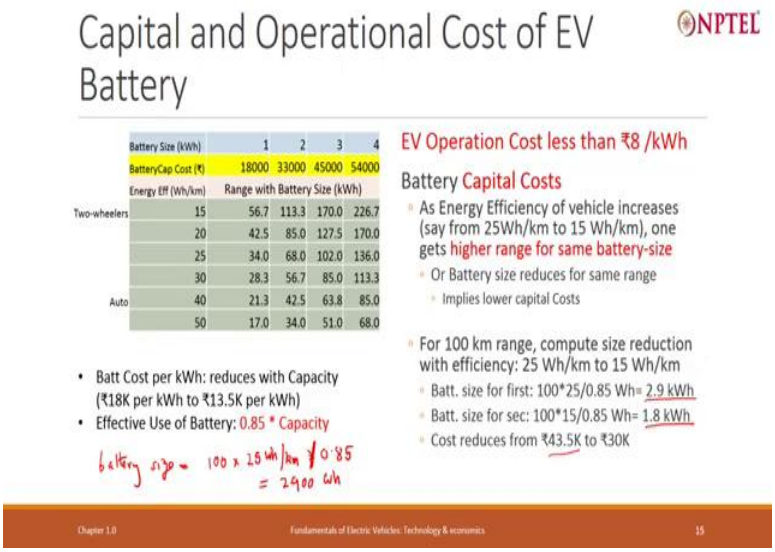
**Fundamentals of Electric Vehicles: Technology and Economics**
**Professor Ashok Jhunjhunwala**
**Indian Institute of Technology Madras**
**Lecture No 3**
**Can India Drive its EV program Innovatively and Differently and scale? Part 2**

As I repeatedly point out, we have to once we talk about electric vehicles, we have to talk about capital cost and operational cost.

(Refer Slide Time: 0:31)




When we talked about IC engine vehicle and we talked about energy per se, we never talked about petrol tank cost, the cost of capital cost, we only looked at petrol as a variable cost or operational cost, here I have to take both into account. Operation cost of electric vehicle costs less than 8 rupees per kilowatt hour is a cost of electricity. Actually it is, if it is a more like home, it is 5 rupees per kilowatt hour. I have taken the cost that will be there if you charge your vehicle using electricity in a commercial establishment.

So it is between 5 to 8 rupees per kilowatt hour. So operation cost is not that high, we will show you a kilowatt hour that it come out to small amount of money per kilometer. The key cost is the cost of the battery. And I am getting into a little bit of introduction. We will get into the details of this later on. And I have taken here 4 different kinds sizes of battery, 1 kilowatt hour, 2 kilowatt hour, 3 kilowatt hour and 4 kilowatt hour, I have taken 4 of these batteries.

And the cost of the battery 1 kilowatt hour cost 18,000 rupees a particular battery, 2 kilowatt hour 33, 45 and 54, see that is not linear. 4 kilowatt hour does not cost 72,000 rupees because

larger the size of the battery a lot of costs are actually there in 1 kilowatt hour and we will carry on to 4 kilowatt hour, incremental costs are less. So, between 1 kilowatt hour to second kilowatt hour you only increase by 15,000 rupees.

Next third kilowatt hour you increase only by 12,000 rupees and finally you increase only by 9000 rupees. Now, what I have done, I have taken for 2 wheelers and for auto, I have assumed let us take a 15 watt hour per kilometer, 20 watt hour per kilometer, 25 watt hour per kilometer, 30 watt hour per kilometer and for our auto 40 watt hour per kilometer and 50 watt hour per kilometer.

Now, if I take 1 kilowatt hour battery, what is the range that I get? Now, how do I do that? First thing that I have to do is, of course, battery cost is there, effective use, I cannot use full battery ever. One of the things that you will learn is that you can use only a fraction of the battery, you cannot fully charge or fully discharge. That is called depth of discharge, we will learn this in detail. Right now, just assume that we can use 85 percent for battery capacity.

So though it is 1 kilowatt hour, I can use only 0.85, if it is a 2 kilowatt hour, I can use only 1.7 kilowatt hour. So given 1.1 kilowatt hour and I am using therefore 850 watt hour, if I use 15 watt hour per kilometer, I actually calculate my total range that will give me 56 kilometers with 20 watt hour per kilometer I use little less range. So, if you see as the energy efficiency improves the range that I get in 1 kilowatt hour battery keeps on reducing.

And I got the same thing for 2 kilowatt hour battery, 3 kilowatt hour battery and 4 kilowatt hour battery. Using this, I can now look at my capital cost. As energy efficiency improves from 25 to 15 watt hour per kilometer, one gets higher range for the same size battery. Or in other words, for getting let us say my target is to get 50 kilometers range, how my battery size is reduces? Suppose I need only 50 kilometer per range, I will 1 kilowatt if it is a 15 kilometer watt hour per kilometer, 1 kilowatt hour is more than enough.

2 kilo, if my range, if my thing is 30 watt hour per kilometer, then I will probably need 2 kilowatt hour, double the size of the battery, which means my capital cost doubles. So, I actually put this whole thing so that you can get a feel that what it means. For example, suppose I want to get 100 kilometer range. A question that I am asking, compute size reduction when my efficiency improves from 25 watt hour to 15 watt hour, what happens?

So for my100 kilometer range, and I can use a blank slide or I can write here for a 100 kilometer range and suppose I use 25 watt hour per kilometer, my battery size is how much

100 kilometer range, 25 watt hour, so 100 and I need 25 watt hour per kilometer multiplied by what percentage of battery I can use 0.85, sorry divided by, divided by not multiplied, divided by, because only 85 percent of the battery is usable. That comes out to be 2.2900 watt hour or 2.9 kilowatt hour.

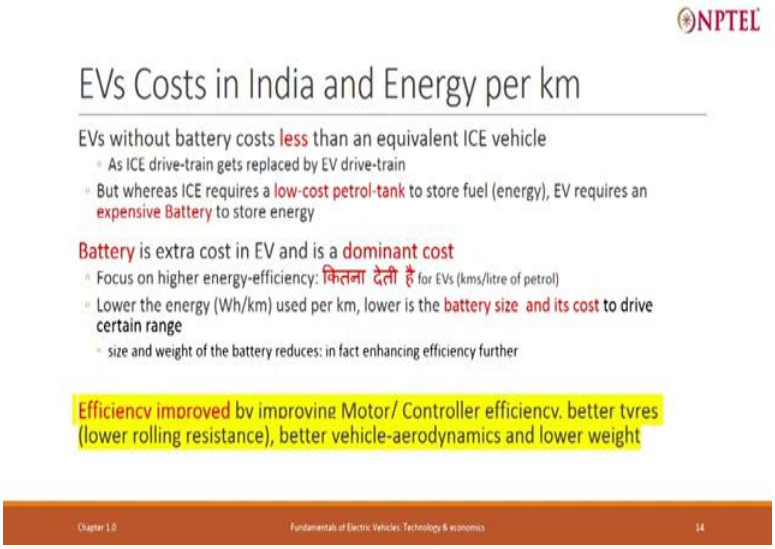
If on the other hand instead of 25 watt hour kilometer, I use 15 watt hour per kilometer my battery size will be 100 multiplied by 15 divided by 0.85 and it goes down to 1.8. Now, from this table I can see that 2.9 kilowatt hour battery will be between 33,000 and 45,000 rupees, it is close to 45,000, but slightly less I can calculate that I can assume the linear between 33,000 to 45,000, 12,000 rupees per kilowatt hour.

So for 0.9 I will require only 10., approximately 10.5 above this. So my cost will be around 43.5 kilowatt, but for similarly, for 1.8 kilowatt battery, my cost is going to be 80,000 plus for 800 I have to do that and that comes out close to 30,000 rupees. So if you see that, what I am pointing out, if I improve my watt hour per kilometer, my cost of battery goes down. So this is a simple calculation. We will do more detailed calculation later on, when we actually compute the battery cost, here we are talking about the capital cost only.

And therefore, I am giving you an assignment, a very similar question. A 2 wheeler uses 25 watt hour per kilometer, and we need a range of 80 kilometer. Keep the 0.85 effective usage in mind, calculate the size of the battery required and estimate the cost of the battery by looking at the table, the table that we have given you on the previous slide.

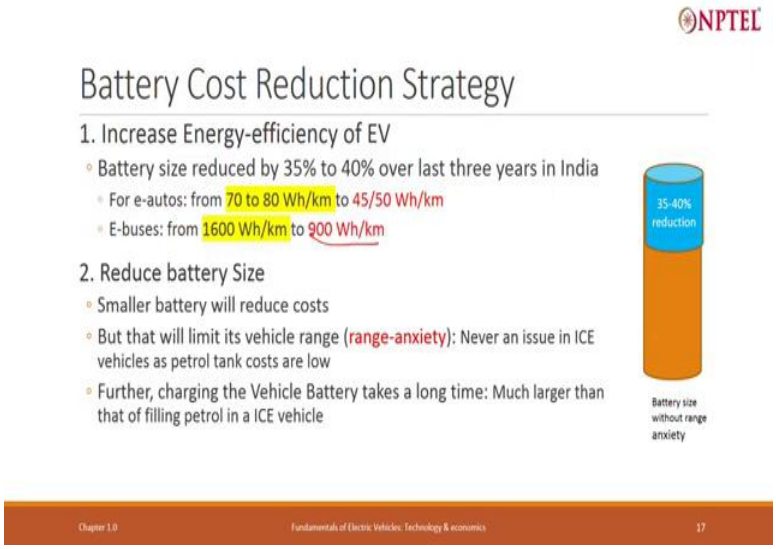
And remember that you will not get the exact number, so you have to do linear interpolation between 2 points and compute that and submit that as assignment. So I have actually given you 2 assignments now, one I gave you earlier, now another, you need to submit that in a week's time. I will give you the date for submission later on. Let us go on and look at what else can be done.

(Refer Slide Time: 9:25)




We have already looked at that improving the energy efficiency will help us reduce the costs. We already looked at, that is something that we have, if I can improve my energy efficiency, reduce the energy required per kilometer, my cost goes down. This as I have also pointed out basically requires improving the motor efficiency, including the, reducing the getting better tyres with lower rolling resistance, trying to make the vehicle aerodynamics better and lower weight. Now suppose vehicle is given to me and I cannot do much more than that, then what else can I do? So, let me look at it.

(Refer Slide Time: 10:19)




For example, let us take, what else can be done. Let us take a battery of a certain size. As I improve the energy efficiency of the battery, what happens? I require smaller battery. So, for

autos for example, 3 years back our energy efficiency used to be 70 to 80 watt hour per kilometer, that is the amount of energy that they were used to use. And once we figure out that these 4 things better motor and controller, better tyre, lower weight and better aerodynamic will help the industry got together, occasional with academia and today it has reduced to 45 to 50 watt hour per kilometer, same thing has been done for the buses.

Buses used to be highly energy consuming, 1600 watt hour per kilometer, these are all pretty much technology brought from outside. And then once it was understood, the Indian engineers got together and today it is only 900 watt hour per kilometer. What does it really mean? It means, the size of the battery original size was what I see here, now the size of the battery actually goes down by 35 to 40 percent.

Why, because we reduce the energy required by 35 to 40 percent, size of the battery for the same range has gone down by 35 to 40 percent. This has been done and has to be always done, for any new kind of vehicle, focus on energy efficiency. What is the next thing? Can I reduce the battery size further? Instead of even using what I pointed out here, can I use even less? Can I use even less? If I use smaller battery, what will happen? It will give you a smaller range.

And a smaller range basically means that you start with a charged battery. It is a small battery, it has a limited range and you will run out of the range once you are driving. And all the time it will make you worry, am I going to run out of range, run out of battery? Why do you not worry about this in a petrol car? Well, if you are about to run out, you will get an indication in the vehicle and then you go to the nearest petrol station and pretty much in most urban areas every kilometer to 2 kilometer, you will find a petrol station.

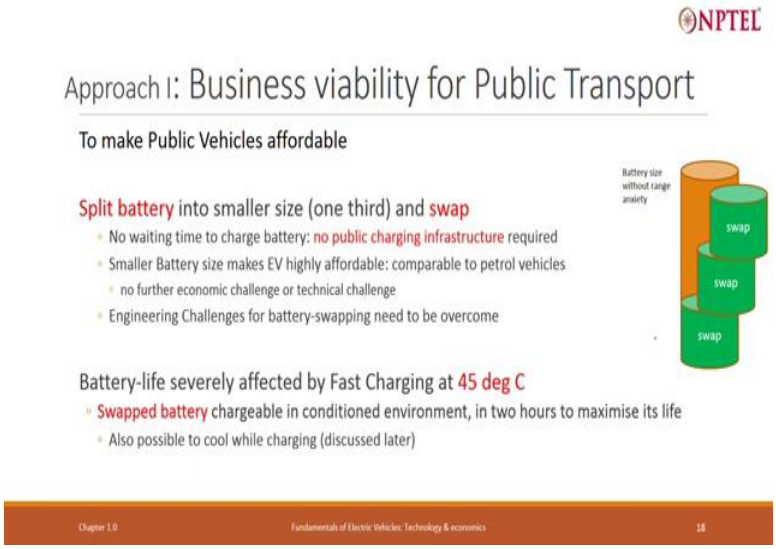
And you will go there, get the petrol filled in 3 to 5 minutes and now you drive. When you talk driving electric vehicle and suppose your battery energy goes to nearly 0, you know that you will run out in the next 5 kilometers. The question is, can you find a charger where you can charge your battery? There are not too many, petrol pumps are large, number of chargers are very small, so you may not find.

Even if you find one and go there, how long will it take you to charge? A battery charging takes a long time. There is a whole focus on this and we will study this, a typical battery is best charge in 4 hours. Even if you fast charge, it takes 45 minutes to 50 minutes. So, you can

just quickly go to a charging station, charge it and go further, it completely messes up your program.

So, you all the time worry about am I going to be able to complete the journey without battery running out of energy. This is called range anxiety, here along with EV has come the range anxiety. So, this is something that we have to worry about. So, yes, by reducing the size of the battery, you can reduce cost, but you will create a huge amount of range anxiety. And basically it becomes unusable.

(Refer Slide Time: 14:59)




What if we use a totally different strategy? Let us suppose you, let us look at it, suppose there is a 3 wheeler auto or a bus and suppose you use small size of the battery. And you further split the battery into smaller size and say you use only one third of the size of the battery. It was designed for large battery but I will use smaller size. As I pointed out if you use smaller size you have a small range and then you would have been worried about charging.

But what if there are large number of what is called swapping station, swapping station, where you go, you give your battery and take another charged battery. Now that will not take more than 4 to 5 minutes, maybe less, 3 minutes. You know, I have got equivalent to petrol filling time you can easily go and get up, swap a battery. Of course, the other thing is proliferation of that. You should get enough such battery swapping station where you can go and swap.

And suppose you have at every alternate street corner or even every 3 street corners, there is not much of a problem. So, alternative strategy for India could be instead of having large

battery, use smaller battery and swap it at fairly large number of swapping stations. This was proposed 3 years back, the question that many of the senior government officials asked, which are they used to asking, which other country has done it?

We said no one. Then we are told, then how can you do it? Nobody has done it, so it is infeasible. Well, nobody has done it because they did not require it. They could buy a large battery. In India, we cannot buy a large battery to push up the cost, we will require small batteries and therefore, why cannot we be the first. And most government officers do not have the courage to be the first to do something.

We may talk about Atma Nirbhar or this or that, we will always like to follow. This is a problem that we faced. But we kept on talking about it, that why cannot you swap batteries? At least for the lower cost vehicles and then you start with the public vehicles, 3 wheelers and for the buses. You can always buy a large battery and charge, nothing prevents you, but have that as an option.

It took considerable effort, but people have started seeing the merits of it. And today it is important component of Indian vehicles. And therefore, we will discuss this in detail, the swapping. There are other advantages and other uniqueness about India, which is distinct from that of the rest of the world. India is a very hot country, 45 degrees centigrade temperature is not that uncommon and for Indian temperature nowadays reach up to 50 degrees centigrade.

Now, these batteries that are being used are best charged at 25 centigrade. As you start charging at higher temperature, its life goes lower and lower and lower, we will learn about that. If you charge at 45 degrees centigrade, it hurts the battery like anything. So this is a big problem that India will face, whether you have small battery or large battery, you will face the problem, how you charge at 45 degrees centigrade.

Now, in this swapping case, there is a big advantage, you go to a place, give away your battery, take away a new battery, put it in. And suppose it is easy to do it in 3 to 4 minutes, drive along. Then you are given the battery which is now empty battery to this operator who is charging, that person can charge it for in several hours first of all and actually charge it by cooling. The charger itself can cool the battery, you can have a cooling environment.

So you have a double advantage, you do not have to fast charge and you do not have to charge at high temperature. We will show you that both of these are bad for the batteries. If

you try to fast charge, the life gets very badly affected. If you try to charge at high temperature, 45 degrees, even 40 degrees centigrade, life gets very badly affected. Now if you swap both these problems can be overcome. And therefore, we are going to discuss this and that is the reason today, public vehicles, the shared vehicles are increasingly using swappable battery. Though there is still some resistance within the government, most of the resistance has melted out. It takes several years of trials and showing things for people to accept that but it is there.

(Refer Slide Time: 21:32)


Now if you swap the battery, the question is who will be this person at the street corner will give you swappable battery, who will own the battery? Are you going to give away your battery, what if you give away a good battery and you get a poorer battery? All these questions arise. So what has emerged is that you will not buy a battery, a user will not buy a battery, user will buy electric vehicle without battery. Wow, my cost goes down like anything, that is a very big advantage. Then I will go to, there is a energy operator, there is a separate business and we call that energy operator. It is like a petrol tank operator, petrol operator, like what?

Student: Gas cylinder. BPCL.

Professor: BPCL, like IOCL there can be an energy operator. This energy operator will set up a shop every third street, they will own the battery, they will purchase the battery. So, IOCL will own the battery and you go there, you swap the battery. The only thing is that you can, you have to tie up with IOCL and only swap IOCL battery at IOCL Station. But assuming

there a large number of IOCL stations or BPCL stations, you can go, you have tied up with IOCL battery, have a contract, you have taken a battery from them, keep swapping with IOCL, keep going.

Now since you can swap in 3 minutes, probably smaller, you will not get stuck. Now you can have a smaller battery, you do not have to, first user does not have to invest in battery. Battery actually becomes a convertible, is a now operation cost for the user. Whenever they get a charged battery, they will use it, when they return they have to actually pay for the battery rental as well as for the energy used.

This is the model that can be used and if it does, then it significantly helps per proliferate the electric vehicle. As far as user is concerned, is used to buying a 3 wheeler auto at 130-140,000 rupees, they can still buy at 140,000 rupees, even less without battery and they keep on hiring and renting the battery. The only question will be how much will it cost? The battery rental plus including the electricity fill, filled battery cost.

I will show you actually it will cost less than the petrol. And since people are used to paying for petrol, they can actually pay for this quite easily. And the cost will keep coming down as the battery costs keep on falling. The other question is, will IOCL BPCL make money. They are going to buy battery and lease out battery, charge battery and take back discharged battery, will they make money, if they do not make money, they will not set up this business.

The key question is, can they make money, can users still pay less than petrol? This is the economics that needs to be worked on and we will work this economics out and show you in this course, that this is indeed viable and this is the reason why people are setting it up. And the public vehicles like 3 wheelers or even actually it can be purchased by a fleet operator, Ola can purchase it and in fact rent out the vehicle also, the batteries can be leased out by energy operator, and the whole business can flourish like anything.

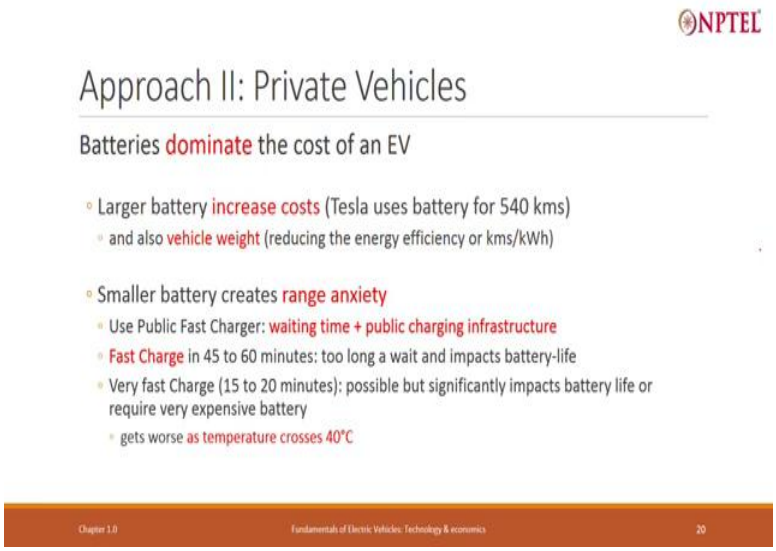
So, one of the first thing that I am pointing out, we mentioned that the cost of battery is very high, this is going to be a big bottleneck, we said that you improve the energy efficiency, it will help and we showed that it will help. Next we sort of said, use smaller battery and swap and bring in a concept of energy operator who will own the battery, so the user gets all the benefit. They do not have to purchase a battery. They do not have to worry about wear and tear of the battery.

It is the IOCL and BPCL or the energy operator who has to worry about it. They have to work out the economics, you are renting the charged battery, give it out whenever it is done. So this is option number 1. This will work very well because you may have a 50 kilometer battery. Now, a typical auto driver travels about 120 kilometer a day. So they may have to swap the battery twice a day, nothing, no big deal. They will be traveling most of the day, whenever the battery is running out, they will go to one of these stations and swap it in 3 to 5 minutes and proceed.

Similarly, buses are typically running from one place to another place and at end of every trip, anyway there is a 5 to 10 minutes gap, that is the time they can swap the battery. So for vehicles like 2 wheelers, 3 wheelers, and for buses, which I will call as a public vehicle, this is a very, very good model. But suppose it is a private vehicle, I am buying a 2 wheeler or a car. And if I say well, you have to swap it every 50 kilometers.

I would like to go to, I do not like to go to petrol pump so often, I would not like to go to swapping place so often. Whether it is a 2 wheeler or a car, car may have a 100 kilometer, even then I may not want to go that often. So, there can be yet another option. So, this I have already pointed out, if you swap capital cost the vehicle is less than that of the petrol vehicle and operation cost is less than that of the petrol, diesel, CNG, so there is a huge advantage.

(Refer Slide Time: 28:16)



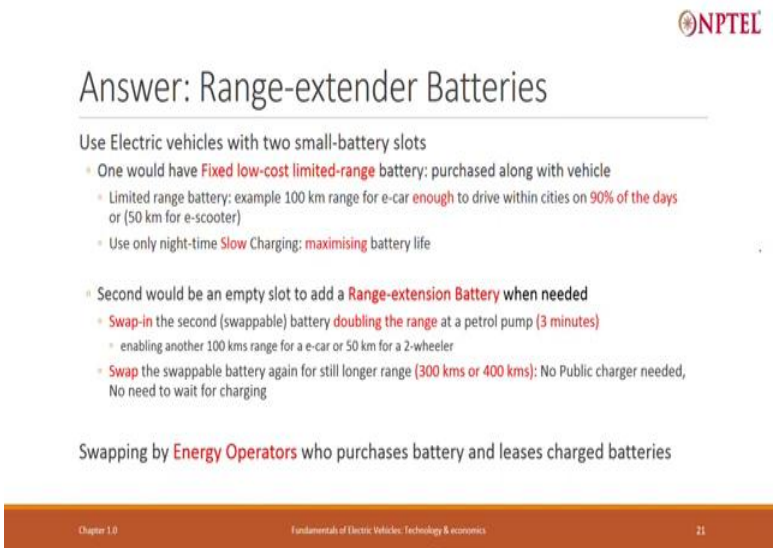

The approach II is of private vehicle, battery costs dominate. So, what happens? People tend to use large battery. Tesla for example, gives you a 550 kilometer range, the cost of this is extremely high, it starts at 4 million rupees. So, that is not India's market. Of course, it also

means large weight, it means more energy consumption, reduced energy efficiency, this is all right for Tesla. And for in India also, of course, there are enough rich men who can actually afford something like that. That is all right, numbers are small, as I pointed out 0.5 percent we will not talk about it.

As we pointed out, the problem is small vehicle will cause range anxiety. You can do something called fast charge but that also takes 45 to 60 minutes and very fast charge pushes off the cost of the battery, we will deal with this subject also. Even if you have a charging station which can charge fast, batteries are not capable of being charged fast. Batteries which are capable of being fast charge are far, far more expensive than batteries which are not capable of being fast charged.

And if you try to fast charge at 45 degrees centigrade or 40 degrees centigrade, you get hurt like anything. So what do you do in countries like India? You cannot use swappable batteries too often swapping, but suppose you use what is called range extension batteries.

(Refer Slide Time: 30:23)




Suppose I have a car and I do 100 kilometer range. I charge it overnight at my home and 100 kilometer I can travel. Question is how often do I need to travel more than hundred kilometers a day? Probably 5 percent of time, not even that, maybe 10 days in a year. Most of the time people do not travel. One of the characteristics of India is that vehicles travel short distances per day. 5 days, 7 days a year is already large, 10 days. So actually I need a solution for those 10 days.

Similarly, for 2 wheelers, suppose I have a 50 kilometer battery, I charge it overnight, how often do I (charge) travel more than 50 kilometers per day? Mostly no, probably 10 days a year. So do I have a solution for those 10 days. The solution for the 10 days is that can I have what is called a second battery, which I will call it a range extension battery. So, the vehicle has a provision for a second battery called range extension, I do not use it every day.

But the day I need to travel longer distance, I go to a one of these swapping station and they will add a battery. So I know that today I am going to travel in a car 150 kilometers, 170 kilometers, I go there, I get a second battery, travel, come back and return that second battery, first battery is always there charged. Similarly, for a 2 wheeler, if I need to travel longer distance, the day I need to travel long distance I will get a second battery the range extension battery.

So, I have a 100 kilometer base battery in my car, another hundred kilometer range extension battery. The question that will again be asked, what if I want to go a long distance, if I want to go from Chennai to Bangalore or let us say I want to go from Delhi to Agra and come back Bombay to Pune, even 200 kilometer range will not be enough. Well, I start with my charged battery 100 kilometer, I pick up my battery as soon as I go out. So I have 200 kilometer range.

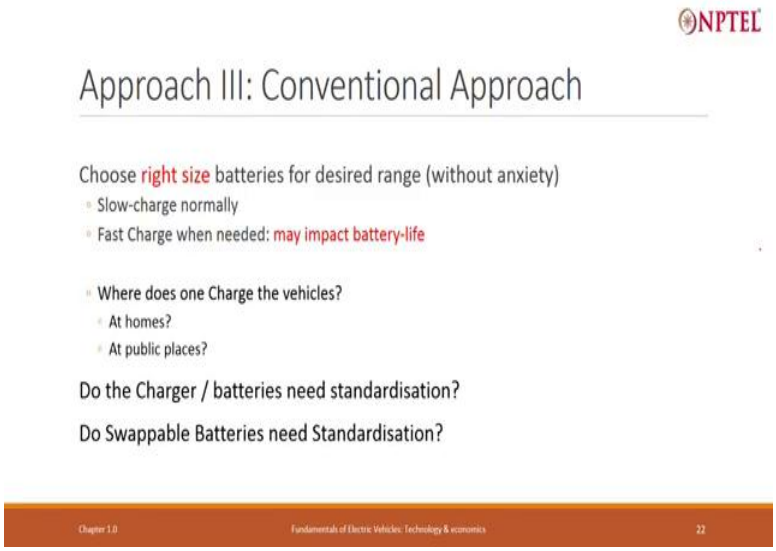
I first use the range extension battery, so after about 100 kilometer it would have run out of it. I have traveled typically that kind of distance in about 2 and a half, 3 hours. I stopped for a cup of coffee, that time the range extension battery is battery is taken out and a new battery put. The IOCL petrol pump is there also, the battery swapping station is there also, they will take out my battery and put a new battery. Now I can go another 100 kilometer, I have got 300 kilometer range.

And I have repeat it once again if I need a 400 kilometer range and I can do the same thing for my 2 wheeler. I start with a 50 kilometer, add a battery of 50 kilometers. I have got 100 kilometer range. If I am going long distance, stop after 60-70 kilometer, get the battery swapped, have a cup of coffee and continue. So the range extension battery could be another way, because I do not need it every day I need it only once in 10 days in a year maybe once in 15 days.

I do not have to invest for that, let IOCL invest. And of course IOCL business should work, they may will charge me, they may charge me slightly extra, but I should be willing to pay

slightly extra for the day when I have to go longer distance. Even details of what will it cost is being worked, will be worked out in this course. So the swapping will be done by the same energy operator who purchases the battery and keep the charged battery ready for swapping.

(Refer Slide Time: 34:59)




Of course, the third option is a conventional approach which is used all over the world. And there we can easily say well we will follow what the world does. Choose the right size of battery, which is enough most of the time, slow charged it normally, fast charge it once in a while, but if my range is good enough, most of the time I do not need it if I go longer distance, I will wait for an hour and fast charge it. That is something that can be done.

And of course, that will bring questions, where does one charge, if this is an option, the batteries. What kind of, do we charge at homes, fine, but that is not if you want to go longer distance. At public places, what are the public places where I can charge, what are these charger, what are the specifications of this charger? What are the specifications of the swappable batteries? Is there a single specification?

How do you set up these charging stations? Is it a profitable business? How do you set up the swapping stations, is it a profitable business? All these questions we will try to answer in this course. So charging and swapping is going to be a very important component. We will talk about what kind of chargers what kind of swappers and we will discuss this in more detail in this course, to stop with that.