Selection of Nanomaterials for Energy Harvesting and Storage Applications
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Lecture - 16
Energy Storage

Hello my friends, in this particular lecture we are going to discuss about the Energy Storage; in our last 15 lectures we have discussed about the different types of materials and how we are generating the energy. So, basically that chapter deals with the energy generations.

So, in these particular 16 to 20 lectures; we are going to discuss that how we are going to store that particular energy what we have already generated. So, this is the basically the preliminary idea we are going to provide you, so that you can understand that in which way or may be in which method we are going to store the energy into different form.

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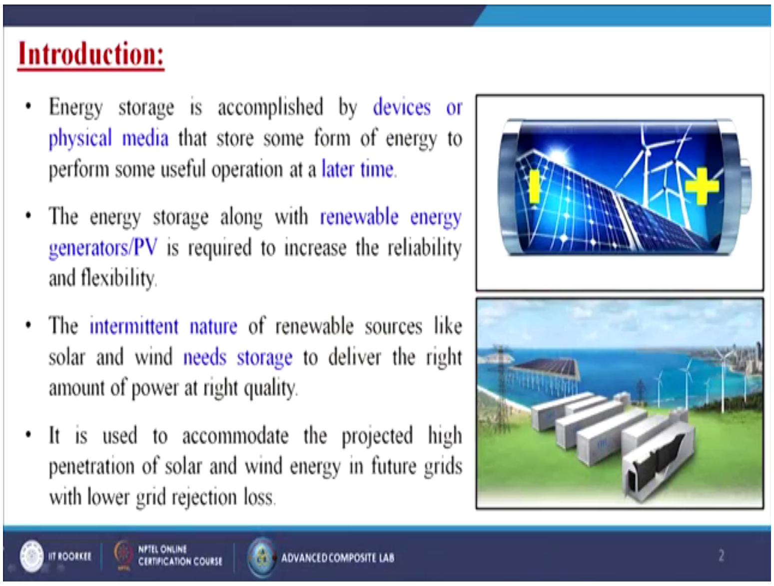

So, basically energy storage is accomplished by devices or physical media that store some form of energy to perform some useful operations at a later time. Yes of course, because when you are generating the energy; so either we are directly using that particular energy, but it is not possible every time that whatever the energy we are generating at a time; we are able to utilize that whole energy. Now, what way we are going to use that particular energy. Now, that extra energy we have to store so that in future when you require we can utilize that particular energy. The energy storage along with the renewable energy is generators or maybe that photovoltaics is required to increase the reliability and flexibility.

The intermediate nature of renewable sources like solar and wind needs storage to deliver the right amount of power at right quality. Basically you can see in the daytime you are getting the solar or may be the sunlight; that time you are generating the huge amount of solar energy. But, it is not that every time we need that particular energy into the daytime; we have to use that particular energy into the night time. So, how we can do it?

So, that is why whatever the energy we are generating into the day time; we are storing that particular energy either maybe some batteries or maybe some kind of storage devices or maybe like super capacitors and as and when required in the night time, we are just taking out that particular energy. It is used to accommodate the projected high penetration of solar and wind energy in future grids with lower grid rejection loss.

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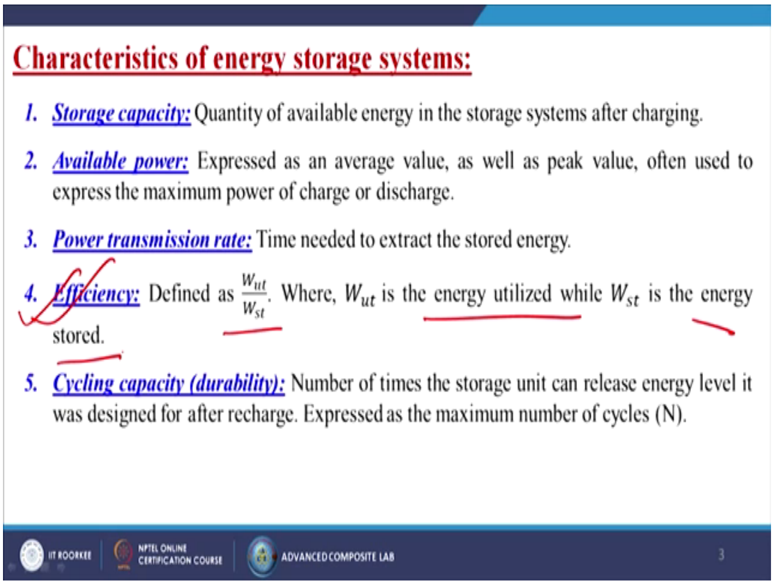

Now; what is the characteristics of energy storage systems? So, first one is called the storage capacity; storage capacity is nothing, but the quantity of available energy in the storage systems after charging; that means, it is like a tank. So, just I am pouring the water; so at the end of the day; how much quantity or may be volume of water I am storing inside that particular tank?

Second is called the available power expressed as an average value as well as peak value of an used to express the maximum power of charge or may be the discharge. So, available power means in a particular time what quantity of power or maybe the energy I am getting? So, you can see that in the daytime; so when in the early morning or maybe the late evening when the sun light is not coming up to that much level; so our energy generation is less at that particular time.

But at 12 o'clock in the noon; so we are getting the maximum sunlight over there. So, automatically we are getting the maximum energy at that particular point. Next one is called the power transmission rate; that is time needed to extract the stored energy. Now, that is depending upon the discharge capacity or may be capability of that particular materials, where we have stored that particular energy.

Next one is that efficiency that is the most important parameters because every time we are talking about the energy generations or maybe the energy storage in terms of efficiency. So, defined as W ut by W st; so ut is nothing, but the energy utilized and st is nothing, but the energy stored. And the fifth one is called the cycling capacity or may be the durability; number of times the storage unit can release energy level, it was designated for after recharge expressed as the maximum number of cycles.

Say for normal battery, it is having already some stored energy; we are using it for certain times and after certain times we are calling it the battery is dead; that means what? It has released all the energy; what we have already stored inside it. But, now talks about the rechargeable battery; so we are utilizing that battery for a certain time, when the battery is getting fully drained. So, what we are doing? Again we are charging that battery; that means, we are keeping the charge inside it and then after certain time, again we are utilizing it for the longer time. So, that is known as the cycle capacity or maybe sometimes we are calling; it as a durability.

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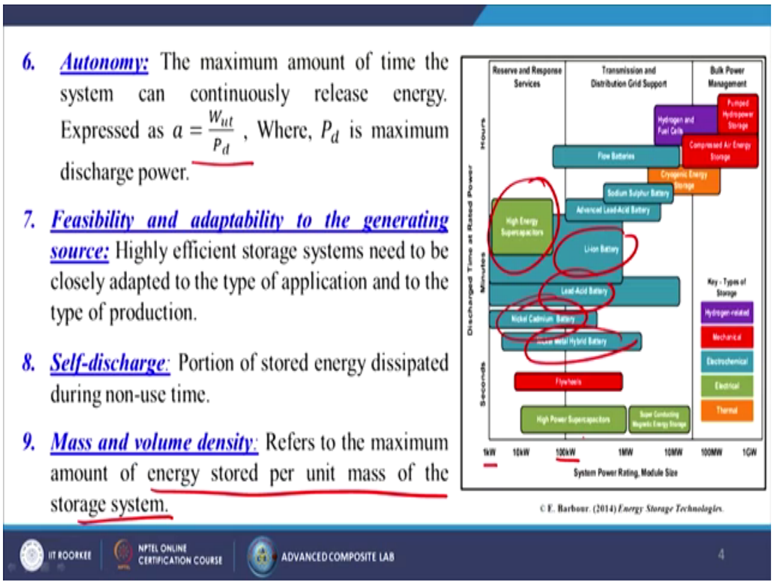

Sixth one is called the autonomy the maximum amount of time by system can continuously release energy expressed as a is equal to W ut by; P d where P d is nothing, but the maximum discharge power. And what is the W ut? That is energy for utilizations; feasibility and adaptability to the generating source, high efficiency storage systems needs to be closely adapted to the type of applications and to the type of production. Self discharge, portions of stored energy dissipated during non use time; yes of course, if you are keeping a battery for a longer time what will happen? The charge will automatically discharged, if you are not going to use it also.

Because every material is having some self life; so after certain time the material will automatically degrade and automatically it will lose its energy. And next one is the mass and volume density; refers to the maximum amount of energy stored per unit mass of the storage system or maybe the volume of that particular storage system. So, this is the overall idea that how you are utilizing the energy. So, when you are talking about the less suppose 1 kilo Watt to 100 kilo Watt we are having that high energy super capacitors, we are having that some battery nickel cadmium battery, lead acid battery that is the oldest one.

Nowadays, people are working on the lithium ion battery, then some nickel metal hybrid battery or may be some kind of flywheels for the tidal energy or high power super capacitors. When we are going for the higher energy storage capacity, say suppose 1 mega Watt to 1 giga Watt; so we are moving towards the hydrogen fuel cells, cryogenic energy storage or maybe super capacitors, magnetic energy storage. So, these all are the kind of things; that means, simple we are increasing its mass and volume density so that we can store the maximum energy inside it.

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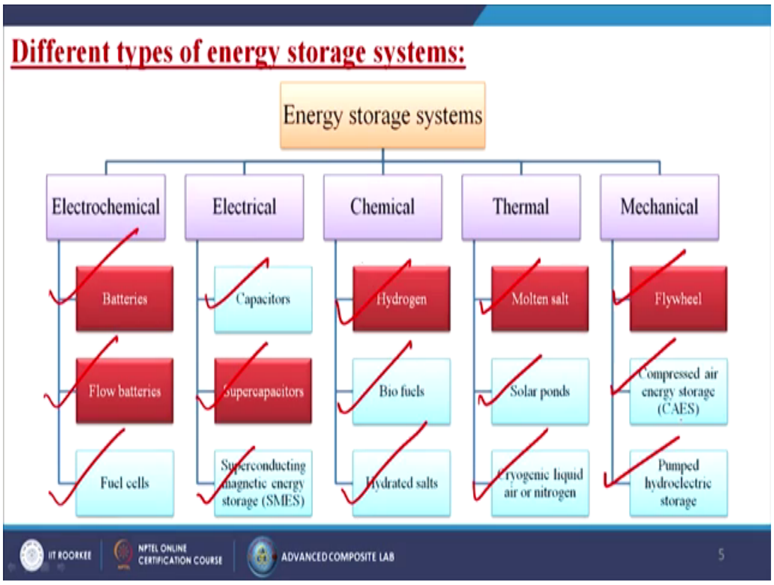

Now, there are several types of energy storage systems; so basically that depends upon the electrochemical, electrical, chemical, thermal and the mechanical energy systems. If we talk about the electrochemical, it is based on the batteries, flow batteries and the fuel cells. If we talk about the electricals; it is about the capacitors, super capacitors, superconducting magnetic energy storage or maybe in short we are calling it as a SMES.

If we talk about the chemical, it is the hydrogen, bio fuels and the hydrated salts. If we talk about the thermal, it is molten salt, solar ponds, cryogenic liquid air or may be the nitrogen. And the last one if we talk about the mechanical; it is about the flywheel, compressed air energy storage; in short it is CAES and the pumped hydro electric storage system.

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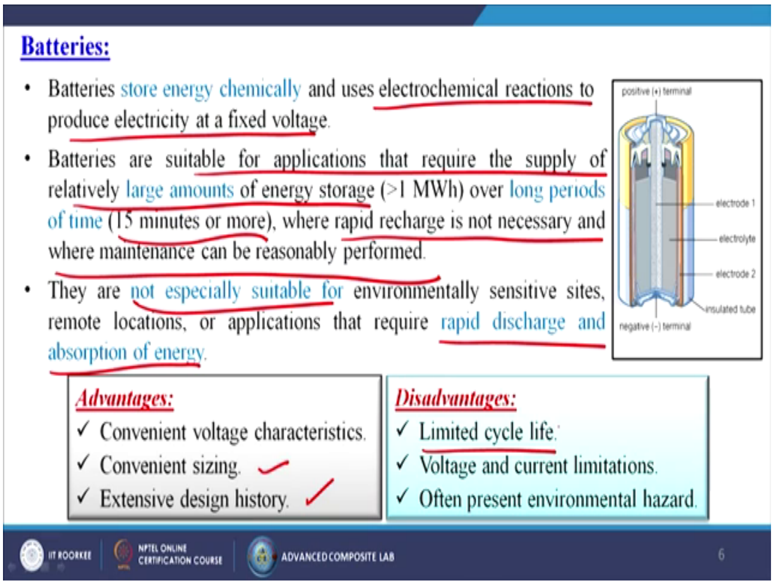

Now, we are going to discuss about the batteries. So, battery store energy chemically and use electrochemical reactions to produce the electricity at a fixed voltage. In class may be 10 or may be 12; we have already gone through the working principle of the batteries.

So, basically the batteries are suitable for applications that require the supply of relatively large amounts of energy storage; that is more than 1 megawatt hour, over long periods of time 15 minutes or more where rapid recharge is not necessary and where maintenance can be reasonably performed. They are not especially suitable for environmentally sensitive sites, remote locations or applications that require rapid discharge and adsorption of the energy; when we are using it as for a rechargeable battery.

Advantages, so first is that convenient voltage characteristics, convenient sizing and the extensive design history. There are certain disadvantages also; limited cycle life as I told already because battery is having certain cycle life; after certain time the whole energy will be drained out. Voltage and current limitations; it is having some maximum efficiency and often present the environmental hazard over there. Now flow batteries; concept is same in that, particular case normal batteries, we are using the solid electrolyte. In this particular case, we are going to use that liquid electrolyte so that is continuously moving inside the systems and the charges transferring.

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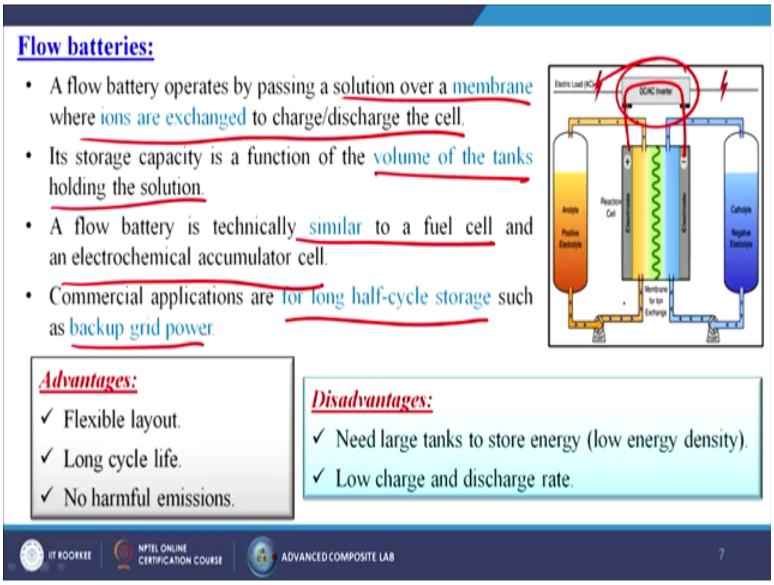

So, a flow battery operates by passing a solution over a membrane where the ions are exchanged to charge discharge the cell; so, basically this green in colour is called the membrane. So, in this particular case we are having that positive electrode, we are having that negative electrode. So, in this particular case what is happening? It is aligned to go the ions from one site to another site, but it is abstracting to move the electrons through that particular membrane.

So, now, the electron is moving like this way and now in this particular case; we are capturing the electrons and; that means, we are capturing the current or may be the energy. Its storage capacity is a function of the volume of the tanks holding the solution, a flow battery is technically similar to a fuel cell and an electrochemical accumulator cell.

Commercial applications are for long half cycle storage such as backup grid power; of course, there are certain disadvantages and advantages. So, advantages is flexible layout, long cycle life and no harmful emissions because it is not creating or maybe generating any kind of toxic gases. There are certain disadvantages also; it needs large tanks to store energy; that means, it is having a very low energy density and low charge and discharge rate.

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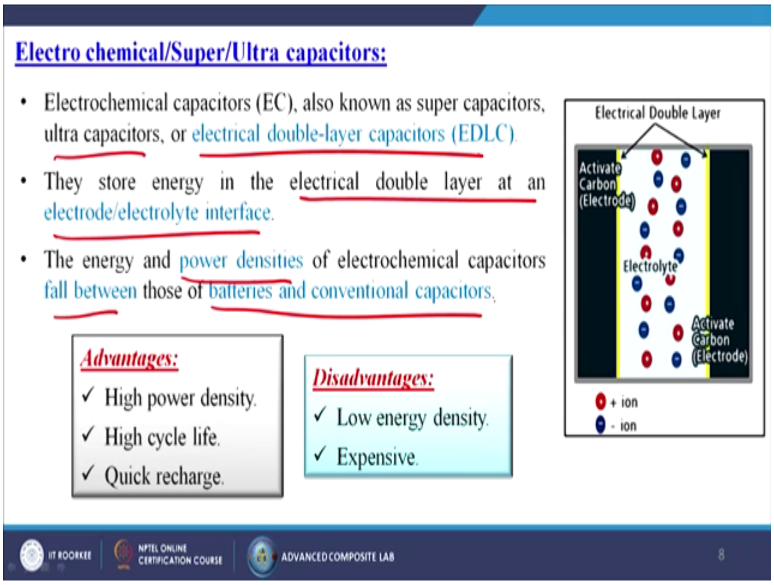

Next one is the electrochemical or maybe the super or may be the ultra capacitors; electrochemical capacitors are known as super capacitors, ultra capacitors or electrical double layer capacitors in short basically we are calling it as a EDLC. So, in this particular case you can see that we are using two electrode over there; both are made by the activated carbon electrode and inside that we are putting the electrolytes.

So, when we are giving the charge over there simple the electrolyte is dividing into two parts; the plus and the negative one and simple we are capturing over there. They store energy in the electrical double layer at an electrode or maybe the electrolyte interface. The energy and power densities of electrochemical capacitors fall between those of batteries and conventional capacitors; advantages it is having a high power density, high cycle life and the quick recharge.

That means when the whole energy will be drained out; simple we can charge it and then again we can use it for a longer time. And of course, certain disadvantages are there it is having the low energy density; that means, the volume or maybe the mass is very very less over here and it is also made by very expensive material.

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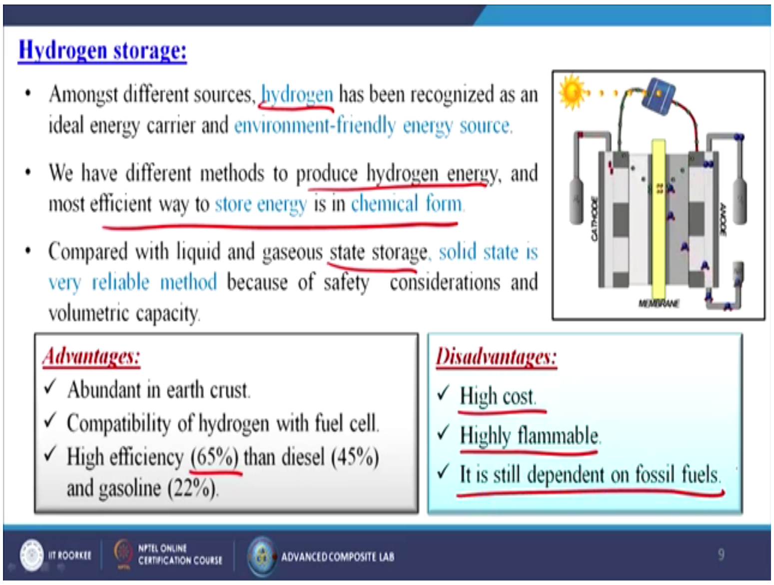

Next one is called the hydrogen storage; amongst different sources hydrogen has been recognized as an ideal energy carrier and environment friendly energy source. In our future slides, we are going to deliver one lecture totally based on the hydrogen storage systems.

We have different methods to produce hydrogen energy and most efficient way to store energy is in chemical form. So, basically that is depends upon the chemi absorption of the materials. Compared with liquid and gaseous state storage; solid state is very reliable method because of safety considerations and volumetric capacity. Yes of course, because for the liquid or may be the gaseous state storing; the biggest problem is that we have to make the container in such a manner that it can withstand the high temperature, high pressure if we keep the hydrogen into the liquid form we have to go to the negative temperature.

So, that is also a very big challenge to us; so that is why the scientist are working to store the hydrogen is into the solid form. Of course, it is having some advantages it is abandoned in earth crust; so we can get it continuously, compatibility of hydrogen with the fuel cell is high, high efficiency like 65 percent than the diesel 45 percent and the gasoline 22 percent. Of course, there is certain disadvantages also it is having the high cost, highly flammable, it is still dependent on fossil fuels.

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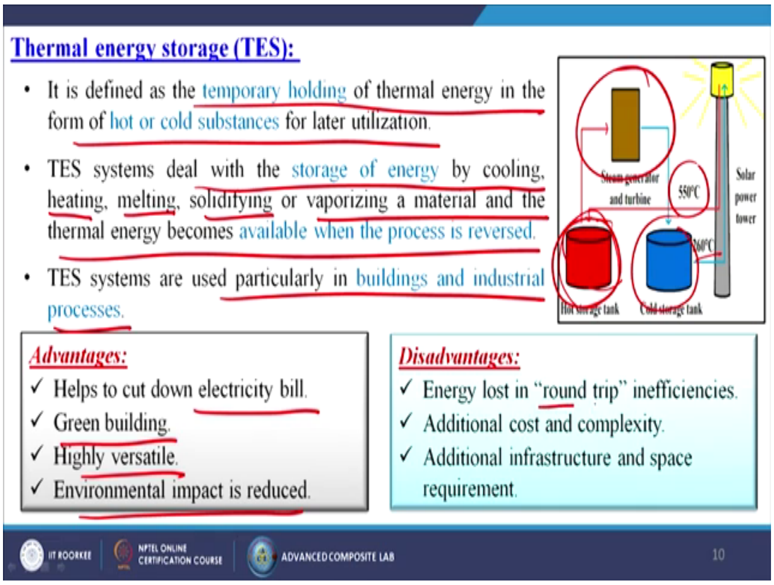

Next one is called the thermal energy storage; it is defined as the temporary holding of thermal energy in the form of a hot or cold substances for later utilizations. So, simple in this particular case what we are going to do? The TES systems deal with the storage of energy by cooling or heating, melting, solidifying or vaporizing a material and the thermal energy becomes available when the process is basically the reversible one. TES systems are used particularly in buildings and the industrial processes. So, in this particular case what happened?

So, I am having that solar power tower; so basically I am having one hot storage tank I am having one cold storage tank over there. Cold storage tank the temperature is around 260 degree centigrade and for hot storage tank; the temperature is five 150 degree centigrade. Now, when the material is heated up; so what will happen? Due to that vaporizations of that particular materials; so what will happen? I am it is coupled with some turbine. So, turbine will be rotate and then through that we can generate the electricity over there. So, basically we are creating the temperature difference in between the two materials.

Advantages, it helps to cut down the electricity bill, green building, highly versatile, environmental impact is reduced. Disadvantages energy lost in round trip inefficiencies, additional cost and complexity, additional infrastructure and the space requirement is required.

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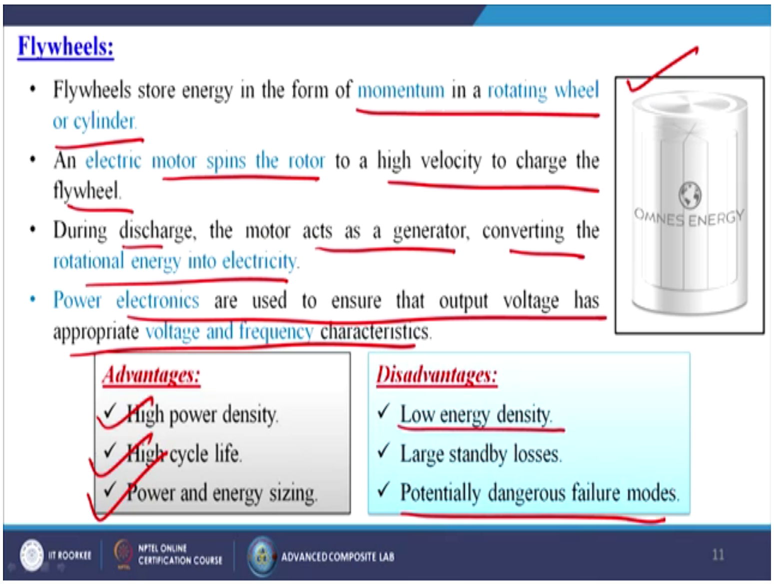

Next come to the flywheels; flywheels store energy in the form of momentum in a rotating wheel or cylinder; which you can see from this particular image. And electric motors spins the motor to a high velocity to charge the flywheel; during discharge the motor acts as a generator converting the rotational energy into electricity. Power electronics are used to ensure that output voltage has appropriate voltage and frequency characteristics.

Of course, it is having some advantages; high power density, high cycle life, power and energy sizing is possible. Disadvantages low energy density, large standby losses, potential dangerous failure modes.

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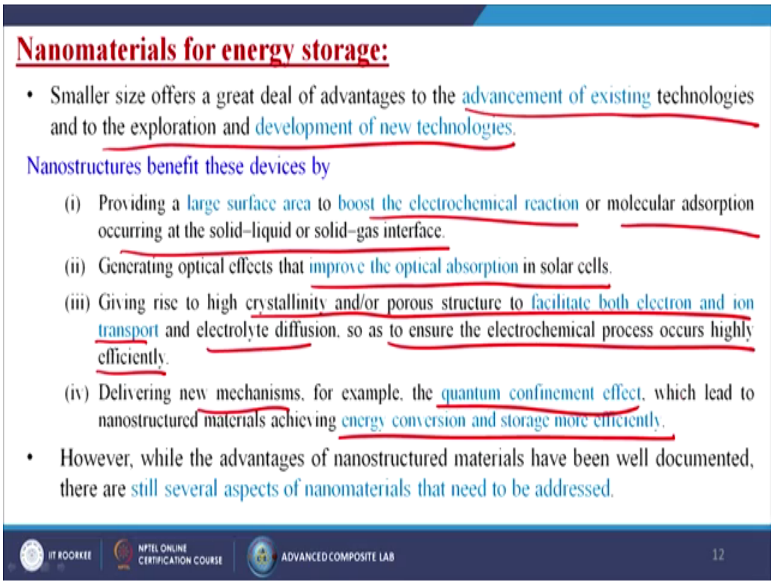

Now, what kind of nanomaterials basically we are using for energy storage? Smaller size offers a great deal of advantage because it is having the maximum surface area to the advancement of existing technologies and to the explorations and development of new technologies.

Nanostructures benefit this devices by providing a large surface area as I told already when we are making that material into the smaller size automatically its surface area is getting to be increased; so, to boost the electrochemical reactions or molecular adsorption occurring at the solid liquid or maybe the solid gas interface. Generating optical effects that improves the optical absorption in solar cells. Giving rise to high crystallinity and or porous structure to facilitate both electron and ion transport and electrolyte diffusion so as to ensure the electrochemical process occurs highly, efficiently.

Delivering new mechanisms, for example the quantum confinement effect which lead to nano structured materials achieving, energy conversion and storage more efficiently. So; that means, this material can withstand the high temperature, high pressure and sometimes it gives the porous like structure so that we can store the maximum energy by using these kind of materials. However, while the advantages of nanostructured materials have been well documented, there are still several aspects of nanomaterials that needs to be addressed.

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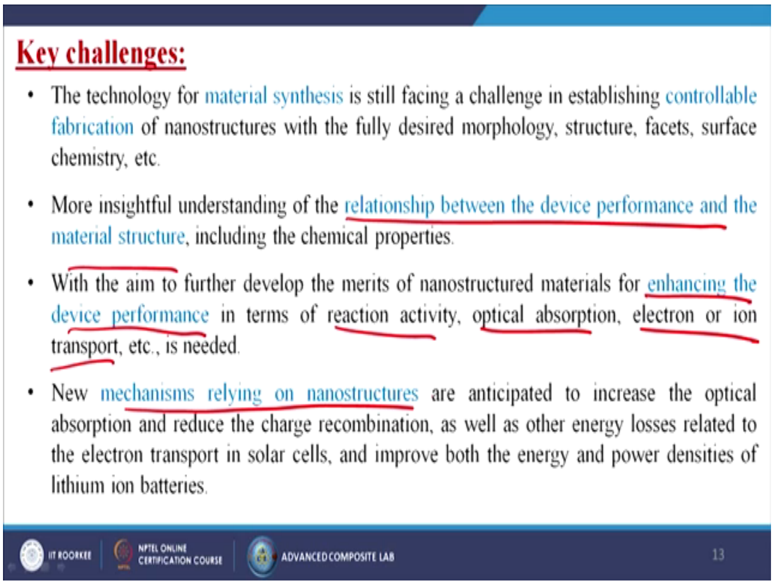

Now, what are the key challenges basically we are facing as a researcher? The technology for materials synthesis is still facing a challenge in establishing the controllable fabrication of nanostructures with the fully desired morphology structure, facts and surface chemistry; more insightful, understanding of the relationship between the device performance and the material structure including the chemical properties.

With the aim to further develop the merits of nanostructured materials for enhancing the device performance in terms of reaction activity, optical absorption, electron or ion transport etcetera is needed. New mechanisms relying on nano structures are anticipated to increase the optical absorption and reduce the charge recombination, as well as other energy resources related to the electron transport in solar cells and improve both the energy and power densities of lithium ion battery.

So, basically what we are trying to do? Simple, we are trying to make certain kind of materials which can sustain for longer life withlosing any kind of physical or maybe the chemical properties. Now what are the solutions to key challenges? Like surface modifications of the nano materials; as I told already when the people are working with the nanomaterials, so everyday our demand is increasing. It is not possible that a single set of nanomaterials can satisfy all the requirements. So, that is why the people are trying to do the modification of those nano materials.

Either they are doing the surface modifications or maybe they are doing the doping or maybe they are doing any kind of coating of the material so that it can increase its efficiency or maybe the other material properties.

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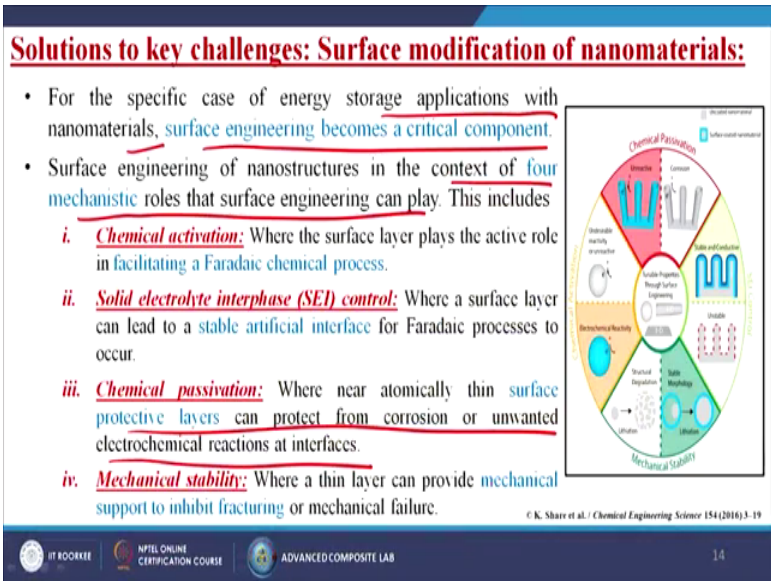

So, for the specification of energy storage applications with nano materials; surface engineering becomes a critical component. Surface engineering of nano structures in the context of four mechanistic roles that surface engineering can play. This includes the number one; chemical activation where the surface layer plays the active role in facilitating a Faradaic chemical process.

Next, second one is the solid electrolyte interface control where a surface layer can lead to a stable artificial interface for a Faradaic process to occur. The third one chemical passivation, where near atomically thin surface protective layers can protect from corrosion or unwanted electrochemical reactions at the interfaces. And the last one is called the mechanical stability, when thin layer can provide mechanical support to inhibit fracturing or maybe the mechanical failure after certain use or may be certain time. So, these all are the chemical passivations, chemical activations, mechanical stability and the SEI control that is Solid Electrolyte Interface control over there.

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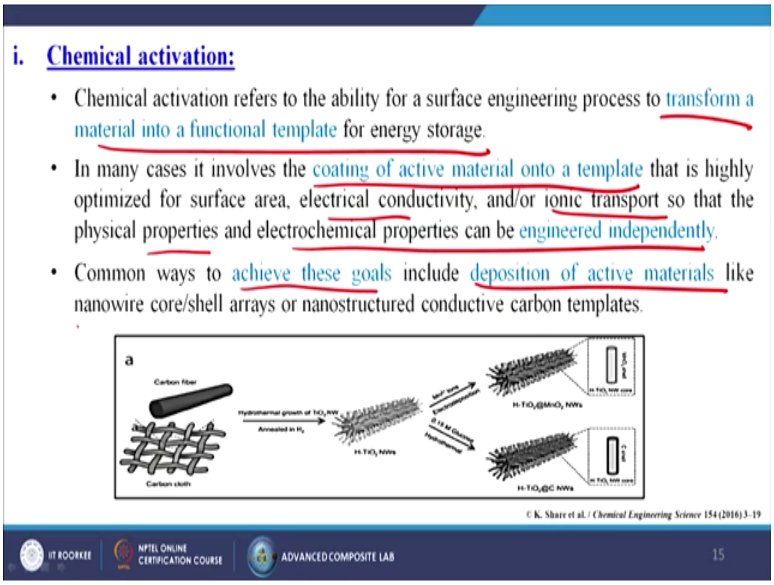

Now, what is chemical activations? So, basically chemical activations refers to the ability of a surface engineering process to transform a material into a functional template for energy storage.

In many cases, it involves the coating of active material onto a template that is highly optimized for surface area, electrical conductivity or maybe the ionic transport so that the physical properties and electrochemical properties can be engineered independently. So; that means, simple; whatever the existing properties are there just we are trying to increase its physical properties enhancement. Common ways to achieve these goals include deposition of active materials; like nanowire core or may be the shell arrays or may be the nanostructured conductive carbon templates.

So, basically we arehaving the carbon cloth, we are having that carbon fibre; so simple we are doing the wrapping of materials on to that; either may be the on the carbon cloth or may be that carbon fibre so that its physical properties can be increased either mechanical properties; in terms of mechanical properties, in terms of thermal properties or may be in terms of electrical properties.

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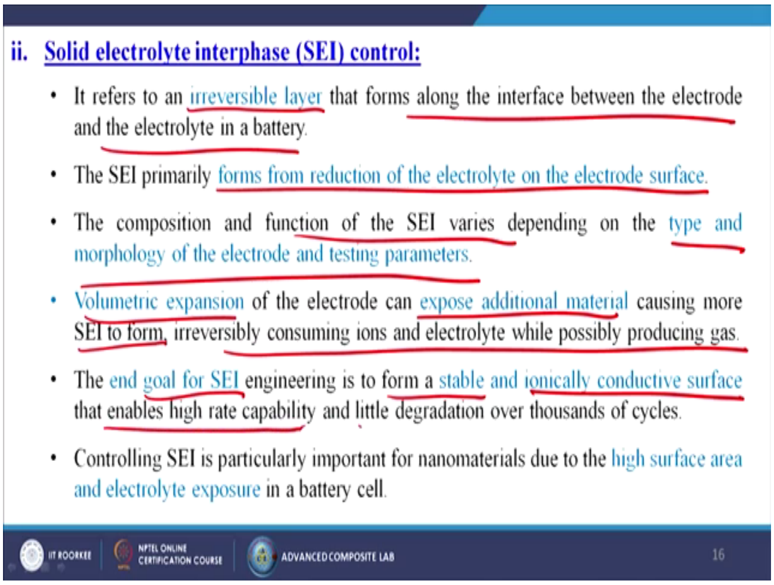

Next, solid electrolyte interface control it refers to an irreversible layer that forms along the interface between the electrode and the electrolyte in a battery itself. So, the SEI primarily forms from reduction of the electrolyte on the electrode surface. The composition and function of the SEI varies depending on the type and morphology of the electrode and the testing parameters. Volumetric expansion of the electrode can expose additional material causing more SEI to form irreversibly consuming ions and electrolyte while possibly producing the gas.

Because it can generate certain kind of gases because some chemical reactions is going to happened inside the system. The end goal for SEI engineering is to form a stable and ionically conductive surface that enables high rate capability and little degradation over thousands of cycles. Controlling SEI is particularly important for nano materials due to the high surface area and electrolyte exposure in a battery cell.

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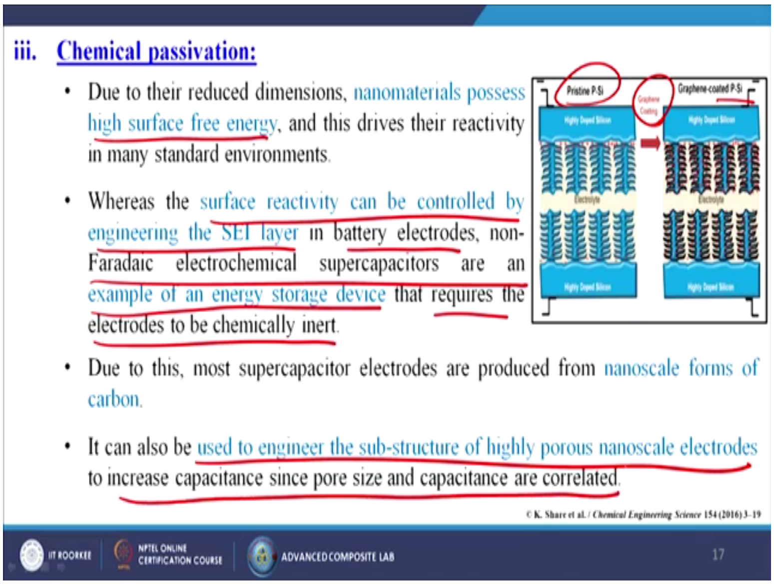

The next one is called the chemical passivations; due to their reduced dimensions nano materials possesses high surface free energy and this drives their reactivity in many standard environments. So, in this particular case what we are doing? Simple we are doing the coating of the graphene layer there. So, we are having pristine P Si materials, highly doped silicon basically we are using and in between that the electrolytes are there.

Now, simple we are coating the graphene onto the psi systems and we are increasing the efficiency; where as the surface reactivity can be controlled by engineering the SEI layer in battery electrodes, non Faradaic electrochemical super capacitors are an example of an energy storage device that requires the electrodes to be chemically inert. Due to this inert super capacitor electrodes are produced from nanoscale forms of carbon.

So, simple a form of carbon it is a grapheme; basically we are wrapping or maybe coating on to that PSI systems, it can also be used to engineer the substructure of highly porous nanoscale electrodes to increase the capacitance since pore size and capacitance are correlated. Yes, now we are using certain kind of materials which can increase the pore size of that particular electrode system so that my efficiency can increase. Graphene not only increase the electrical properties; it will increase the mechanical properties as well; as well as it will increase the thermal properties too.

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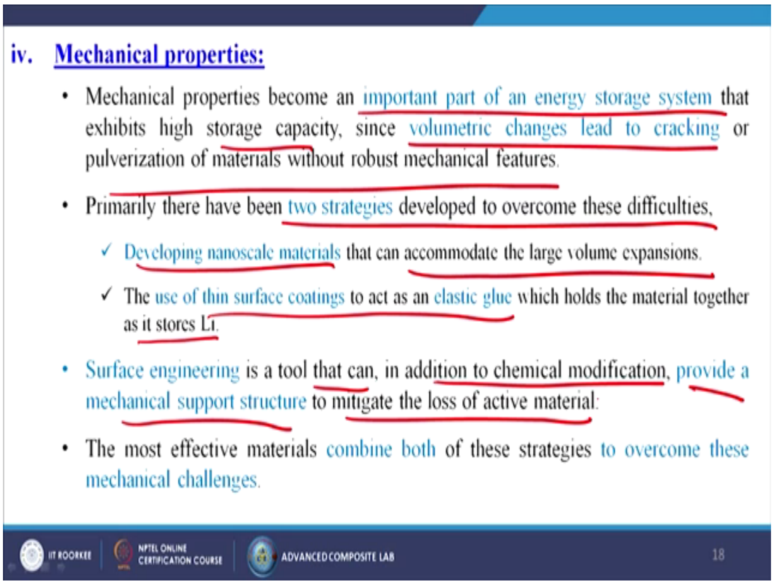

Now, the last one is the mechanical properties; mechanical properties become an important part of an energy storage system that exhibits high storage capacity, since volumetric changes lead to cracking or pulverization of material without robust mechanical features.

Yes, because when I am using certain kind of container or maybe certain kind of materials and to capture certain kind of energy over there. So, that energy creates a high pressure or may be at the time of energy requirement I have to heat that particular container so that material should not decompose or maybe will be able to withstand that particular temperature or maybe the pressure for certain time. So, there should not be any cracking or maybe any kind of porous generation inside the system so that it can be leak proof.

Primarily, there have been two strategies developed to overcome these difficulties; the number one developing nano scale materials that can accommodate the large volume expansion over there at the time of heating or may be giving the pressure. The use of surface coatings to act as an elastic glue which holds the material together as it stores the lithium. Surface engineering is a tool that can in addition to chemical modification, provide a mechanical support structure to mitigate the loss of active material. The most effective materials combine both of these strategies to overcome these mechanical challenges.

Now, we have come to the last slide of this particular lecture. So, in summary we can say that intermittent nature of renewable sources like solar and wind needs storage to deliver the right amount of power at right quality and right time.

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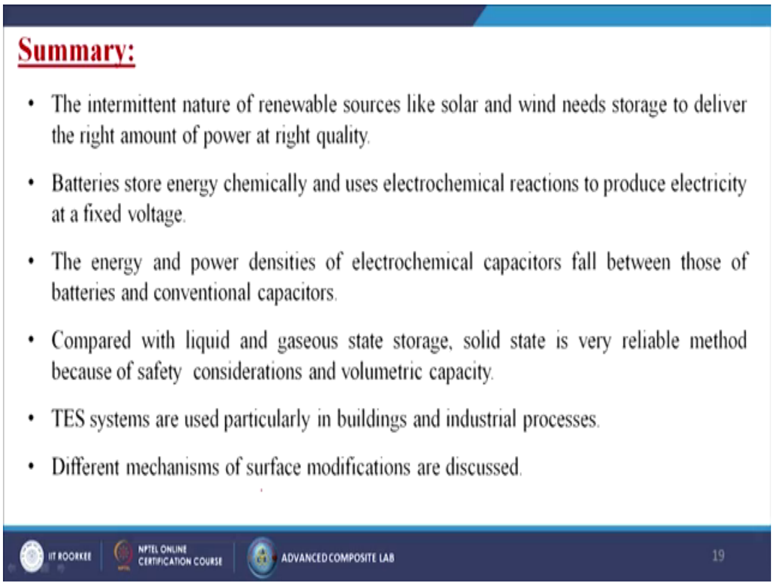

Battery store energy chemically and uses electrochemical reactions to produce the electricity at a fixed voltage. The energy and power densities of electrochemical capacitors fall between those of batteries and the conventional capacitors.

Compared with liquid and gaseous state storage solid state is very reliable method because of safety considerations and the volumetric capacity. TES systems are used particularly in buildings and industrial processes. Direct mechanism of surface modifications has already been discussed, either in terms of coating in terms of doping or maybe in terms of wrapping.

Thank you.