Physics of Renewable Energy Systems
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Lecture 20
Introduction to Energy Storage Systems

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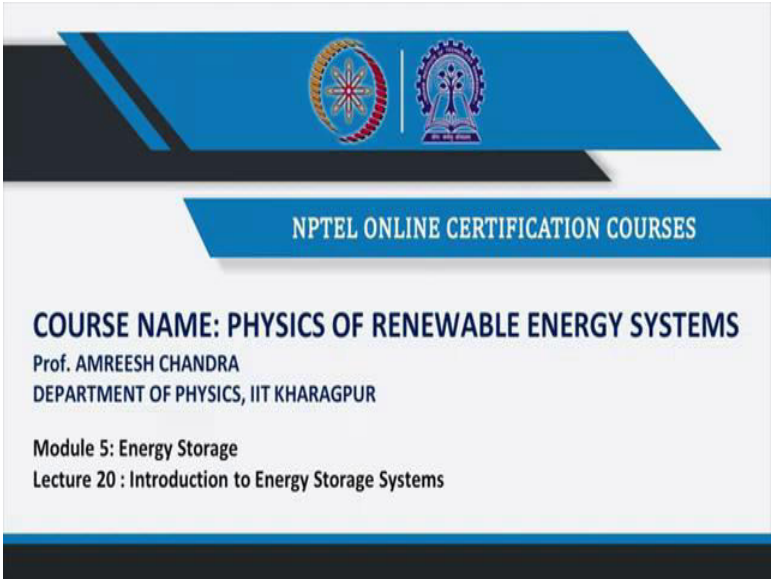

Welcome again. So, let us start the second part of this course. In the first part, we have talked to you about large number of energy generation sources which are used and are useful to us. Today, I will move to the next section of this course that is the need for energy storage technologies, what are the types of storage technologies that are useful to us and then in subsequent weeks you will find details about the technologies which are going to be useful to us.

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In today's lecture, we will give you a brief introduction about the whole topic that is the topic of energy storage. To start with, it is important to also get an idea about the various types of storage technologies that are going to be relevant to us. And the moment I say that there are various types of energy storage technologies that are going to be used or are relevant to us, there must be certain parameters which will be used to compare the performance amongst various such technologies those would also be discussed in today's class.

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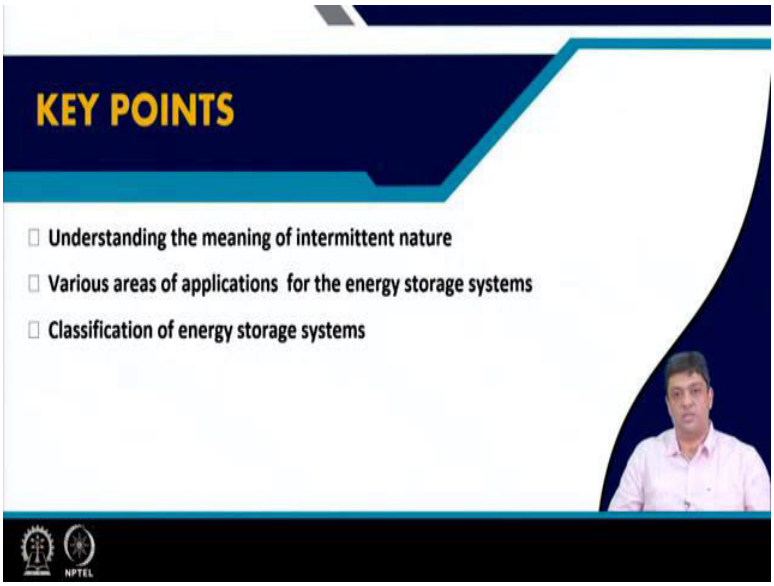

The key points which you would be understanding are, you will understand the word intermittent with respect to renewable based energy sources, what do we really mean by this word and what is the impact of this phenomenon. Then, how do we counter these phenomena that are associated with the intermittent nature of the generation units that would define the various applications of energy storage systems. And it is not that you have one energy storage system and that will cater to the needs of all kinds of systems or units. There are various types of energy storage technologies or systems and they are classified under various subheadings those would also be discussed with you in today's class.

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What have we done till now? We have been focusing on generation of energy using renewable based energy sources. We started our discussion with the use on solar energy. Then we moved on and talked about the usefulness of wind energy and how these two energies are going to be the major players in India for next decade or so. We have already been using hydro energy in India for last many decades.

And what is the future of hydro based energy units that was discussed for after we had discussed wind energy. And in the previous two lectures I have given you the details about the new technologies which are fast emerging and those technologies were based on the use of tidal energy or geothermal energy. And at each point, we had discussed the advantages and the limitations of these energy sources.

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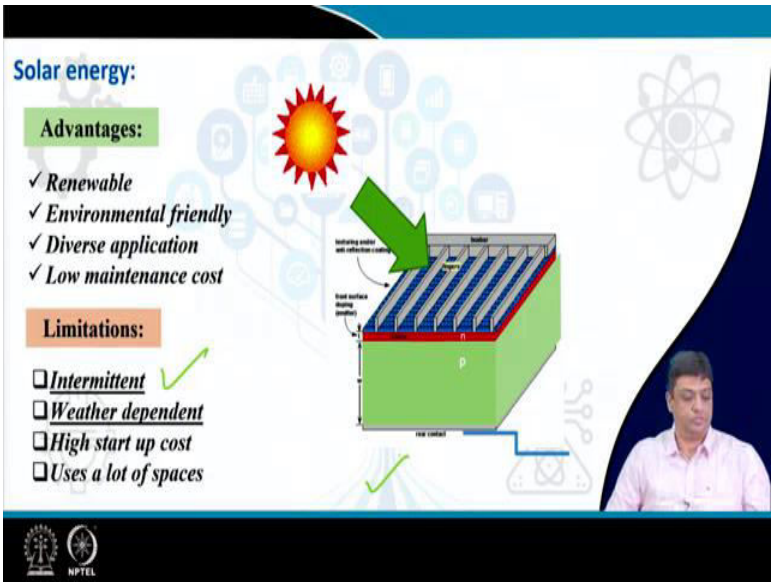

For example, when we started talking about solar energy, we saw the advantages, which included the renewable nature of the source, ensuring sustainability, environmentally friendly devices which are available now, you can have large number of applications which are based on solar energy and once installed these systems have low maintenance cost. These were the advantages.

But the moment we finished the discussions on advantages, there were very clear limitations. And the limitations were predominantly associated with the intermittent nature of the source. That means that the source was not continuously available. So, the p-n junction solar cell which is shown in the figure was operating it at its highest efficiency when the sun was available and when sun was not available or even on cloudy days when you did not have direct sunlight, then the efficiencies would fall. So, that means, the overall performance is having the characteristic of intermittency.

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Then we moved on to wind energy and we saw again the advantages associated with renewable based systems. Along with the intermittent nature of the source, we have another major limitation that is associated with wind energy and that is still not written on the slide. Do you remember what limitation are we talking about? I hope you will be able to give me an answer that we are talking about the variable nature that even if the source is available, you have wind, but wind speeds can change. So, you have variable nature of the source also along with the factor that the source may be intermittent.

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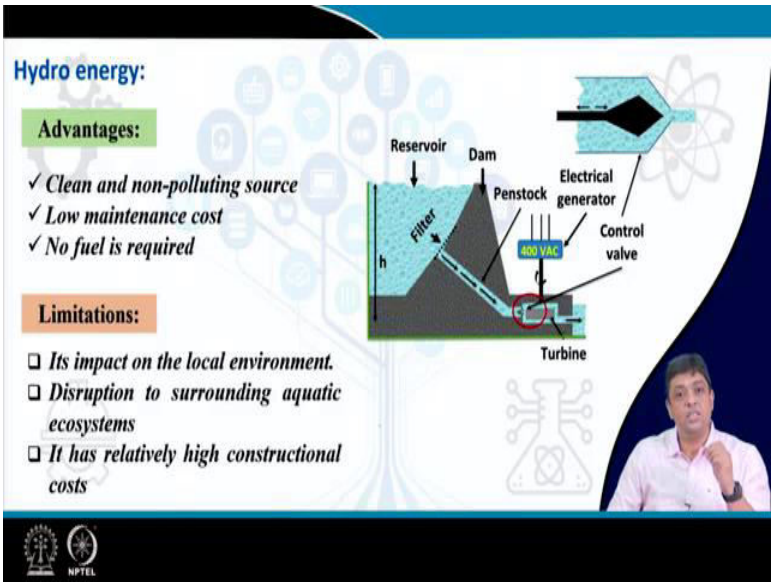

Following wind, we again went to and discussed about hydro energy. Hydro energy has the advantage that you can actually call it a continuous source. But if you are having a condition where the water levels in the reservoirs fall, then you have to switch off the hydro plants and then let the water level rise again and then only you can switch on the hydro base plants. So, they are also associated with the factor that is intermittent nature.

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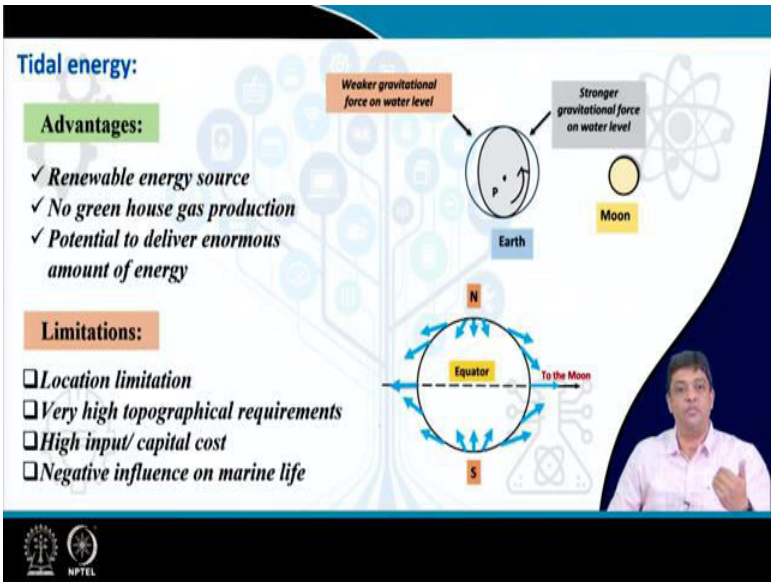

Which were the last two we had discussed, tidal and geothermal. So, in tidal energy, we all know tides, you were using high tides and then storing the water in a reservoir when you had high tides and letting the water flow through the turbine back to the sea when the condition of low tides was observed. But high tides, do you have high tides every time? No. That means you again have the parameter that is intermittent nature.

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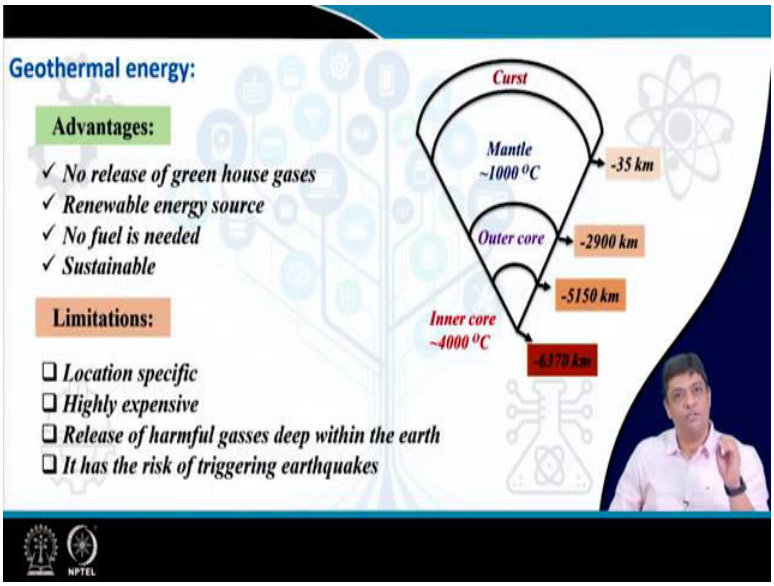

And finally, you have the geothermal energy which is associated with the advantages that again, the ones which are associated with renewable based energy sources. And then there are disadvantages which were also discussed. This also has an intrinsic problem of it can have intermittent nature. If at points your, the duct from which you are extracting the steam or that that gets blocked or any kind of feature which happens which blocks the flow of steam outwards, then you can have the intermittent nature.

Although this seems to be a continuous source, there can be features which can lead to intermittent nature. So, one thing is clear most of them have the common factor that is intermittent nature. All these technologies which we discussed have the common factor that they are suffering from the limitation of being intermittent in characteristic.

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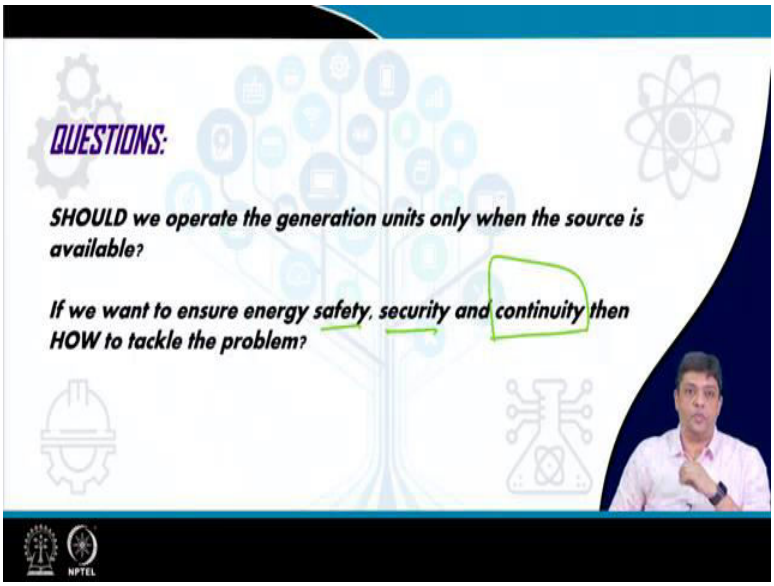

So, what is the solution? What is the solution to tackle this problem of intermittency and ensure safety, security and most important continuity of energy supply? How do we tackle this problem?

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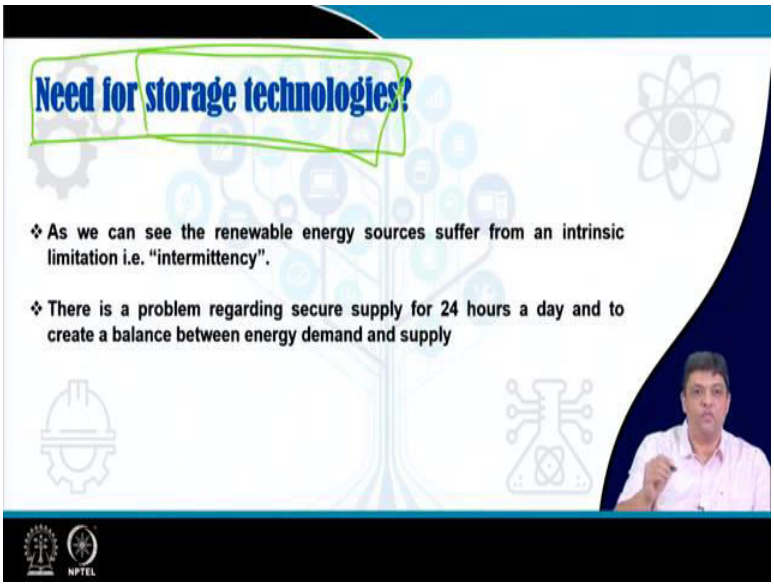

And the answer to this problem actually lies in the use of energy storage technologies.

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So, the answer lies in the use of energy storage technologies, but please note, that I have mentioned suitable with different color. The reason being that you have to choose the proper and the correct type of storage technology to obtain the best performance in a renewable based landscape or a landscape which has source, storage and then transmission. So, these features should be complimentary. Storage and generation units should complement the features of each other.

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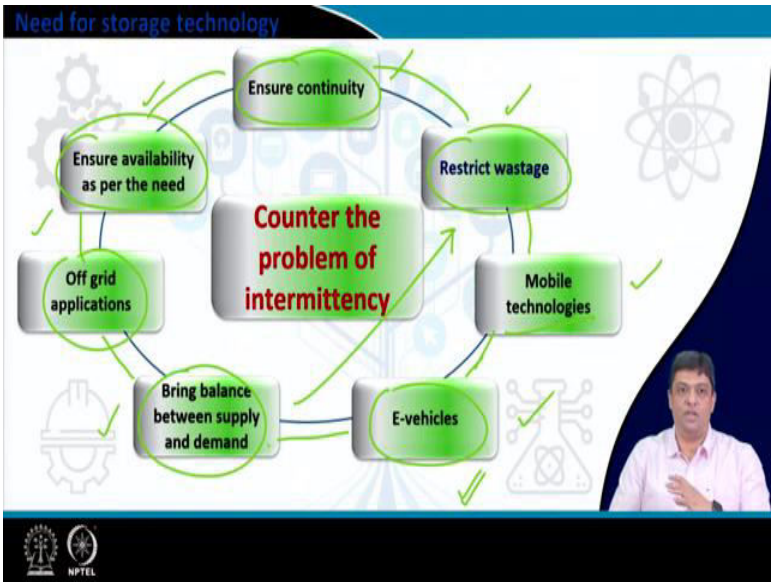

What will the solution lead to? If I rephrase, if you have actually been able to solve the problem of intermittent nature of the generation units, what do you obtain? You obtain continuity, most important, you obtain continuity. If you have ensured continuity, then safety and security follow very quickly. Then suppose the demand goes up then you can increase the transmission using the energy stored from storage units to the end user. If the demand goes down, then the excess energy which is being generated can be stored in the generation unit.

What will this do? This will avoid or prevent the need of increasing the generation units when the demand goes up and then switching off the generation units when the demand goes down, because switching on and switching off of the generation units can be a non-trivial exercise and they are also dependent on the source as we have discussed earlier in this lecture and also, we have been discussing in earlier modules.

So, the next thing, once you have solved the problem of intermittent nature and you have a storage technology, then you ensure the availability as per the need. Now, I have, let us say, solar based generation unit. I store it in a battery. Then I do not need to extract energy or connect to the grid. We can have off-grid applications. So, individually we can make the system ready for the use and you have seen that is what is being done many places all around.

You have solar based lamps, you have street lights, you have the mobile towers which are now being powered by solar based units and that has led to reduced consumption of diesel in the

generation units which was diesel-based generators and so the carbon footprint of the whole process has also come down when you install mobile towers. So, you can have off-grid applications.

As we discussed, you can bring a balance between the demand and the supply. Now, if I can bring a balance between demand and supply, you can immediately restrict wastage. And then the application of these storage technologies is also in many other places, be it be mobile technologies, mobile technologies just do not mean mobile phones, mobile technologies include your laptops, your smartwatches, your tablets, your phones. So, a lot of things go into mobile technologies and all of them are actually based on the efficient use of the energy storage systems which are powering them and these systems are going to be extremely critical for the success of e-vehicles in our country.

Now, if you see I have actually drawn and connected all the subtopics using a solid line. So, they are all connected. So, if you ensure continuity, it also means that you will ensure improved performance of the e-vehicles. Why? When you have continuous supply of the power you can charge the batteries which are used in e-vehicles. If you are bringing balance between supply and demand that means you are restricting wastage. So, all these parameters and usefulness are interlinked and they are interlinked because they have a common feature that they utilize the energy storage technologies and that is the usefulness and impact of the storage technologies.

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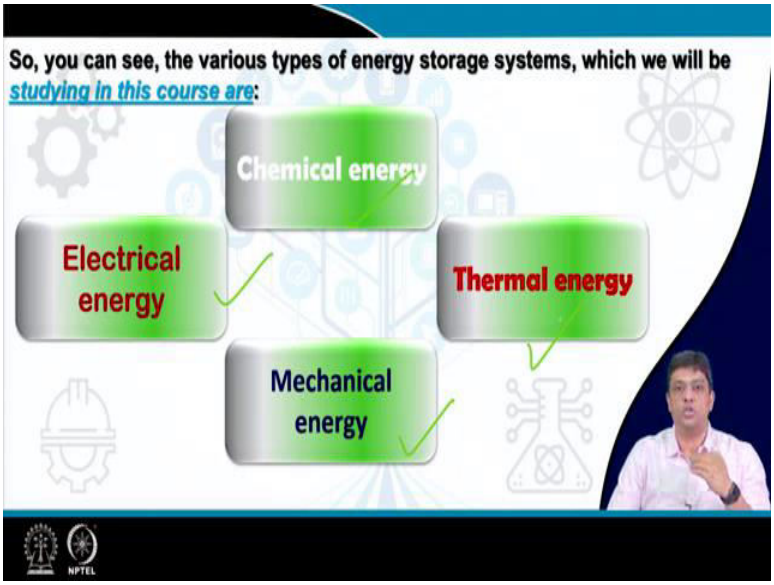

The energy storage technologies, which are going to be useful for us can be sub-classified under four subheadings, either chemical energy, electrical energy, mechanical energy or thermal based energy storage systems or technology. So, we will have chemical-based energy storage technologies, thermal based energy storage technologies, mechanical based energy storage technologies and electrical based energy storage technologies. And we will cover all these topics.

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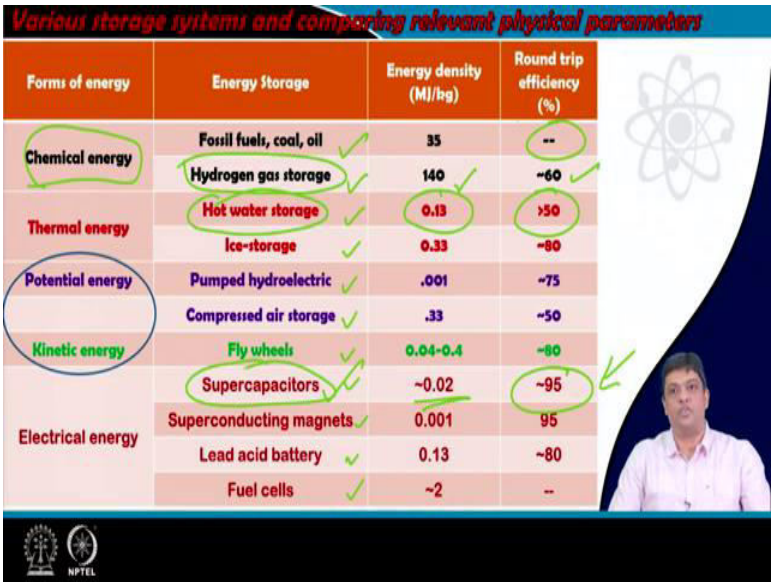

If you see these forms of energy or the subheadings, there are various parameters that are used to compare and you would see that if you compare any technology with the other, one of them has higher value for one parameter and may have a lower value for the other parameter. For example, hydrogen gas storage which is classified under chemical energy has an energy density of 140 mega joules per kg with a round trip efficiency of 60 percent.

So, efficiency is only 60 percent and if I compare supercapacitors, they have energy densities which are as low as 0.02 mega joules per kg, but the efficiencies are extremely high, the round-trip efficiencies are very high compared with other system be it be hot water storage that we have already discussed when we were talking about solar based systems. What is the typical energy density we are talking? We are talking about 0.13 mega joules per kg with a round trip efficiency of only 50 percent.

This table is clearly demonstrating that the use of a storage technology depends on the end user. If an end user wants low energy densities, but very fast and high roundtrip efficiencies, then you

would be using supercapacitors. But, if you are talking about very high energy densities, along with reasonably high round trip efficiencies, then you are going to use hydrogen gas storage.

Can you please tell me why this value in fossil fuels, coal, oil is actually left blank when they are also classified under chemical energy, because they are non-renewable, correct. What happens? You use them and you lose them. So, there is no round trip efficiency. Once you use them, you use them and that is why the round trip efficiencies are not mentioned.

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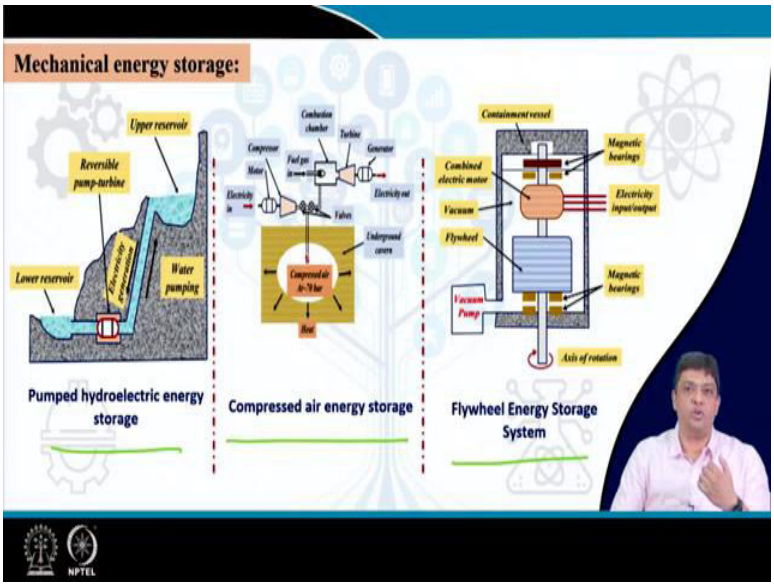

In the subheading mechanical energy storage, we will be talking about these three main systems the pumped hydroelectric energy storage, compressed energy storage and flywheel-based energy storage systems. We will discuss in detail the whole, there will be a lecture fully dedicated to these technologies, but you can see that there are a lot of components which must be understood so as to ensure the performance of these storage technologies.

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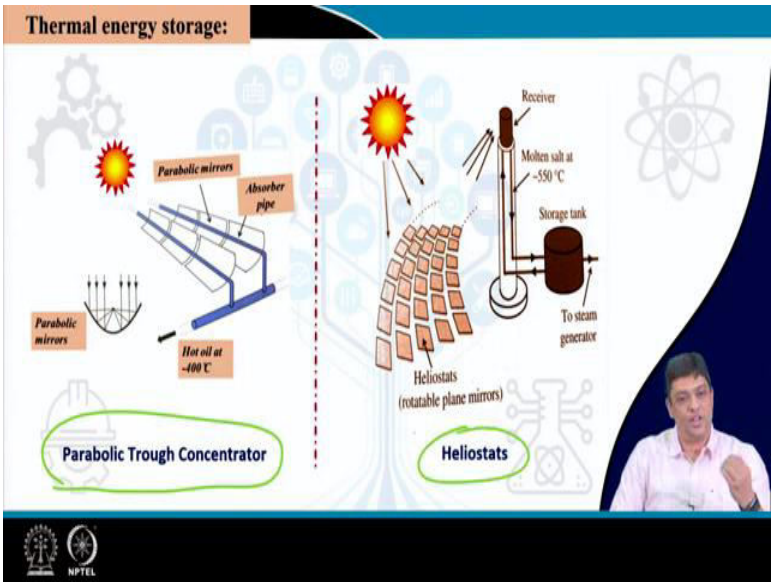

For the next example that is thermal energy storage systems, we will be focusing mainly on two types of systems, the parabolic trough concentrators and heliostats. The water heaters and the process of storing energy in a heat transfer fluid or using heat transfer fluids transferring heat to water or any other fluid that can be stored in a tank was discussed earlier and that is also considered as part of the thermal energy storage.

But we discussed it as solar based systems and that was relevant in the earlier part of the course also and that was therefore discussed at that time, but those technologies also become a part of the thermal based energy storage systems. So along with parabolic trough concentrators, we will also be talking about the heliostats.

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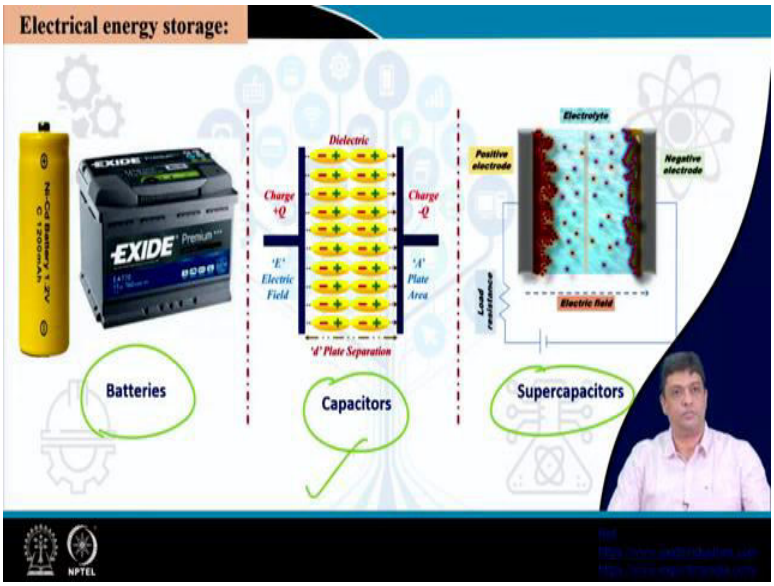

Most commonly these are the energy storage systems which you talk about. You talk about batteries and capacitors. These are the two electrical based energy source systems which you routinely talk about. But other than these two routinely talked about electrical energy storage systems, there is a new player in the market and that is called as supercapacitors. And supercapacitor actually helps to bridge the gap between the battery technology and the conventional capacitor technology. So, we will also focus quite a few lectures on supercapacitors after giving you the details about the conventional capacitors.

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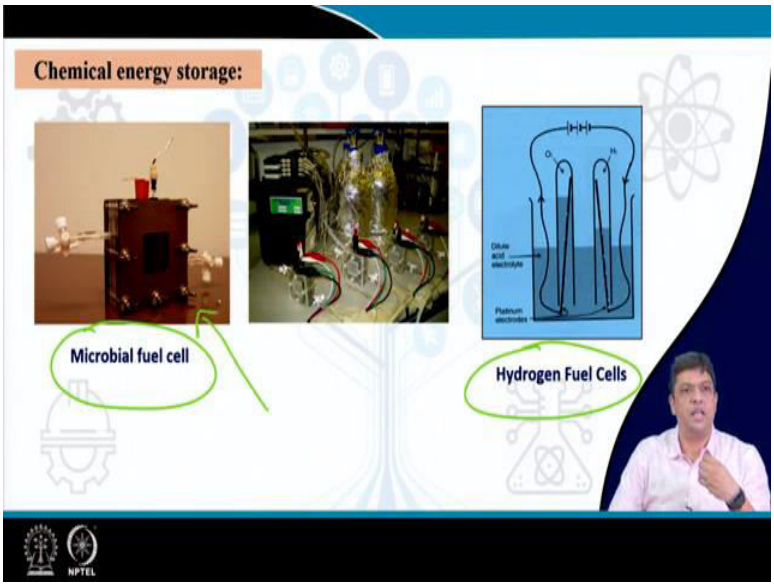

Similarly, the next subheading that will be talked about is the chemical energy storage system. And you have been talking about or you have heard about various types of fuel cells, alkaline fuel cells, PEM fuel cells, hydrogen fuel cells, but in India we have also been working on a very new and novel kind of fuel cells and those are called microbial fuel cells. These fuel cells, although they are low power devices, are expected to serve two purpose; they can be used to treat water, they can give you clean water, while they are actually also delivering electricity. And therefore, these kind of fuel cells would also be discussed with you and this is a picture of a typical microbial fuel cell that is fabricated here in IIT Kharagpur.

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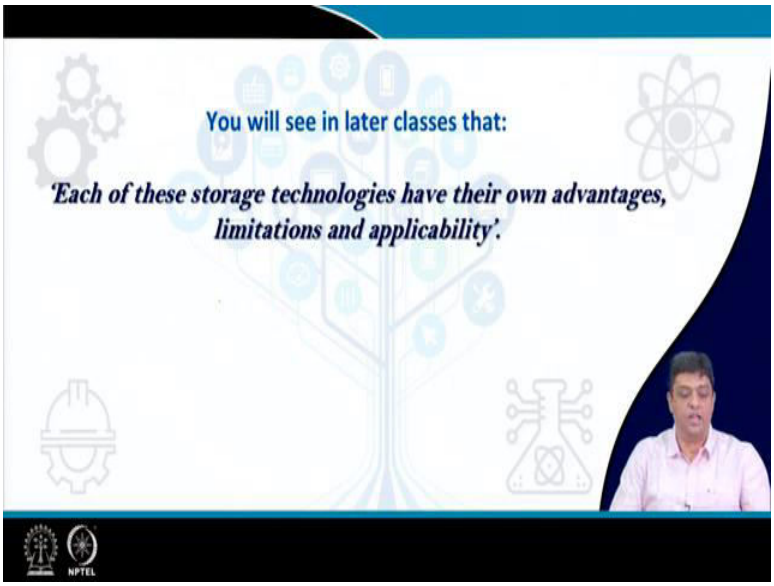

Once we have given you the details about the various storage technologies, you will also see in the later classes that each of these storage technologies have their own advantages, limitations and applicability. There is no one technology which can cater to the needs of all the end users. This is a sentence I have repeated just to make sure that this point is clear to you.

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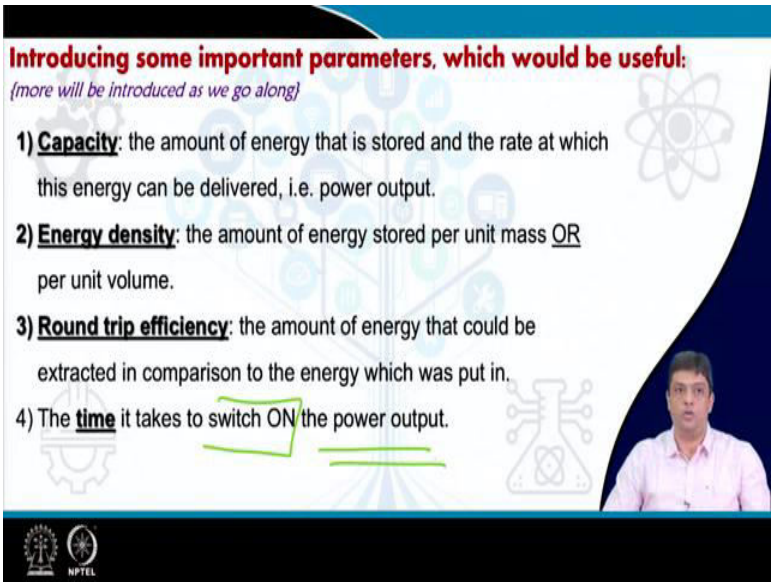

So, the parameters which are used to compare these technologies and which would be used during this course or this section of the course are; the first one is the capacity. How do we define capacity? It is the amount of energy that is stored and the rate at which this energy can be delivered. Second, energy density, that is the amount of energy stored per unit mass or the amount of energy stored per unit volume. Round trip efficiency, the amount of energy that could be extracted in comparison to the energy which was put in. And the time, what do we mean, the time we are talking about these systems is the time it takes to switch on the power output.

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In each of these technologies, you will find that materials will play a crucial role and they will decide the efficiency and also the final performance. You will have to then understand about the crystal structure, the redox reactions, the chemical reactions, lot many things which are associated with physics or physical chemistry. But one thing would be clear that nanotechnology is actually driving the advancement of these technologies. Nanotechnology be it be at the level of device fabrication or be it be at the size confinement considerations for materials, materials and then nanomaterials.

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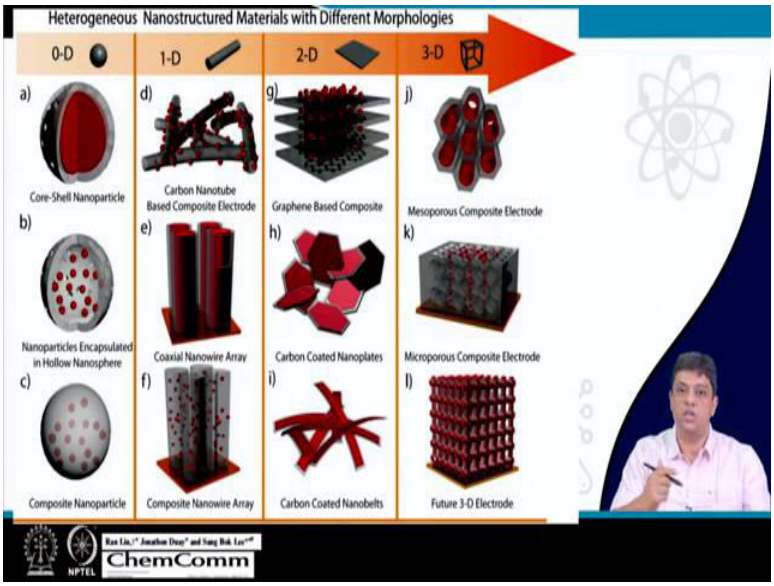

What do we understand by materials and nanomaterials? So, if you talk about bulk, then we mean that you have a system which is, let us say, three-dimensional structure and where all the three dimensions are having the values of more than 100 nanometers. So, nanomaterial is defined as the material which has at least one of the three dimensions in the range 1 to 100 nanometers. That is a typical definition for nanomaterials. So, you can have 0D, 1D, 2D or 3D structures.

Just to explain it further, let me give you a brief discussion using an animation and more detailed discussion will be done when we reach the point where we will be talking to you about the fabrication of materials used in energy storage devices.

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So, you can let us start with a 3D structure. So, you have an x direction, y direction and a z direction. So, if in all the three dimensions, the dimensions are more than 100 nanometers, then you have the bulk structure. Now, if you start cutting in, let us say, from the z-axis, so the second animation, so you have started reducing the size in the z direction, and you reach the point which is encircled now.

Then you have the y and the x direction which are still quite large, but the z-axis is now showing that the structure is much smaller and you have induced a condition where the movement of the free charges are confined in one direction, that means they do not have free movement in one direction, but they can move freely in the other two direction, that is what we mean by the term confinement.

So, these kinds of structures are the 1D structures. Then you have the two-dimensional confinements, where you also reduce the other axis. So, only, let us say, here the structures are moving in the y direction, but the movement in x direction and the z direction is confined. And then if you induce a condition where you have reached a point where the movement is confined in both in, all the z, x and y direction then those kinds of structures are called quantum dots. So 0D structures. So, these are quantum well, quantum wire or quantum dot structures. And these are related with the dimensionality of the structures.

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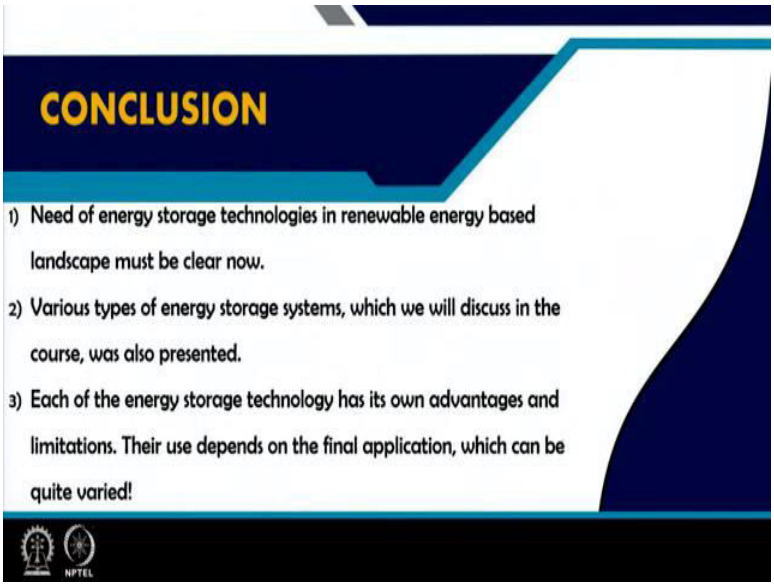

I hope in today's lecture I have been able to convince you the point that there is a need to use energy storage technologies in the renewable based energy landscape. There are various types of energy storage systems which would be discussed during this course. Each of this technology has its own advantage or advantages and limitations. These would also be discussed when we talk in detail and you will find that their use depends on the final application which can be quite varied.

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These are the references which we used to prepare today's lecture and obtain the data. And I hope you enjoyed the lecture. And we will start in the next lecture with more details about the energy storage technologies. Thank you very much.