by the manufacturer and it actually depends on a number of factors, such as charge rated, C rate, all battery cells depending on the charge rate and discharge rate the C rate that use it impacts the life of the battery. Most cells are such that if use higher C rate for charging or discharging the battery life will be significantly deteriorated, if you use lower C rate the battery life will not be impacted much.

So, therefore in general you will say slow charging is good, any fast charging is bad, but now there will be different cells which will be able to withstand fast charging up to a certain extent, that we will get into that. Invariably all cells, the temperature for charging and discharging matters, as well as storage temperature. But storage temperature you can more control, charging and discharging temperature you may not be able to control, you are going driving in India temperature goes to 48 degrees centigrade, What happens to cell temperature?

Well, you can cool the battery, but if you cool the battery the energy part of the energy of this battery itself will be used to cool, so and it is costly. If you do not, whatever the ambient temperature is directly going to impact you, so temperature ideal temperature is 25 degrees centigrade as we will look at later on, higher temperature is bad for the battery and cells, lower temperature is bad for the battery and cells. We will look into that details.

Depth of discharge, remember that I have been talking about I will not like to use the battery beyond a certain depth of discharge, if I try to charge it full or if I try to discharge it full it impacts a life of the battery, if you leave something on the top, leave something on the bottom, batteries likes it.

So, as I pointed out about 85 percent is generally used sometime 90 percent depends again on the battery chemistry and what the manufacturer gives you. To that extend capacity goes for a toss but life goes up. So, as I pointed out most lithium-ion battery functions best when its temperature is 25 degree centigrade, at 30 it behaves slightly poorer, 35 poorer, above 35 starts deteriorating rapidly.

At 20 behaves alright slightly poorer, 15 slightly poorer, 10 you have to start worrying deteriorating fast, in fact if you make it much lower temperature battery stops working. Ideal charge rate discharge rate is 0.1 C, 10 hours for charging, 10 hours for discharging, well 5 hours also is okay. Any attempt to charge or discharge a battery faster than that impacts battery life. How much it impacts? Depends on the kind of cells.

Ideal depth of discharged is about 70 percent, you leave 10 percent with the bottom and do not go above 80 percent, but that will mean 30 percent capacity loss, so you do not use it and you find depends again on cell maybe 5 percentage enough in the bottom, maybe 10 percentage is enough on the top.

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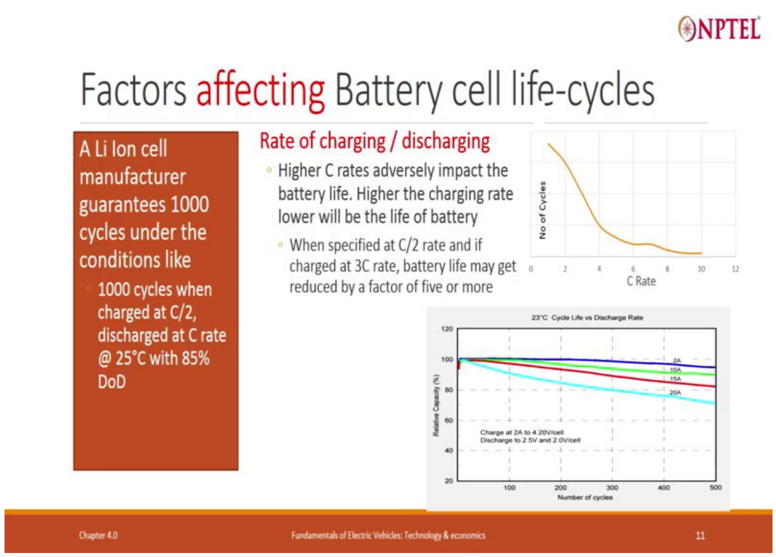

Factors affecting battery cell life, a lithium-ion battery manufacturer may tell you that I am giving you a battery cell which lasts for 1000 cycles, but they will always define, that the 1000 cycles is charging at C by 2 rate, discharged at maximum 1 C rate and always at 25 degree centigrade with 85 percent depth of discharge.

These numbers will vary, but life cycles by a manufacturer is defined like this, as you deviate from that there 1000 cycles will start reducing. For example, if you take 1000 cycle charged at C by 2 rate, what happens if you charge at 2 C rate? We will be surprised, sometimes it will not give you more than 250 cycles. If you do not get a full details, very often you have to conduct measurement to figure out all this, in our lab you do detailed characterization.

So, rate of charging discharging higher C rate always decreases, so this is a very rough curve, so if you see it has a decent number of cycles at low C rate, as it goes up either charging or discharging the number of cycles goes down like anything. Now, exactly to the curve we will depend on the battery chemistry, as I pointed out when specified at C by 2 rate for charging you do 3 say battery life may be down by a factor of 5 or even more, that is the point that I want to make.

So, very often people say why cannot I fast charge, well I why cannot I get a charger which can fast charge, is not a matter of charge, battery cells itself, battery pack itself, battery pack was may not be designed to take fast charging. This is another curve which shows the same, look at this, relative capacity and as the number of cycles increases if you see if you charge or discharge, this is a cycle life for discharge rate this is discharge rate, if you discharge it a 2 amperes 2 amperes the in 500 cycle you are still left with about 95 percent of the battery, so probably it will last to 2000 cycles, before it comes to 80 percent.

But, let us say that suppose you instead of 2 amperes if you do at 10 amperes, well battery life has gone to 90 percent in has gone down by 10 percent in 5 minute cycles is okay, if you do 15 ampere, then battery life is infinite cycles of battery life is over 80 percent is reached and if you do 20 amperes it is it takes only 300 cycles for battery life to become 80 percent, this is for a typical cell.

So, your life will significantly deteriorate actual value you can ask the manufacturer they will give you, they will give you something, not necessarily fully but some idea. This is a something that you must remember rate of charging and discharging, ideally do it law small, of course if you want faster rate charging-discharging you try to purchase cells which are able you to do that.

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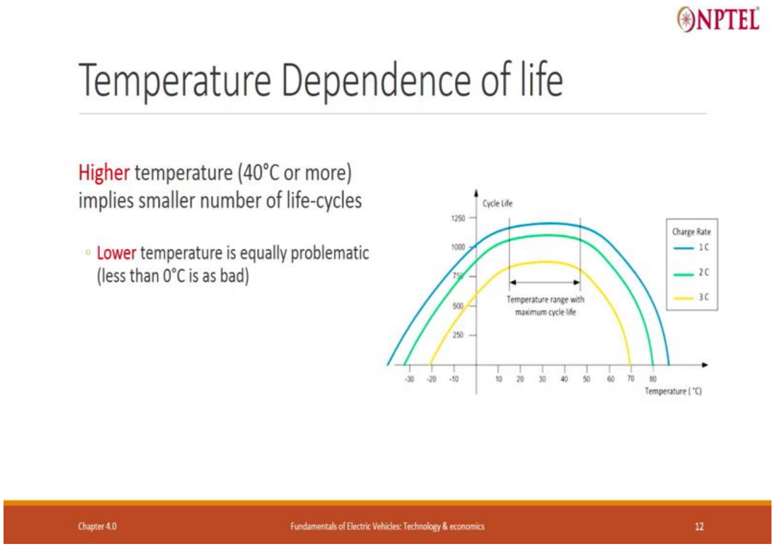

Higher temperature or lower temperature as I said effects the battery life, battery life is ideally between 20 and I will say 15 and 35, 15 and 35 it is okay, it deteriorates not as bad, but if you see even the deterioration is more at 3 C rather than 2 C and 1 C, 1 C it may handle larger temperature range and 2 C does not handle as much, 3 C it handles much less number of life cycles can go down like anything.

Below 15 degree centigrade you start seeing very rapid decline and you will see that most batteries below 0 degree centigrade will not even work, at higher temperature it drops down even worse, from 35 you go to 40 45 it gets much worse. It depends again on the characteristics depend on the cell, this is for a cell which can handle 40 degree centigrade reasonably well, the cells which will not handle even 40 degrees centigrade.

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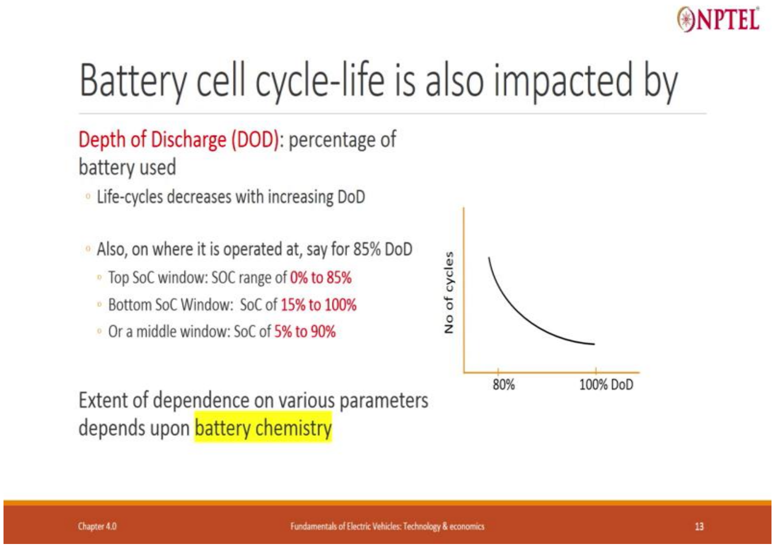

This is a depth of discharge, another number of cycles if you have 80 percent very good, as you increase as you start going to 100 percent number of cycles goes down like anything, these three things you must remember is always there so you can say, what is the window in which we will operate? Will it be top SOC window with 0 percent to 85 percent?

Bottom SOC window 15 percent two 100 percent? Or middle 5 percent to 90 percent? Normally this middle window is always better. Again depends on the battery chemistry, the manufacturer you can ask them, but this is what happens, extend of dependency on various parameter depends upon battery chemistry that way it is manufactured.

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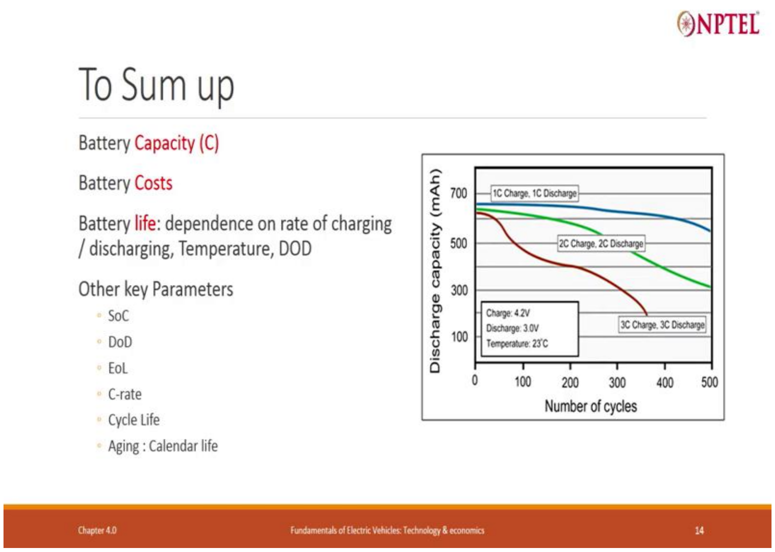

To sum up, what have we done so far, we have defined battery capacity, we have always said battery costs are very important we will look into it that more detail, battery life dependence on rate of charging discharging, temperature and depth of discharge, look at this, this is 1 C charge 1 C discharge and you see discharge capacity 1 C charge discharge, in 500 cycles the battery life goes down, but it looks like the battery will last for at least another 5 minutes cycles 1000 cycles.

You see 2 C charge discharge, it has gone down to 300 and 3 C charge discharge do not even ask, it is going down, your battery is over, so it started with 650 cycles it going down to 100 cycles well with number of cycles sorry, the capacity went down by from 600 to almost 100. So, the if you look at 80 percent it would reach very, very rapidly. This is important to understand with battery life.

The other key parameter state of charge is always important, how much it is discharged, depth of discharge, which is same as well I have mentioned that. End of life, what is the end of life, is important, C rate we have define which is again rate of charging discharging, cycle life, what is the total cycle life? We have talked about aging, calendar life, so calendar life plus charge discharge cycle. This is what we have done so far about the first part of looking at battery.

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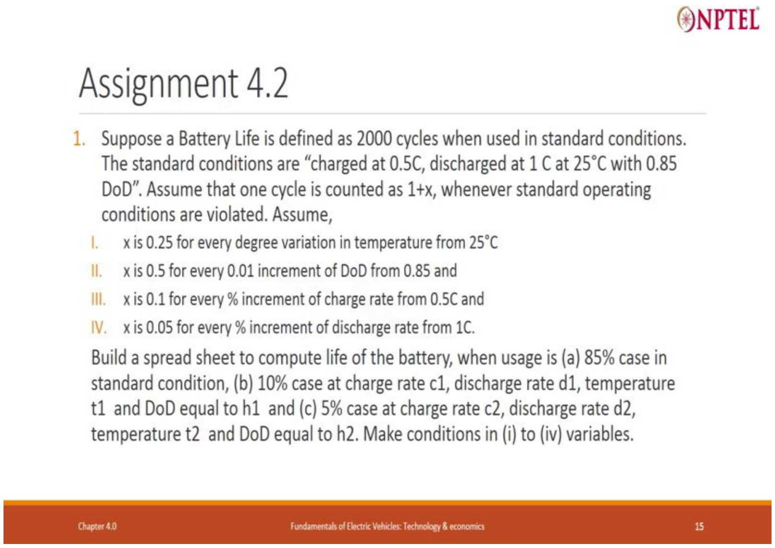

And we will there is an assignment problem, it is a fairly standard problem, but it is a interesting problem in the sense that we sort of say that yes it is supposed to do at 25 degree centigrade, but what if it is operated at 30 degree centigrade? What if it is done at 35 degree centigrade? Yes, it is supposed to be charged at 0.5 C, but what happens if it is charged at something else?

So, what I do is that I have try to build a model here saying this much deterioration will be due to this and I have taken combination the homework problem is now it is not done at the ideal rate it is discharged charged, temperature is different the depth of discharge is different, what is the impact on life? This is a model, now this model is may not be the actual model does not matter, but it will actually tell you how to go about doing this.

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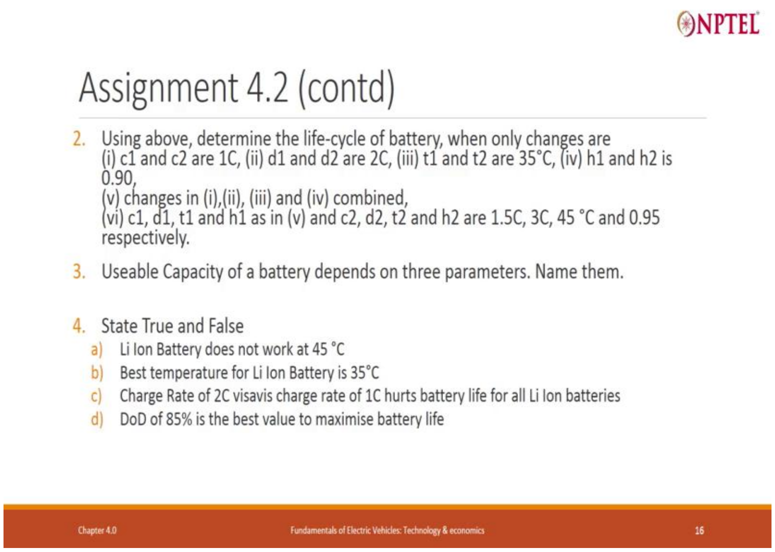

And I have other problems, first the same problem I am going to give you more variation, it will give you a feel. It is, you can do it simply by a spreadsheet on the answers. Usable capacity of a battery depends on three parameters name them I have done it repeatedly, temperature, depth of discharge and rate of charge C rate. Then I am asking you some true and false questions.

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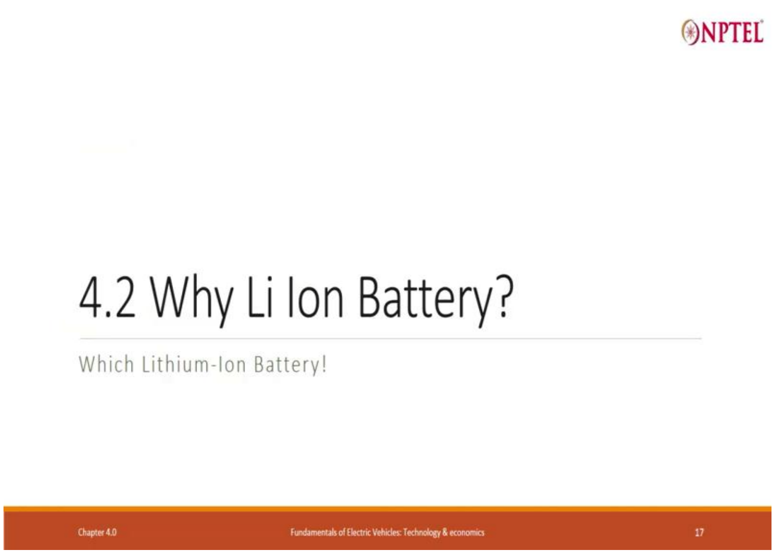

Well, that is what I am asking you so far, what we will do on Friday next class is start looking at why lithium-ion battery, why not other batteries? We will look first at what are the other options, where does lithium-ion stand (())(26:21) others? Where do other batteries do have a chance?

There will be another section after that 4.3 where we are looking at future batteries, is lithium ion battery would last forever or what is it evolving into? We will look at future batteries which may tomorrow replace lithium-ion battery.

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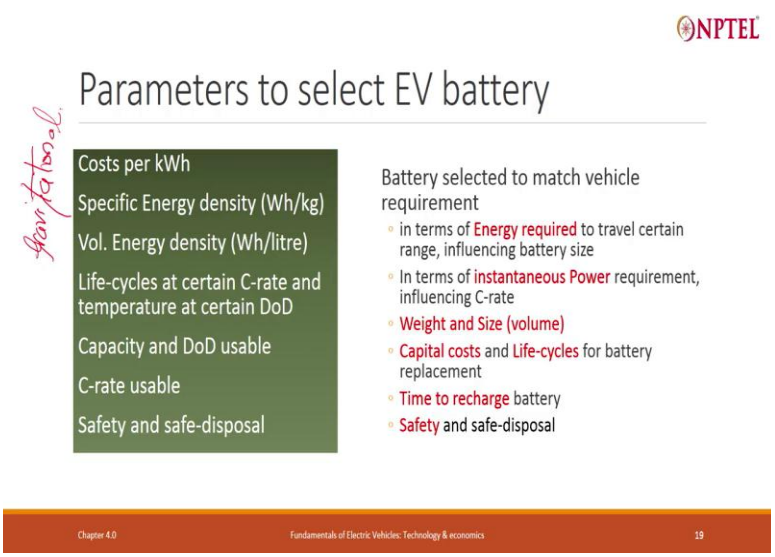

After having done 4.2 and 4.3 all these things then only we will be looking at and this is getting into details.

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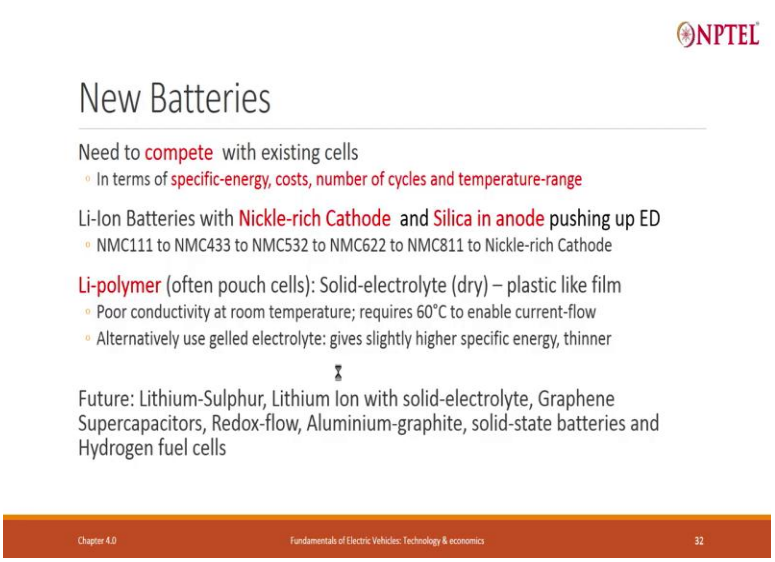

And after that 4.3 battery new batteries future batteries, batteries in future and I look at future batteries, all the kinds of future batteries that are talk, being talked about, I would not say all but to the extent that I commonly talked about and I was familiar with what I will do is that look at each of these battery.

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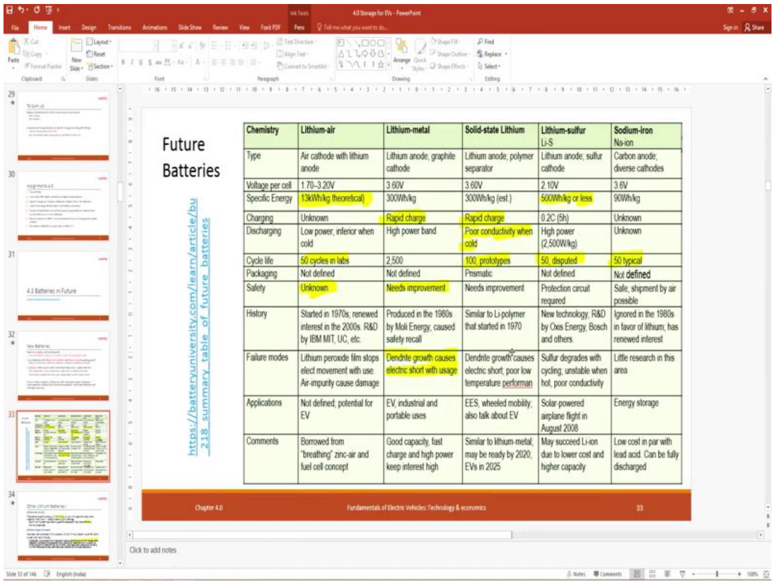

So, I will look at the future batteries, lithium air, lithium metal, solid-state lithium, lithium sulfur sodium ion battery. And Look at the pluses and minuses of all of these batteries.

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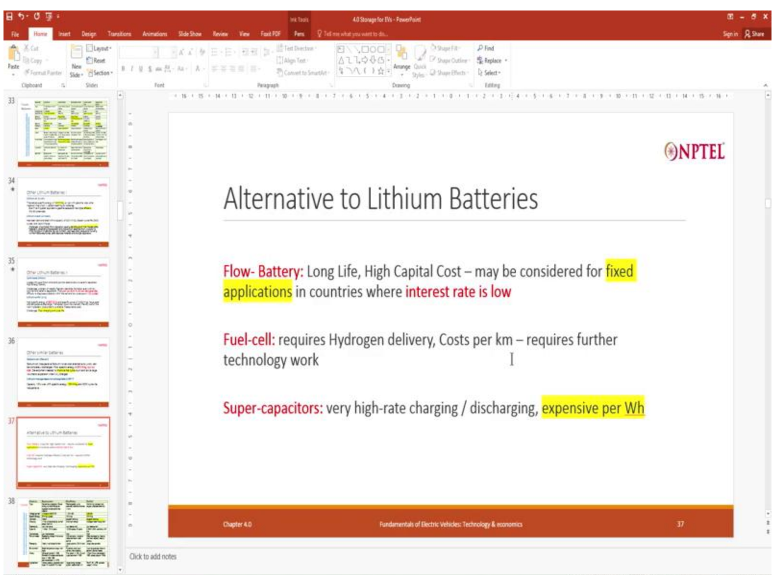

I will also look at some other alternatives that are sometime talked about where they are, flow battery fuel, cells and super capacitor, the reason I am going to talk about is all the time before you actually get into it, people say no no new batteries are coming new batteries are coming, tomorrow is something else as a person who had worked with good men who got the Nobel Prize this year for lithium ion battery a professor at Texas he told me but tomorrow never comes, lithium-ion batteries is there to stay. For some time, they are not, that there are not be future and we look into this and then we will get into detail of battery cells and battery pack design. Thank you very much.