Fundamentals of Electric Vehicles: Technology and Economics
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Lecture No. 35
Battery Swapping

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So this is basically, I have given you some idea, what the charger is and I talked about what is a slow charge, fast charge and heat dissipation. So, this is something that I have done. The next chapter is on swapping. Remember I had given introduction about swapping right in the beginning of the course, we will revisit it in a slightly more details now.

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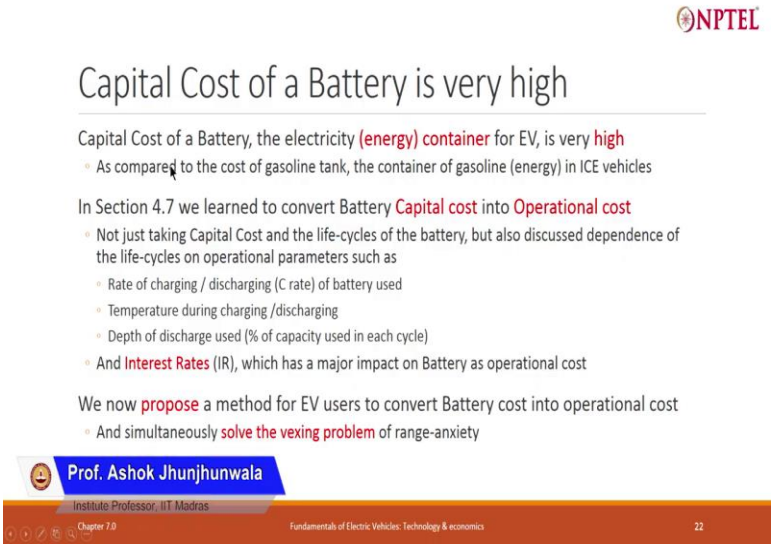

Remember capital cost of the battery, battery is electricity container for EV is very high, as compared to the cost of gasoline tank, we have been talking this from day 1. In chapter 4.7, when I was doing that battery introduction chapter, we learned to convert battery capital cost into operation cost. We took the initial cost of the battery and we say what is the usage cost, the operational cost, not just taking the capital cost and the lifecycles of battery but also discuss the dependence on life cycles on operational parameters such as rate of charging, discharging; temperature during charging, discharging; depth of discharge used as well as the interest rate.

We now propose a method for EV users to convert battery cost into operational cost and simultaneously solve the vexing problem of range anxiety. So, this is something that we are done, I will not say we now this is what was done.

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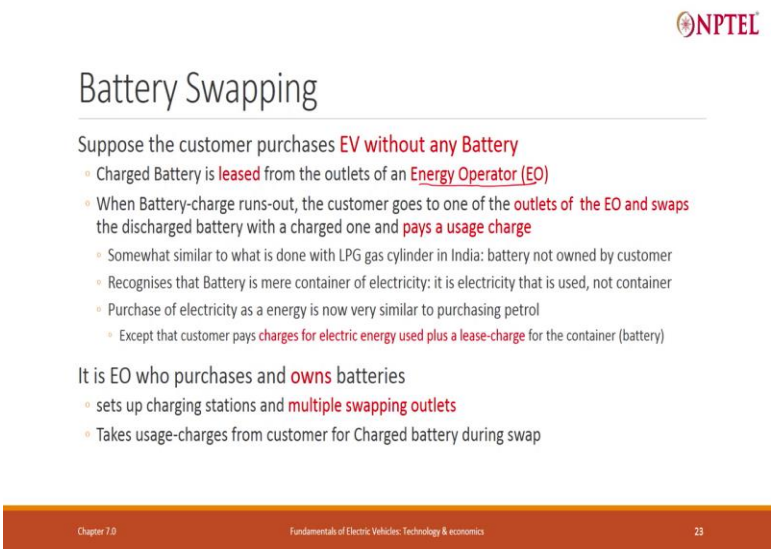

Because of this, because you have already done that, I am trying to sort of say why invest so much in the battery upfront? Can you do battery swapping? And buy the electric vehicle without any battery, buy the vehicle without any battery. And take the battery, a charged battery, lease it from what is called a energy operator, lease it. When you run out of it, you go back to the energy operator, energy operator may have multiple outlets and give back the discharge battery, take another charged battery, and pay the usage charge.

You have, I use the battery so many kilowatt hour or watt hour, I will pay that. Somewhat similar to what is done for LPG gas cylinder in India, battery is not owned by the customer, just like LPG gas cylinder is never owned by a customer, they get the gas cylinder, they use it, after that give it back, another cylinder comes in. In a same manner, you get a charged battery, use it, give it back and you do not own the battery.

It recognizes that battery is more container of electricity, it is electricity that is used not the container. The one thing every time the battery is used, its life goes down a little bit, so that you have to take into account. Purchase of electricity as energy is now very similar to purchasing petrol, you are like buying petrol, buy petrol, you fill up a tank, run, it gets empty. Here you are taking a container and the energy, use the energy, give back the battery, expect the customer pays the charges of electric energy used plus a lease charge of the battery, because battery is expensive and it is deteriorating small amount every time you charge discharge.

So, you have to pay for that. It is the energy operator who purchases and owns battery. It is a separate business just like the, for the gas cylinder, gas supply company which owns the cylinder. So, energy operator will buy all the batteries, it will setup multiple swapping outlet. Takes usage charges every time you use it. Now this concept has been there but it was not legal in India, in fact it is not legal in most of the places, this is not even conceived, this fuel tank is never removed and all that, so we went in a similar manner, this was not even conceived.

About 3 and a half years back it was recognized as this can be a very, very good way because you do not have to pay, customer does not have to pay upfront for a battery. But the law did not permit it to. Law did not permit it, the day I recorded the first lecture of this course, on the beginning of August. Today it is September tenth, now the law permits it. Suddenly in a sometime in August order came from government of India, now you can buy vehicle without a battery and take battery on lease. So now in India, all this has become total illegal.

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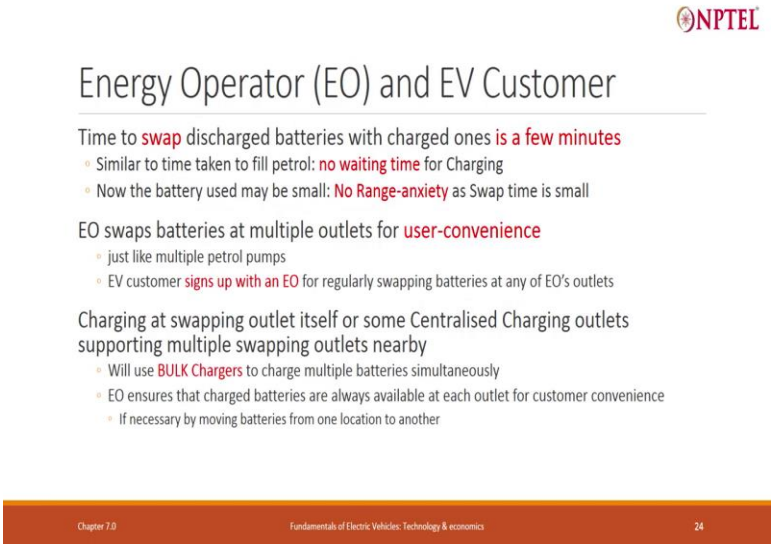

So, let us drill this further, now it is actually becoming very common. Remember time to swap a battery takes only few minutes, 2 to 5 minutes. For small vehicles 2 minutes 3 minutes; for larger vehicle you may have to a (())(6:33), you have to carry the battery mechanically by some automatic system and remove the battery and put in a new battery, a large battery so it will take up 5 minutes.

This is a time similar to what you need to fill petrol, because a time is small you can keep on doing it very often, you run out of battery, go to the nearest place, go and battery swapped, continue. So, something a range anxiety goes away, assuming that there are enough outlets. So, the energy operator who wants to make it as a business, will have to create multiple outlets, every kilometer maybe even less, you may see outlet, just like multiple petrol pumps, in fact more than petrol pumps.

Now every customer will sign up with one energy operator, there may be more than one energy operator, just like there is a BPCL petrol pump, IOCL petrol pump; there may be party x as energy operator, party y as energy operator, each of them will setup its swapping outlet. You will sign up with one of them and because you are taking that x's battery you have to return it at x and swap the battery. If you are signed up with y, you go and swap the battery at y.

Somewhat like your telecom operator and SIM, you can take one person SIM or another person SIM, similarly you sign up with one of the energy operator and keep swapping the battery with them. Charging at swapping outlet itself or some centralized charging, now the, where will the battery be charged? It could be at multiple outlets, each outlet is charging and giving back the battery, taking it discharging, alternately what we say okay I will have 100 swapping outlets but only 10 charging.

So, each charging outlet will cater to 10 swapping outlet, so you bring the batteries and then do it. Later on Doctor Prabhajot will talk about this in detail. Charging at swapping outlet, so far this, you normally use bulk chargers, you do not use single individual charger, you use a charger which can charge 10 batteries at a time, 20 batteries at a time. Why? Because batteries will be coming and you will be giving, so you want a number of batteries to be charged simultaneously.

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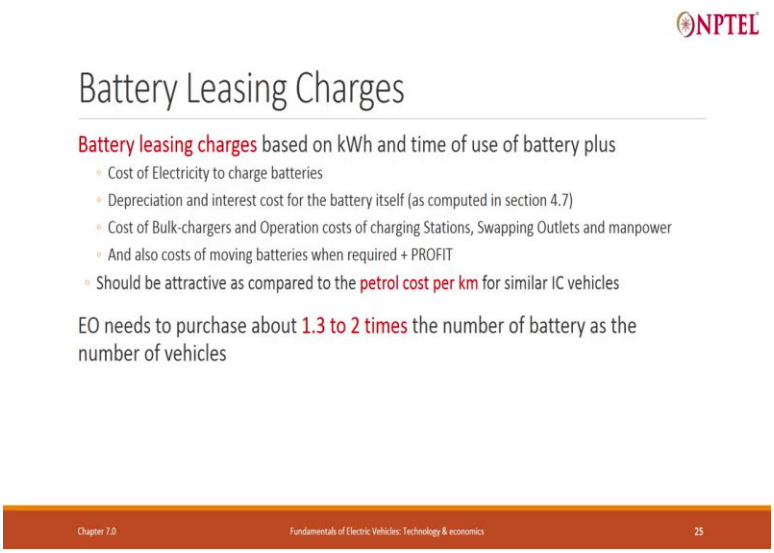

What will be the battery leasing charges? Now this is important, what will it per kilowatt hour, you use 1 kilowatt hour, what will you have to pay? First you have to pay cost of electricity obviously, that is let us say 6 rupees that you have to pay plus the fact that you are using the battery. For 1 cycle what is the depreciation and interest cost of the battery for 1 cycle, that becomes important.

We will compute this in section 4, it was computed in section 4.7, in 1 cycle how much it is used. So you, we had calculated depreciation, interest rate and computed it. So, you have to pay that whatever the (depre), this may come to 6 rupees, this may also come to each time you use it maybe another 6 rupees, maybe even more. Then I will require to put this bulk charger charges where I will actually charge, so you have to take the cost of the bulk charger and the swapping outlets and cost of that, again divided by the number of swapping that it does.

And if the batteries are to be moved from one place to another, you have to take that cost also into account, finally the profit. The energy operator has to make some profit, maybe small amount. Now, so we will pay that those who have not purchased the battery upfront, finally will you be happy paying it or unhappy paying it? Well, now we will think of those of vehicles has been purchased without battery, so vehicle's cost was less than petrol vehicle cost. If the cost of leasing the battery and giving back and using 1 kilowatt hour is less than the petrol cost for per kilometer, then you have no problem.

So, if petrol cost per kilometer, for example petrol cost is let us say 80 rupees per liter and suppose you the vehicle goes 40 kilometers, so it is a 2 rupees per kilometer. So, actually if the battery here also gives me less than 2 rupees per kilometer, you will be very happy. And will that 2 rupees per kilometer give energy operator some profit, that is the key issue. And we find that if are going to use the vehicle quite a bit, it does make economic sense.

Now remember the energy operator cannot, if there are 50 vehicles or 500 vehicles at the energy operator is serving, cannot just buy 500 batteries, because 500 batteries will be in the vehicle, I have to keep charging the other batteries, so that whenever a person comes I am able to swap. So, I have to probably buy maybe 650 batteries, maybe 200 batteries, 1000 batteries, 1000 batteries, 1.3 to 2 times.

And I must make sure that in spite of all this, the energy operator makes money. And I have shown that energy operator does make a money, provided the vehicle is used sufficiently and battery is swapped. Even at high interest rate it happens, as the battery cost slightly fall down, it will become more, more viable.

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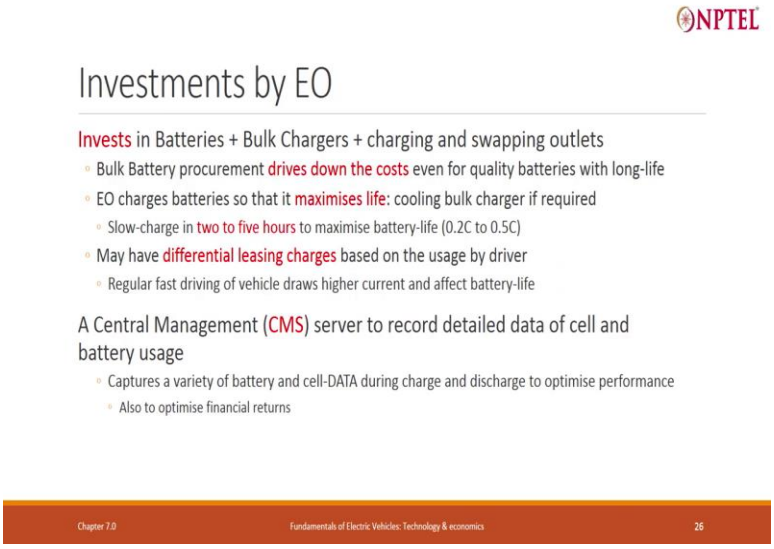

So, the energy operator will invest in batteries, bulk charger, charging and swapping outlets. Bulk battery procurement will drive down the cost, so that is a big advantage, the person does not have to spend so much, it maximizes life because you, the bulk charger can be cooling the battery, so at charging time temperature is 25 to 30 degrees. If you did not do that and if you are

charging, somewhere the temperature may have been 40 degrees, 45 degrees, would have been bad for battery.

Now this is good for battery. Similarly, you do not have to charge fast because person has come, given you the discharge battery, taken a charged battery has gone. You can charge in 3 hours, maybe even 5 hours, you have to take into account how many batteries do you have, how many people are coming continuously for swapping, you will keep that in mind and it is a operation research problem, you can figure out or you can charge in 4 hours without any problem, that is very good for the life of the battery.

And remember that it is the energy operator who has invested in the battery, they will be interested now to maximize the life of the battery. Now, it is also possible that the, it starts looking at drivers and say some driver is actually using the battery very badly, is accelerating most of the time and therefore drawing 1.5 C, 2 C most of the time. And therefore, is impacting the battery more, though they have taken for 1 charge discharge.

But in, suppose in 1 charge discharge, if the battery life cycle is let us say 1000, in 1 charge discharge you are supposed to take away one thousandth of the capacity that is available, net capacity that is available, one thousandth of the capacity. Net capacity I mean I am only taking from 100 percent to 80 percent, after 80 percent you may not use. So, you are supposed to do this with that. But if you are discharging very fast, you are driving fast, accelerating all the time, then the actually you were using equivalent to 2 cycles.

Now I can do this, as I know this person is using very nicely, I will give 10 percent discount, other person is using badly I will give him charge, so this kind of thing can be built in, based on the vehicle, based on the driver. Because the vehicle may also be bad, drawing all kinds of current, Kannan may have designed his motor badly and he has a lot of losses, efficiency remember that we talked about, suppose efficiency is poor and the person is driving at speeds where efficiency is poor, drawing lot of current, it is the C rate that matters.

So, what is a C rate at which you have been doing? A central management server to record detail data of the uses of each cell and the battery and you use that to optimize the performance of the battery. This is possible by energy (boat) operator.

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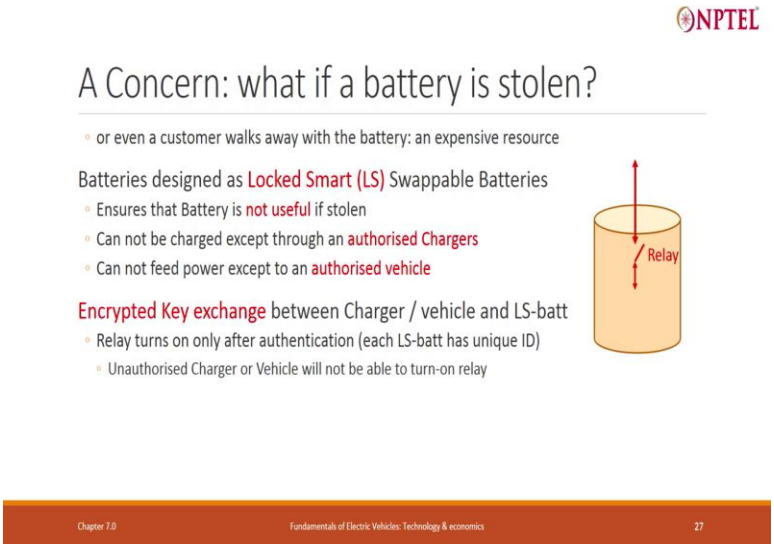

When we first came with the idea, by the way we are one who came with this idea of battery swapping. And say energy operator will buy battery, give it to a auto driver. The first reaction was what if auto driver runs away with the battery or what if somebody steals it? Well if the, we can take enough guarantee from the auto driver, that if he or she steals the battery, they pay for it. What if somebody else steals it?

So, we came away with a concept of what is called as locked smart batteries. So, it is like a battery with a built in relay, it is not really relay, it is equivalent to a relay. What we have to ensure that if a battery stolen, it becomes a useless battery. So, if I have leased it out to Doctor Kaushal's vehicle, so it is leased to that vehicle, now somebody steals that battery and tries to use it in another vehicle, the relay is off. What happens is the (batter), vehicle and the battery are talking. They are talking in a secure manner and sending a secure code like a block chain code.

If you are not able to send that code, the relay is off, relay it, as soon as you connect, normally relay is off, relay will be turned on only if the code matches and you marry the battery to a vehicle at the time of giving the battery. Now if you take it out and use it anywhere else, it cannot be used, vehicle or anywhere else it cannot be used, unless its code comes and code is secure. And the vehicle was programmed simple using a blue handset with a Bluetooth, you programme the vehicle, you programme the battery, now the two are married, only the two of them can be used together.

In the same manner you take out the battery to try to charge, from ordinary charger, relay is off, you cannot charge the battery, unless a code matches. A very simple encrypted key exchange ensures battery is useable or chargeable only with authorized vehicle and authorized charger. Now what will happen, if somebody steals the battery what can they do? They cannot use it. If you cannot use this, there is a huge discouragement to steal the battery. Sometime, you may still do that, but then it does not benefit you, normally stealing is done to benefit, may be in the beginning one or two times they may do it and find that it is not usable.

Of course you can also put a mechanical lock in addition to this, but this concept essentially ensures that one person's energy operator batteries cannot be stolen and given to even another energy operator, cannot be.

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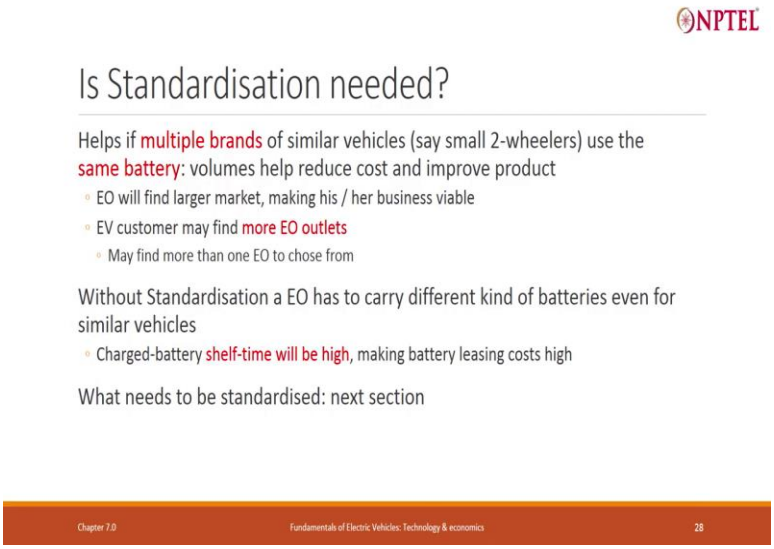

Then next question that kept on coming up, that if this is so, is standardization needed? Well, it helps very clearly. Why? Because I am an energy operator, I like to service let us say 2 wheelers and whether is a 2 wheeler is Bajaj or Hero or somebody, I am not bother I should be able to give you the same battery. You will find larger market making his or her business more viable. EV customer may itself find more outlets because the multiple different brand of vehicles are using the same battery, so the business grows, they will put more outlets.

And of course there may be multiple energy operators, you can choose from one to another. Without standardization EO has to carry different kind of batteries, so I may have to carry same

1 kilowatt hour battery for Hero, 1 kilowatt hour battery from Bajaj. And I have to actually carry to every outlet, remember I cannot because you do not know where the person will come to swap the battery, becomes painful. So, normally standardization helps.

The question therefore comes what needs to be standardized. And this is something that was not thought through, many people say standardize but they have not thought through, we have to standardize only so that you can service Hero as well as Bajaj. That is the only reason or any other similar manufacturer. So, what do you need to standardize and that is the next session.

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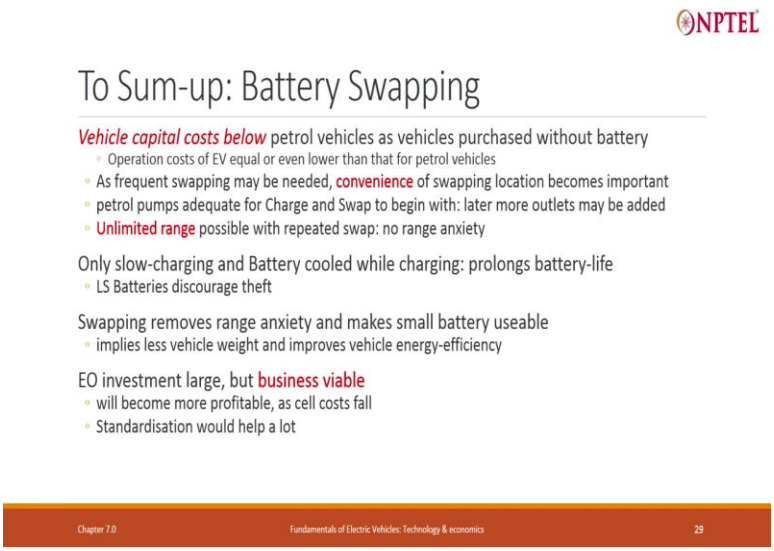

So, first before I do that, let us sum up this. Vehicle capital costs below petrol vehicles if purchased without battery. Operation costs of electric vehicle or is equal or even less than the petrol vehicles. As frequent charging may be needed, convenience swapping locations becomes important, unlimited range possible with repeated swapping. Petrol pumps adequate for charge and swap to begin with, later more outlets can be added. So, this can also be additional business for BPCL. Only slow charging and battery cooled while charging prolongs life of the battery. Locked smart batteries discourage theft.

Swapping removes range anxiety and makes small battery useable, now you can use small battery. For a auto driver, if they use 50 kilowatt or 60 kilowatt hour range, they may have to swap the battery twice in a day, does not matter, they are driving, they can just stop, swap and move. Energy operator investment will be large, they are the one who are investing in battery

and you must make it a viable business. Will become more profitable as the costs of cells comes down, cost of battery comes down. Standardization would help a lot.

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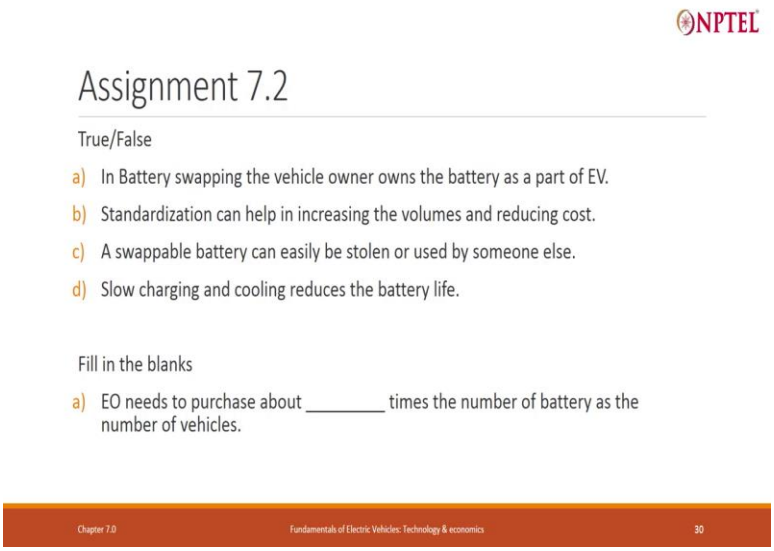

This is a assignment, simple, true false questions, try to provide that answer and you will see what it means.