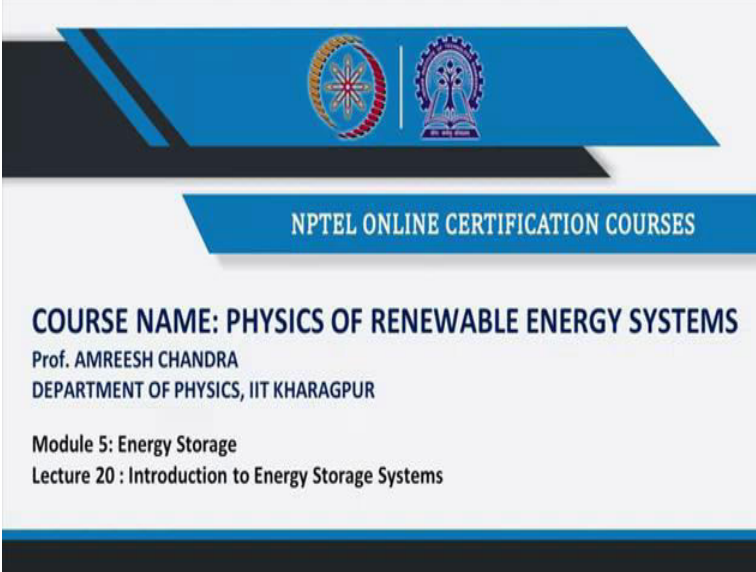


Physics of Renewable Energy Systems
Professor Amreesh Chandra
Department of Physics
Indian Institute of Technology Kharagpur
Lecture 20
Introduction to Energy Storage Systems

(Refer Slide Time: 00:34)



The slide features a blue header with two logos: the Indian Institute of Technology Kharagpur logo on the left and the NPTEL logo on the right. Below the header, a blue banner contains the text "NPTEL ONLINE CERTIFICATION COURSES". The main content area is white and contains the following text: "COURSE NAME: PHYSICS OF RENEWABLE ENERGY SYSTEMS", "Prof. AMREESH CHANDRA", "DEPARTMENT OF PHYSICS, IIT KHARAGPUR", "Module 5: Energy Storage", and "Lecture 20 : Introduction to Energy Storage Systems".

COURSE NAME: PHYSICS OF RENEWABLE ENERGY SYSTEMS
Prof. AMREESH CHANDRA
DEPARTMENT OF PHYSICS, IIT KHARAGPUR

Module 5: Energy Storage
Lecture 20 : Introduction to Energy Storage Systems

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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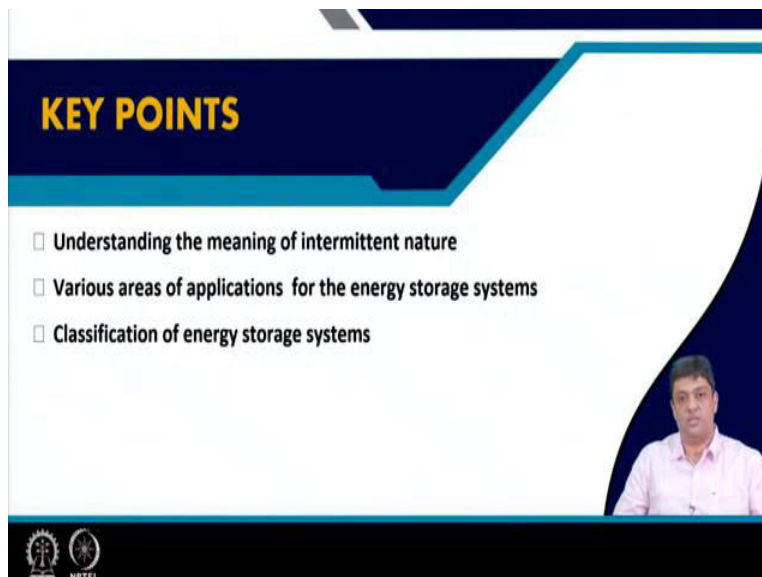
CONCEPTS COVERED

- Need for storage technology
- Various storage technologies
- Parameters used to compare various technologies

The slide features a dark blue header with the title 'CONCEPTS COVERED' in yellow. Below the header is a white area containing a bulleted list of three items. In the bottom right corner, there is a small video inset showing a man in a light pink shirt speaking. At the bottom of the slide, there are two circular logos: one for IIT Bombay and one for NPTEL.

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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KEY POINTS

- Understanding the meaning of intermittent nature
- Various areas of applications for the energy storage systems
- Classification of energy storage systems

The slide features a dark blue header with the title 'KEY POINTS' in yellow. Below the header is a white area containing a bulleted list of three items. In the bottom right corner, there is a small video inset showing a man in a light pink shirt speaking. At the bottom of the slide, there are two circular logos: one for IIT Bombay and one for NPTEL.

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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Till now we have discussed about the following renewable energy sources:

- ❖ Solar Energy
- ❖ Wind Energy
- ❖ Hydro Energy
- ❖ Tidal Energy
- ❖ Geothermal Energy

Each of these energy resources has its own advantages and limitations.

The slide features a background with a stylized tree of energy icons and a speaker's video feed in the bottom right corner. Logos for IIT Bombay and NPTEL are visible at the bottom left.

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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Solar energy:

Advantages:

- ✓ *Renewable*
- ✓ *Environmental friendly*
- ✓ *Diverse application*
- ✓ *Low maintenance cost*

Limitations:

- Intermittent* ✓
- Weather dependent*
- High start up cost*
- Uses a lot of spaces*

The slide also features a diagram of a p-n junction solar cell. A sun icon is shown above the cell, with a green arrow pointing to the top surface. Labels include 'Incident solar radiation', 'Front surface (n-type)', 'Back surface (p-type)', and 'P-N JUNCTION'. A small video inset in the bottom right corner shows a man in a light blue shirt speaking.

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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Wind energy:

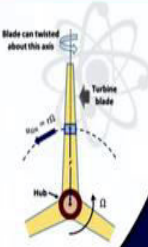

Advantages:

- ✓ Renewable
- ✓ Clean
- ✓ Low operating cost


Limitations:

- Intermittent
- Noise and visual pollution
- Some adverse environmental impact

Variable



The wind farm [Jaisalmer](#) is the largest onshore wind farm in India, situated along the river Yamuna, between the Vindhya and Himalayan mountains.



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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 of the source 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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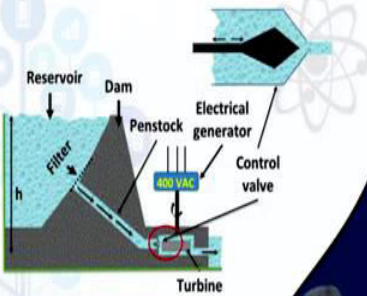
Hydro energy:

Advantages:

- ✓ Clean and non-polluting source
- ✓ Low maintenance cost
- ✓ No fuel is required

Limitations:

- Its impact on the local environment.
- Disruption to surrounding aquatic ecosystems
- It has relatively high constructional costs



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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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Tidal energy:

Advantages:

- ✓ Renewable energy source
- ✓ No green house gas production
- ✓ Potential to deliver enormous amount of energy

Limitations:

- Location limitation
- Very high topographical requirements
- High input/ capital cost
- Negative influence on marine life

The diagram illustrates the Earth and Moon system. The Earth is shown with a dashed line for the Equator and labels for North (N) and South (S) poles. The Moon is shown to the right. Arrows indicate the gravitational pull of the Moon on the Earth's water levels, with labels for 'Weaker gravitational force on water level' and 'Stronger gravitational force on water level'. A small inset shows a person speaking.

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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Geothermal energy:

Advantages:

- ✓ No release of green house gases
- ✓ Renewable energy source
- ✓ No fuel is needed
- ✓ Sustainable

Limitations:

- ❑ Location specific
- ❑ Highly expensive
- ❑ Release of harmful gasses deep within the earth
- ❑ It has the risk of triggering earthquakes

The diagram illustrates the Earth's internal structure. It shows a cross-section of the planet with four main layers: the Crust, the Mantle (at approximately 1000 °C), the Outer core, and the Inner core (at approximately 4000 °C). Depth markers are provided for each layer: the Crust ends at -35 km, the Mantle ends at -2900 km, the Outer core ends at -5150 km, and the Inner core ends at -6370 km. The diagram is part of a presentation slide, with a small inset video of a man speaking in the bottom right corner. The slide also includes a list of advantages and limitations for geothermal energy, and logos for IIT Bombay and NPTEL at the bottom.

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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The image shows two presentation slides. The top slide has a background of a tree with various icons (gears, atom, hard hat, flask) on its branches. The text on the slide is as follows:

Some of the energy sources, which we have discussed till now:

- can provide a continuous supply of energy

while some others

- produce energy intermittently!

The bottom slide has the same background and presenter. The text on the slide is as follows:

QUESTIONS:

SHOULD we operate the generation units only when the source is available?

If we want to ensure energy safety, security and continuity then HOW to tackle the problem?

On the second slide, the words "safety, security and continuity" are underlined in green, and the word "HOW" is enclosed in a green hand-drawn box.

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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Need for storage technologies?

- ❖ As we can see the renewable energy sources suffer from an intrinsic limitation i.e. "intermittency".
- ❖ There is a problem regarding secure supply for 24 hours a day and to create a balance between energy demand and supply

The slide features a background with icons of gears, a hard hat, a beaker, and an atom. A presenter is visible in the bottom right corner. The NPTEL logo is at the bottom left.

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

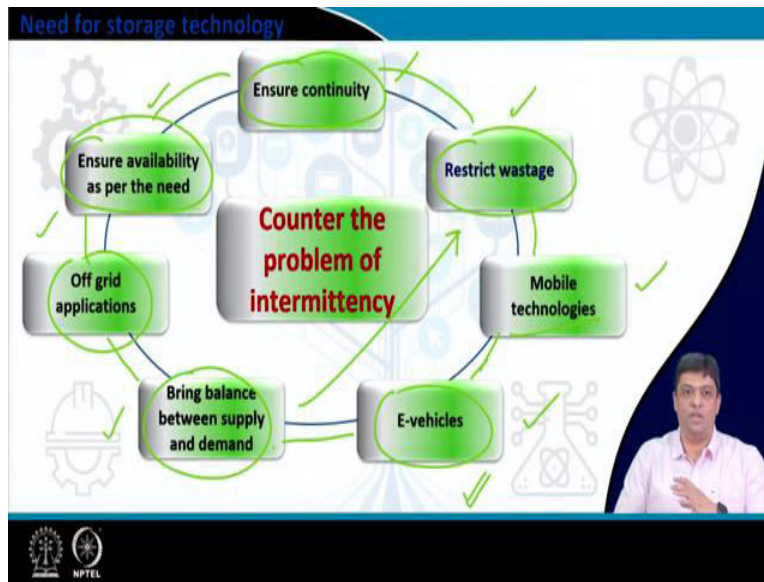
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The answer lies in the
USE OF A SUITABLE
ENERGY STORAGE TECHNOLOGIES

The slide features a background with icons of gears, a hard hat, a beaker, and an atom. A presenter is visible in the bottom right corner. The NPTEL logo is at the bottom left.

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.

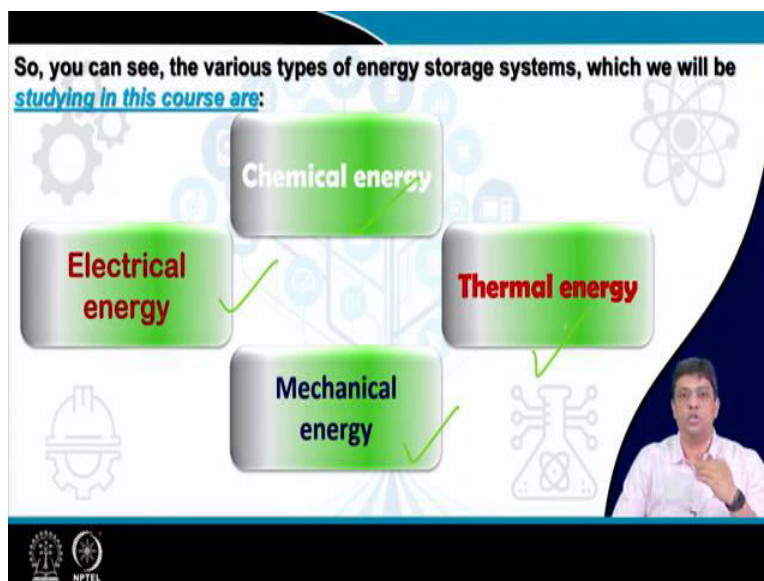
You have solar based lamps, you have street lights, you have the mobile towers which are now being powered by solar based units and that has led to reduced consumption of diesel in the

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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Various storage systems and comparing relevant physical parameters

Forms of energy	Energy Storage	Energy density (MJ/kg)	Round trip efficiency (%)
Chemical energy	Fossil fuels, coal, oil	35	--
	Hydrogen gas storage	140	~60
Thermal energy	Hot water storage	0.13	>50
	Ice-storage	0.33	~80
Potential energy	Pumped hydroelectric	.001	~75
	Compressed air storage	.33	~50
Kinetic energy	Fly wheels	0.04-0.4	~80
	Supercapacitors	~0.02	~95
Electrical energy	Superconducting magnets	0.001	95
	Lead acid battery	0.13	~80
	Fuel cells	~2	--

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.

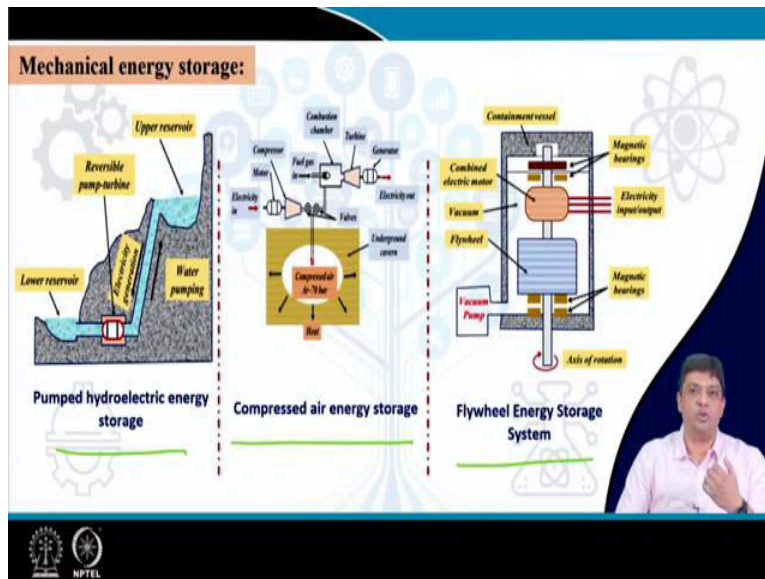
So, efficiency is only 60 percent and if I compare supercapacitors, they have energy densities which are as low as 0.02 mega joules per kg, but the efficiencies are extremely high, the round-trip efficiencies are very high compared with other system be it be hot water storage that we have already discussed 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.

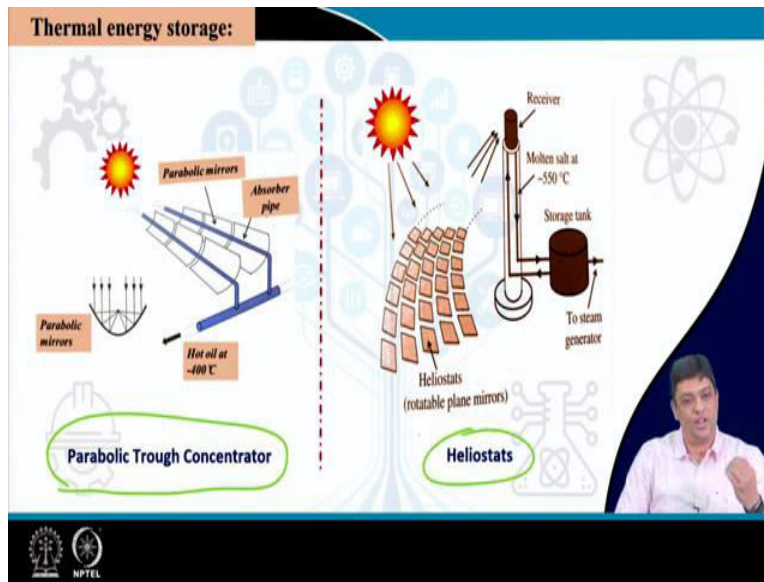
Can you please tell me why this value in fossil fuels, coal, oil is actually left blank when they are also classified under chemical energy, because they are non-renewable, correct. What happens? You use them and you lose them. So, there is no round trip efficiency. Once you use them, you use them and 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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Electrical energy storage:

The diagram illustrates three types of electrical energy storage systems. On the left, under the heading "Batteries", are a yellow cylindrical battery and a black EXIDE Premium car battery. In the center, under "Capacitors", is a schematic of a parallel plate capacitor with a dielectric material between two plates. It shows positive charges (+) on the top plate and negative charges (-) on the bottom plate, with an electric field (E) and charge (Q) indicated. On the right, under "Supercapacitors", is a schematic showing two electrodes (positive and negative) immersed in an electrolyte. It highlights the "Electric field" and "Local resistance" within the electrolyte. A presenter is visible in the bottom right corner of the slide.

Batteries

Capacitors

Supercapacitors

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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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Chemical energy storage:

The diagram illustrates two types of chemical energy storage systems. On the left, under the heading "Microbial fuel cell", is a photograph of a dark-colored device with several wires connected to it. On the right, under "Hydrogen Fuel Cells", is a schematic diagram showing two platinum electrodes immersed in a dilute acid electrolyte. The diagram shows the flow of electrons (e-) and the chemical reactions occurring at the electrodes. A presenter is visible in the bottom right corner of the slide.

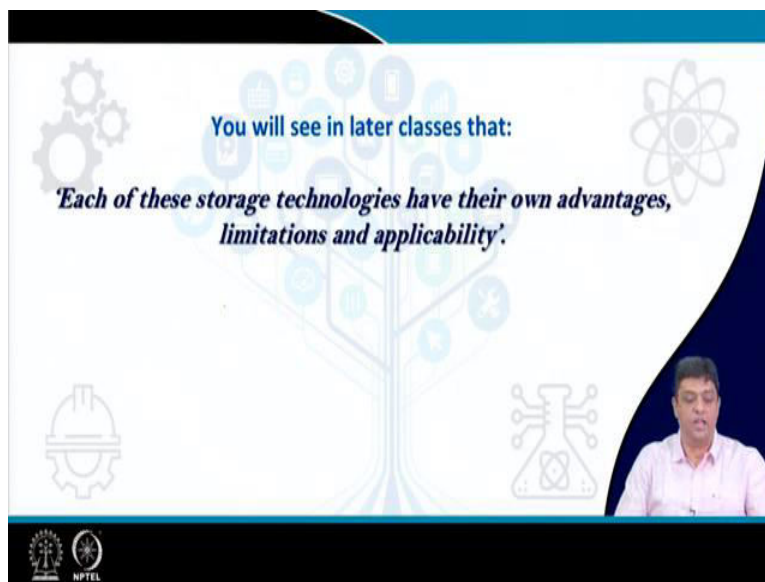
Microbial fuel cell

Hydrogen Fuel Cells

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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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Introducing some important parameters, which would be useful:
(more will be introduced as we go along)

- 1) **Capacity:** the amount of energy that is stored and the rate at which this energy can be delivered, i.e. power output.
- 2) **Energy density:** the amount of energy stored per unit mass OR per unit volume.
- 3) **Round trip efficiency:** the amount of energy that could be extracted in comparison to the energy which was put in.
- 4) The **time** it takes to switch ON the power output.

The slide features a blue header, a white background with faint technical icons (gears, atom, circuit), and a small video inset of a presenter in the bottom right corner. The NPTEL logo is visible in the bottom left corner.

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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You will also see that 'materials' will play a crucial role in making these technology useful for us.

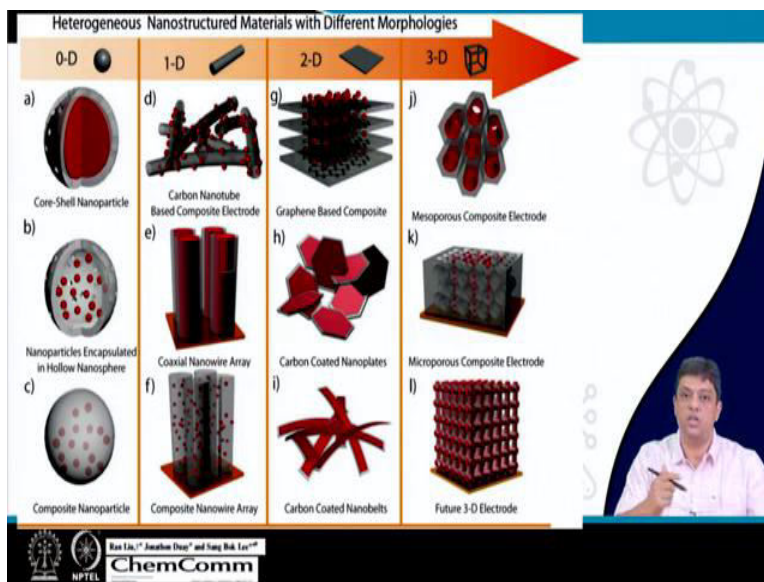
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NANOTECHNOLOGY IS DRIVING THE ADVANCEMENT OF TECHNOLOGIES.

The slide features a blue header, a white background with faint technical icons (gears, atom, circuit), and a small video inset of a presenter in the bottom right corner. The NPTEL logo is visible in the bottom left corner.

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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CONCLUSION

- 1) Need of energy storage technologies in renewable energy based landscape must be clear now.
- 2) Various types of energy storage systems, which we will discuss in the course, was also presented.
- 3) Each of the energy storage technology has its own advantages and limitations. Their use depends on the final application, which can be quite varied!

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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.

(Refer Slide Time: 34:17)

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- Energy Storage – Batteries and Supercapacitors Set (Vol. 1,2,3,4)
by Patrice Simon & Jean-Marie Tarascon
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by B.E. Conway.

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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.