Selection of Nanomaterials for Energy Harvesting and Storage Applications

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Lecture – 01
Introduction

Hello my friends, we are going to start our lecture on Selection of Nanomaterials for Energy Harvesting and Storage Applications. So, basically this lecture series rather I can say because there are total 20 number of lectures under this category that selection of nano materials for energy harvesting and storage applications. So, in this particular lecture series we are going to discuss about the different types of materials generally what we are using for energy harvesting and storage applications.

Before, that we are going to discuss about that what is the mechanism for energy harvesting and the storage applications. And what is the latest research are going on worldwide for this energy harvesting and storage applications just to increase their performance or maybe the efficiency. So, basically this is the Introduction chapter, in this introduction of chapter we are going to cover the whole syllabus just a glimpse of those. Because, we are going to discuss each sub chapter in a subsequent lectures.

So, that you will better understand, but this is the introduction part where we are going to give a whole idea about our course structures and what we are going to cover in this particular course. So, in this particular lecture first we are starting with the nano materials just to give an brief idea about what is the meaning of the nano materials or maybe rather we can say what kind of nano materials basically nowadays scientist are using for energy storage and the harvesting applications. So, basically nano materials means that the size of that materials into the nano scale that is the overall layman idea in our mind.

But, actually if you see that those basically who are working on the nano materials basically they are every time talking about that 0D, 1D, 2D, 3D kind of nano materials. So, D is nothing, but the dimensions. Now, in this particular case when you are talking about the 0D; that means, the nano material size all the scales say xy and z are into the nanometer range. When we are talking about the 1D, one dimensions is into the micro scale and others are into the nano scale.

When we are talking about the 2D so, basically in this particular case two dimensions are into the micro scale, one dimension is into the nano scale. When you are talking about the 3D so, all the dimensions add into the microscale. So, basically the nano materials has been classified into 0D, 1D, 2D, 3D best on their shape and size.

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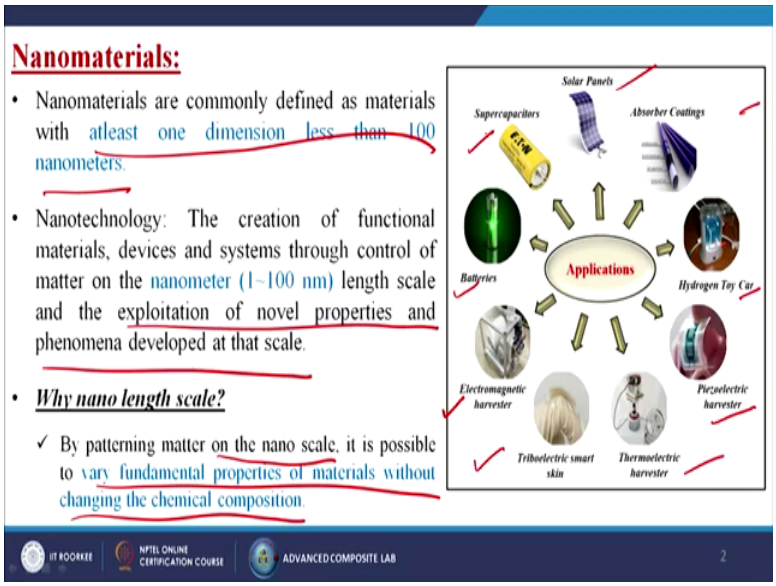

So, basically nano materials are commonly defined as materials with at least one dimension less than 100 nano meters which I was talking about. So, when you are talking about the 0D there is nothing into the micro scale everything are into the nano scale. When we are talking about the 1D so, one dimensions is into the micro scale and others are into the nano scale. Now, what is nanotechnology? So, basically the technology which deals the nano materials is known as the nanotechnology. The creation of the functional nano materials devices and systems through control of matter on the nanometer basically, the nanometer is also having some range.

So, when we are talking about the nano; that means, it defines from 1 to 100 nano meter. So, the dimension should be below 100 nanometer then we are calling it as a nano materials. Length scale and the exploitation of noble properties and phenomena developed at the scale yes of course, because when we are making the materials any materials from the micro to nano; that means, we are reducing its shape and size. So, automatically when you are going to reduce its shape and size.

So, as per the science the surface area is increasing and when the surface area is increasing so, automatically the its property is going to be increased. And not only that it only about the surface area there are some other properties like physical properties, chemical properties or rather I can say some kind of thermal properties or may be the morphological properties these are also changing. Due to that the material is showing the better results in nano-size than the micro size.

So, why nano length scale? By patterning matter on the nano scale it is possible to vary fundamental properties of materials without changing the chemical composition. So, here we are not going to change its chemical composition, simple we are making from the large to the small or maybe the nano and the material physical properties is going to be changed. Now, in this particular image you can see that we have given so many examples like solar panels, absorber coatings, hydrogen toy car, piezoelectric harvester, thermoelectric harvester, triboelectric smart scheme, electromagnetic harvester, battery, super capacitors.

So, basically these all applications we are going to discuss in this particular topic. So, now what is energy? So, energy basically defined as power derived from the utilization of physical or chemical resources especially to provide light and heat or to work machines. So, what I can say that energy is nothing, but a power which can light up, which can run the machines or maybe which can do something.

So, it is a one kind of power kind of things which we cannot see by our naked eyes, but its presence is there. So now the energy; energy means it does not have any loss over there means we cannot generate the energy nothing neither we have cannot destroy the energy also. So, energy can transfer from one system to the another systems. So, basically the energy when we are generating or maybe we are storing. So, there are two things: first we have to harvest the energy; that means, we have to generate the energy.

Now, the question is that when we are generating those energy so, at the generation time we are not able to utilize the whole energy for running any machines or light up the things. In future or maybe in the other time also we need that particular energy. So, keeping that point in our mind that energy storage has come because whatever the energy we are using at that particular point that we are utilizing. But, rest of the energy when we

need we are storing those so, that at our requirement simple we can get that particular energy.

So, if we talk about the energy harvesting systems so, there are so, many energy harvesting systems. Harvesting means which is generating the energy like solar the sunlight is the biggest source of the energy. Now, the sunlight is coming to the earth and as we know that a little portions we are utilizing and the rest of the portions just we are wasting. Now, if I am having certain technology by which we can capture that wasting sunlight and we can able to generate the electricity from that wasting sun light so, it will be a great achievement.

Same thing like hydrogen they are enormous amount of hydrogen are there in the earth crust. So, if we able to capture that hydrogen and if we able to convert the hydrogen energy into production of that electricity it will be nice. Then nano generators it is made by some kind of waste kind of materials like simple aluminum or rayon or maybe by rubbing our hands also we can generate a little bit of EMF force in our hand itself; not only that by applying any kind of low dot pressure so, when we are walking.

So, if you are able to generate the electricity by our walking that will be a great achievement, then some kind of other conventional energy. Basically, these all these things we are going to discuss in the subsequence slides and in depth.

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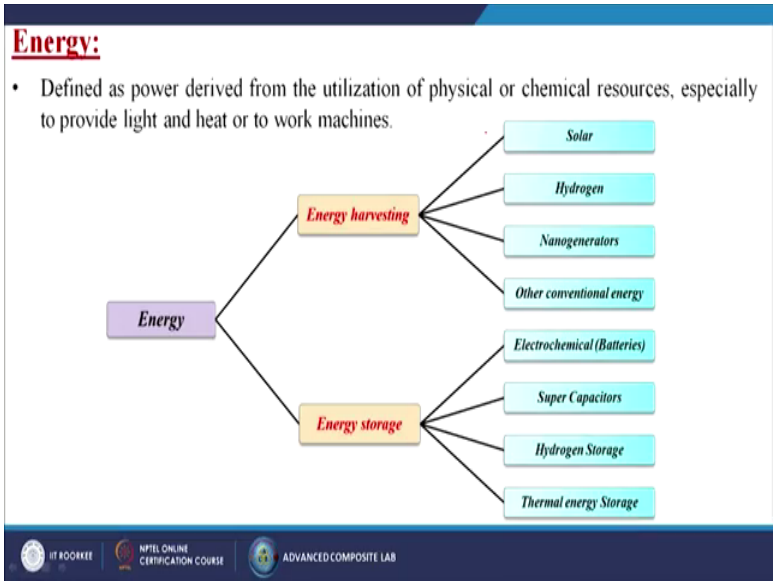

Next if you talk about the energy storage; so, basically first it comes to our mind is the batteries from childhood to we are seeing that one. So, basically there are two types of batteries also; one is the direct battery; that means, we are generating the electricity into that and after certain time we are taking out the energy from that. And when it is finished we are trying it and we are purchasing the new one that is the one kind; another kind is that we are having that nowadays it is called the rechargeable battery.

So, simple we are storing the energy inside it as and when it requires we are taking out the energy from these batteries and then after that when the energy finishes again we can recharge that battery. That means, again we can store the energy inside it and when we requires we can take out that energy once again. So, we can use that batteries for longer time; next is called the super capacitors. So, basically super capacitors is nothing, but a accumulation of the energy. So, basically at certain time I need a huge amount of energy.

So, I am keeping that energy into the super capacitor and certainly I can get electricity from there or maybe the energy from there; next is the hydrogen storage. So, basically hydrogen storage is also the same thing as we know that maybe in the future we can run our vehicles by storing the hydrogen itself. That means, we can use the hydrogen as a fuel and not only that in the spacecraft also people are trying to use the hydrogen as a fuel.

So, these all are the unconventional energy sources and the energy storage systems and last one is called the thermal energy storage. Because, when we are heating our water or maybe some other materials if the waste heat we are able to capture and we can convert that waste heat into some generation of the electricity. So, automatically that will be a great achievement for us. So, basically this chapter with will this will define by the energy harvesting and the energy storage system. Now, we are going to discuss about the energy harvesting systems little bit in to depth.

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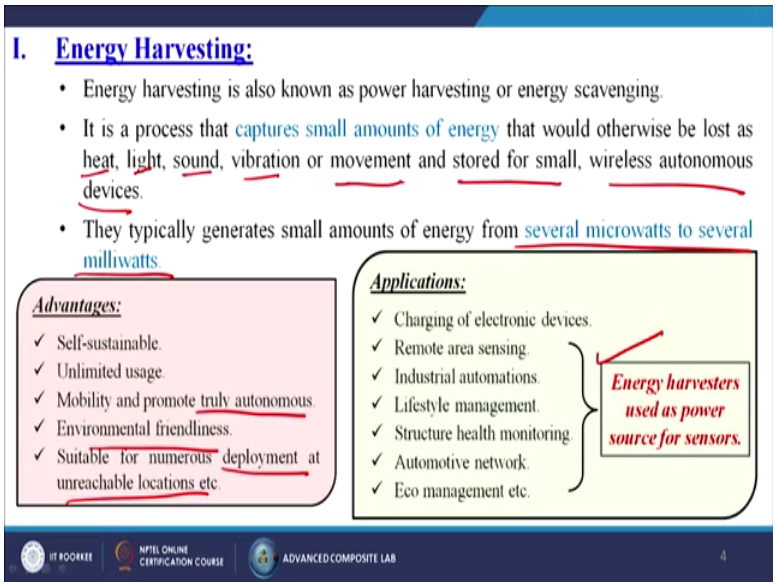

So, energy harvesting is also known as power harvesting or maybe the energy scavenging; as I told already simple just we are generating the electricity or maybe the energy. It is a process that capture small amount of energy that would otherwise we lost as heat, light, sound, vibration or movement and stored for small wellness autonomous devices. They typically generate small amount of energy from several microwatts to several milliwatts. What are the advantage?

So, of course there are having so, many advantages like it is self sustainable, it is having the limited usage, mobility and promote truly autonomous, environmental friendliness, suitable for numerous deployment at unreachable locations; that means, it is too handy. So, we can take it from one place to another place or may be any complicated systems and we can do the energy harvesting kind of things. Applications: charging of electronic devices, remote area sensing, industrial automations, lifestyle management, structure health monitoring, automotive network, eco management etcetera. So, basically the energy harvesters used as power source for the sensors. So, these all are the for this particular purpose.

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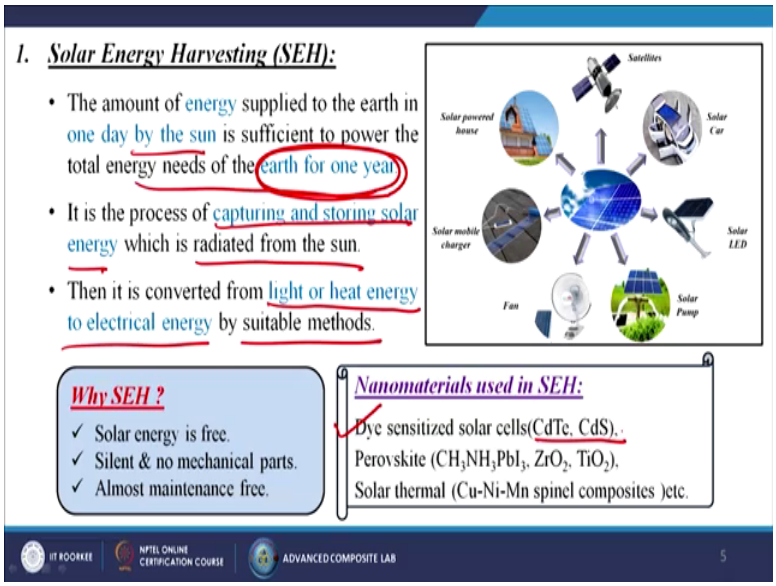

Now, in the energy harvesting systems first comes to our mind is called the solar energy harvesting as I told already; so, the sunlight is coming on to the earth. So, we are unable to utilize the whole sunlight. So now, the wasting is too much; if we are able to store that wasted sunlight and we will be able to convert it into generation of the energy or maybe the electricity that will be great.

So, the amount of energy supplied to the earth in one day by the sun is sufficient to power the total energy needs of the earth for one year. Now, you can understand that what miracle we can do from the sunlight itself. It is the process of capturing and storing solar energy which is radiated from the sun. Then it is converted from light or heat energy to electrical energy by suitable methods. Why solar energy harvesting? The question may come in our mind, the reason is that solar energy is free.

So, every day we are getting silent and no mechanical parts and almost maintenance free. Yes, no maintenance automatically it will come to the earth surface. Now, we are going to discuss about what kind of nano materials we are using for solar energy harvesting. As per the mechanisms there are lots of materials people are using, earlier days people were working on dye sensitized solar cells. So, basically they are using the cadmium, tellurium or maybe the cadmium sulfide, but maybe the efficiency is not up to that much level. Now, people has moved to the perovskite materials; basically the perovskite materials is having a good efficiency, but the material is not stable.

So, that is why nowadays people has moved to the solar thermal like copper, nickel, manganese, final composites kind of things. So, basically just to increase the efficiency, increase the quantity of that energy generations people are moving from one material to the another material and they are changing the mechanisms. But, basically in every cases the sources is same that is the sunlight. Next second one is called hydrogen energy harvesting, how we can generate the hydrogen.

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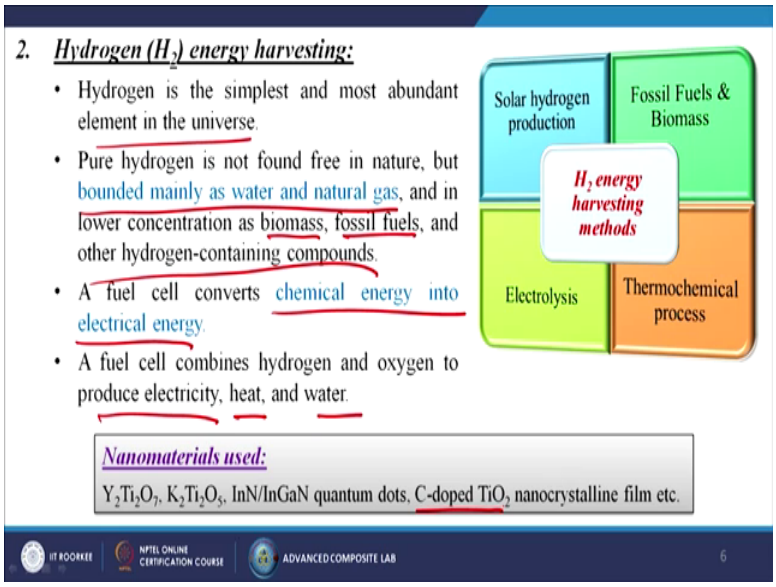

Hydrogen is the simplest and most abundant element in the universe. Pure hydrogen is not found free in nature, but bounded mainly as water and natural gas yes because in water the formula is H 2 O. So that means, 2 hydrogen atom and 1 oxygen atom. So now, if you are able to break that hydrogen from the oxygen atom we can generate the hydrogen and exactly the same thing people are doing nowadays. So, when will come in depth in this particular hydrogen storage systems in our lectures. So, automatically there you are going to see that people are breaking the hydrogen and oxygen and simple they are generating the hydrogen gas from that particular equations.

And in lower concentrations as biomass fossil fuels and other hydrogen containing compounds. A fuel cell converts chemical energy into electrical energy, a fuel cell combines hydrogen and oxygen to produce electricity, heat and water. So, now there are so, many types of hydrogen energy harvesting methods based on their efficiency, based on their availability of the materials low cost and the for longer life. So, like solar

hydrogen productions, fossil fuels and biomass, thermo chemical process and the electrolysis. What kind of materials nowadays we are using? Basically you are using the yttrium Y 2 some kind of rare of materials; so, Y 2 Ti 2 O 7 K 2 Ti 2 O 5.

So, titanium compounds basically then indium nitrate or maybe indium gallium nitride quantum dots, carbon dots titanium dioxide some kind of nano crystalline film. So, basically these material people are using nowadays; now come to the third one that is nothing, but the nano generators. So, basically nano generator means what? Generator means it generates the electricity and for producing that electricity we are using the nano materials, that is why the name has come nano and generator. That does not means the generator is into the nano scale, basically generator is into the bigger scale, but for generating the electricity we are using the nano materials.

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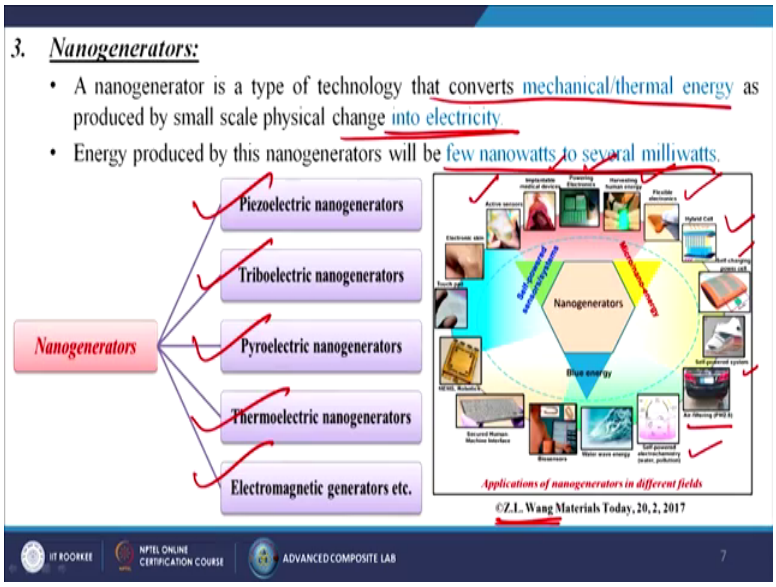

So, that is why nano generators has come. So, a nano generator is a type of technology that converts mechanical or maybe the thermal energy as produced by small scale physical change into electricity. Energy produced by this nano generator will be few nanowatts to several milliwatts. Now, the nano generators also based on so, many mechanism. What are those? First one is called the piezoelectric nano generators, from the name itself can understand for making the electricity or maybe the energy we are using some kind of piezoelectric material over there. Next is called the triboelectric, tribo it is a Greek form or maybe the Greek word basically it is known as the friction.

So; that means, we are generating the friction in between the material and we are generating the electricity, then the pyro. Pyro means its heat so, pyro means we are generating some kind of heat energy over there and converting that heat energy into the electric energy; thermo simple its the temperature about. So, due to the temperature changing we are generating certain kind of electricity over there and electromagnetic is nothing, but the simple by using the electricity we are generating the magnetic force over there or maybe by using the magnetic force we are generating the electricity over there.

So, based on the mechanism we can classify the nano generators into different types. Now what are the applications? So, basically we are using for the active sensors, implantable medical devices like our pacemaker kind of things. Powering electronics, harvesting human energy, flexible electronics, hybrid cell, self charging power cell, cell power systems, air filtering, self powered electro chemistry, water wave energy, biosensor, then MEMS robotics, touchpad, electronic skin.

So, n number of applications were nowadays we are using the nanogenerators and basically he is the pioneer of that nano generator Professor Zhong Lin Wang. Basically, who is working intensively in all the mechanism and he is basically very famous in this particular nanogenerator kind of things; now we are going to discuss one by one.

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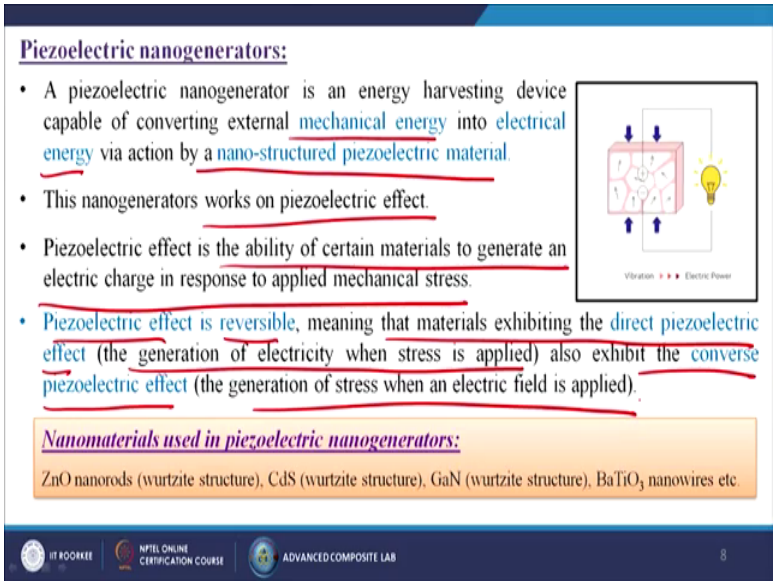

So, as I told you first is called the piezoelectric nano generator, so a piezoelectric nano generator is an energy harvesting device capable of converting external mechanical

energy into electrical energy via action by a nano structured piezoelectric material. This nano generators works on the piezoelectric effect. So, piezoelectric material means it is having one capability that if we give the load or pressure from one side then other side it can generate the electricity.

So, basically the piezoelectric effect is the ability of certain materials to generate an electric charge in response to applied mechanical stress. Piezoelectric effect is reversible meaning that materials exhibiting the direct piezoelectric effect, the generation of electricity when stress is applied also exhibit the converse piezoelectric effect the generation of stress when an electric field is applied.

That means, it is the vice versa kind of things; if you give the stress on to that material it will generate the electricity. Same thing if you give the electricity to that material it will generate the stress over there. Now, what kind of nano materials basically we are using for piezoelectric nano generators? Zinc oxide nano rods which is nothing, but the wrutzite structure, cadmium sulphide wrutzite structure, gallium nitride BaTiO 3 nano wires; so, these all are the materials nowadays people are using, next is called the triboelectric nano generator.

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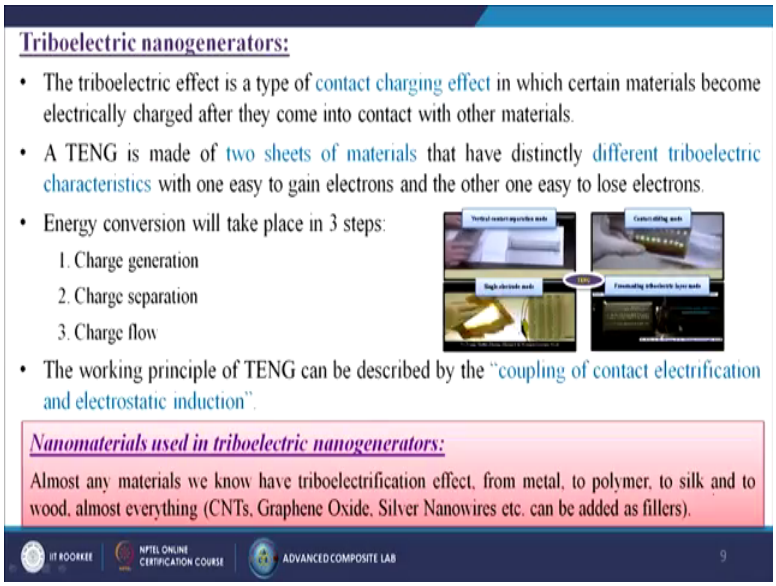

So, triboelectric means simple as I told already tribo; that means, the friction it is a Greek word. So, basically we are generating the friction in between the materials. So, that triboelectric effect is a type of contact charging effect in which certain materials become

electrically charged after they come into contact with other materials. A TENG in this a TENG is nothing, but the short form of the triboelectric nano generators is made up two sheets of materials that have distinctly different triboelectric characteristics with one easy to gain electrons and the other one easy to lose electrons.

That means, one is highly positive another one is highly negative. So, energy conversion will takes place in three steps: first is that charge generation, then charge separations and the charge flow. So, basically these three. The working principle of TENG can be described by the coupling of contact electrification and electrostatic induction. What kind of materials nowadays we are using? Almost any materials we know have tribo electrification effect; from metal to polymer to silk and to wood almost everything like carbon nano tubes, graphene oxides, silver nano rods etcetera can be added as a fillet materials.

That means, simple we are trying to increase the efficiency, but if you take simple aluminum with the reyon or maybe cotton also you can generate the electricity. But, the electricity quantity is very very less or maybe power is very less. So, just to increase the efficiency nowadays we are introducing so many types of nano fillers or maybe sometimes we are using the modified nano fillers in terms of doping, wrapping, coating. So, just simple we are doing and then we are adding in to the system so, that the efficiency can be increased. Next one is called the pyro electric nano generators.

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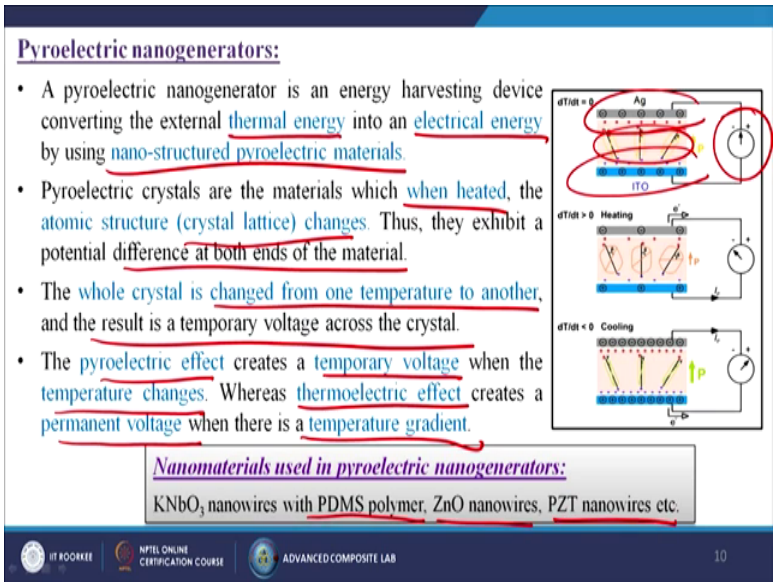

So, a pyro electric nano generator is an energy harvesting device converting the external thermal energy into an electrical energy by using nano structured pyro electric materials. Pyro electric crystals are the materials which when heated the atomic structure changes. Thus, they exhibit a potential difference at both ends of the materials. So that means, inside this the material crystal structure is basically changing. So, when we are applying the heat over there and then after that the charge separation is taking place. You can see one side is getting negatively charged, one side is getting the positively charged.

So, automatically the electron flow will start. And now in this particular case simple we are putting the storage systems in which we are storing the electricity or maybe directly we can utilize it also. The whole crystal is changed from one temperature to another and the result is a temporary voltage across the crystal. The pyro electric effect creates a temporary voltage when the temperature changes whereas, thermoelectric effect creates a permanent voltage when there is a temperature gradient. Now, what kind of nano materials? Like potassium, nubium oxide KNbO 3 nano wires with PDMS polymer, zinc oxide nano wires, PZT nano wires etcetera nowadays people are using.

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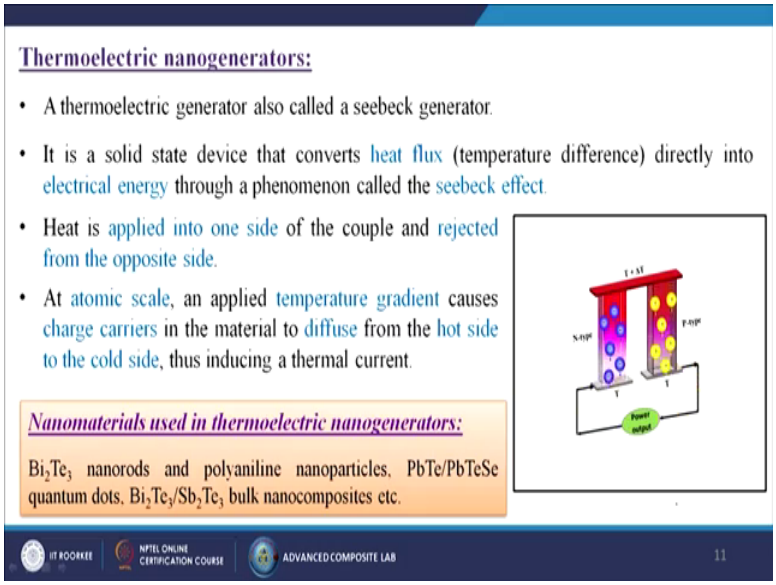

Next is called the thermoelectric nano generators. So, a thermoelectric nano generator also called as the seebeck generator because, the mechanism is called the seebeck effect. So, seebeck is the name of the scientist who has invented this particular effect. So, from his name we are knowing it as seebeck generator. It is a solid state device that converts

the heat flux temperature difference directly into electrical energy through a phenomenon called the seebeck effect. Heat is applied into one side of the couple and rejected from the opposite side. At atomic scale, an applied temperature gradient causes the charge carriers in the material to defuse from the hot side to the cold side.

So, this side is the hot side and this side is the cold side so now, thus inducing a thermal current. So, del T is nothing, but the we are giving the heat over there. So, what kind of nano materials basically we are using? Bi 2 Te 3 nano rods and polyaniline nano particles, lead tellurium, lead tellurium selenium quantum dots or maybe Bi 2 Te 3 Sb 2 Te 3 bulk nano composites. Now, we can see that simply we are adding different types of materials to make a combination so, that the efficiency can be increased. So now, next one is called the electromagnetic generators or maybe simple in this technology if we are able to add some kind of nano materials we can call it as a electromagnetic nano generators also.

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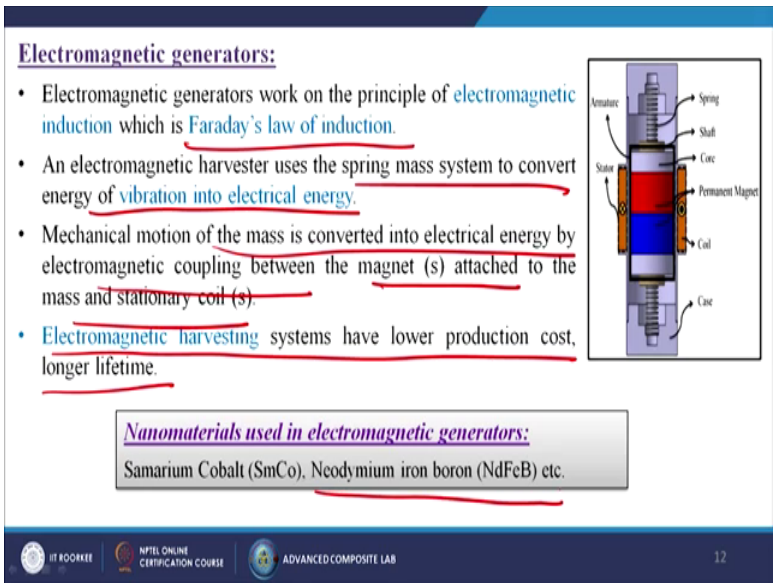

So, electromagnetic generator work on the principle of electromagnetic induction which is based on the Faraday's law of induction. And electromagnetic harvester uses the spring mass system to convert energy of vibration into the electrical energy. Mechanical motions of the mass is converted into electrical energy by electromagnetic coupling between the magnet attached to the mass and stationary coil. So, in this particular case

you can see that we are applying the permanent magnet over there and then we are having that coil.

So, simple we are generating the magnetic field over there, now it is having that spring. So, what the mass will do? Mass will go up and down so, automatically it will generate the electricity over there. Now, electromagnetic harvesting systems have lower production cost and the longer life time. What kind of materials? That samarium cobalt, neodymium iron boron etcetera basically nowadays we are using.

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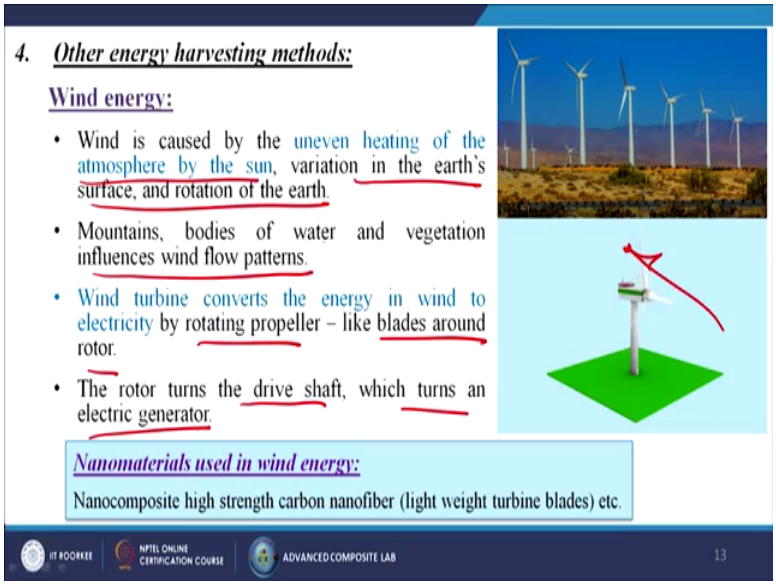

Next one is called the other energy harvesting methods. So, first is called the wind energy that is also a in a plenty of source basically we can get it, at the seashore or maybe at the top of the hill or maybe any kind of mountain. So now, how we are converting? Simple we are changing that wind energy into the electricity. So, wind is caused by the uneven heating of the atmosphere by the sun, variations in the earth's surface and the rotation of the earth. Mountains, bodies of water and vegetarian influence the wind flow patterns.

Because, at the seashore what is happening? So, water is getting heated up and the shore side that there is nothing. So, automatically there will be a temperature difference in between the water and water side and in between the solid or maybe the surface side. So, due to that the window will flow. So, when the window will flow automatically it will rotate this turbine blades over there, now through this turbine we have coupled the

generator. So, automatically the generator will rotate and it will generate the electricity over there.

So, simple by flowing of the wind due to the temperature change so, it is a automatic process and the continuous process itself. Wind turbine converts the energy in wind to electricity by rotating propeller like blades around the rotor, the rotor turns the drive shaft which turns an electric generator. So, basically what is happening? When the sea sides or maybe the normal mountain side also there are plenty of green trees or maybe we are doing the farming or maybe the vegetations. So, due to that what is happening? The temperature changes continuously taking place, due to that the wind is flowing from one side to the another, due to that your turbine blades is rotating and then we are generating the electricity.

So, basically it is known as the green technology. So, nano materials used in wind energy basically high strength carbon nano fiber for making that fan blades or may be the turbine blades which should be lightweight. And it should be non corrosive in nature and it should be high wear resistance because, every time the wind will pass through that particular blades. So, it should not be corrode or there should not any weight loss or maybe the material damage to that fan blades itself. Next one is called the tidal energy so, tidal energy from the name itself we can understand that basically we are putting this into some sea, where the tides are frequently coming.

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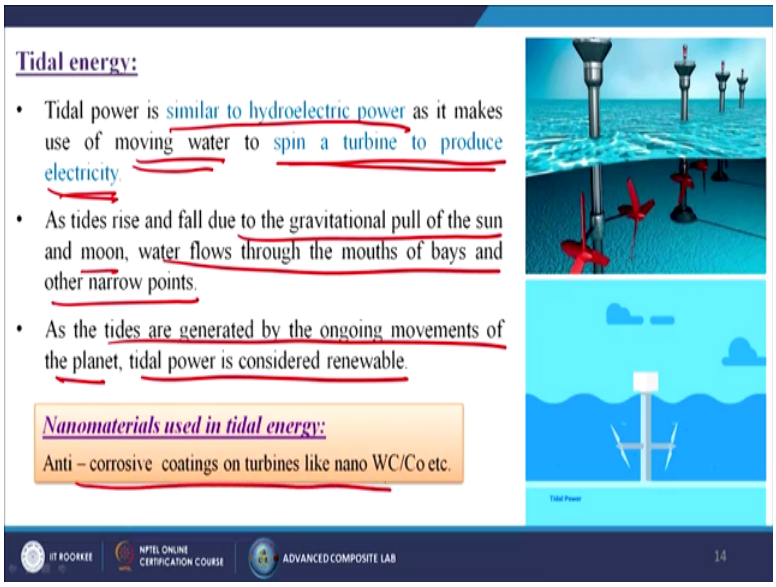

So, tidal power is similar to hydroelectric power as it makes use of moving water to spin a turbine to produce the electricity. So, as tides rise and fall due to the gravitational pull of the sun and the moon because in the night time basically it does by the moon itself and in the day times basically it runs by the sun or may be lesser power by the moon itself. So, water flows through the mouths of bays and other narrow points. So, in sometimes the water level is going to be higher or maybe some case lower.

So, automatically due to that the tides are flowing on to the system, as the tides are generated by the ongoing movements of the planet tidal power is considered the renewable energy source. What kind of materials basically we can utilize? We can utilize the anti-corrosive coating on turbines like in nano tungsten carbide or maybe the cobalt combinations or maybe some other kind of materials which does not have any reactions with the salt water or maybe which can work for a longer time. The material should have high strength so, that it can withstand that tidal energy. So, these all are the basically the requirements by which the people are choosing the materials and going for the better efficiency.

Next is called the geothermal energy. So, from the name itself you can understand that in our earth surface the temperature is something. When we are going to the down our temperature is going to be increased and not only that if we go to the centre of that earth we are going to get the maximum temperature at that particular point. So, basically what we are doing? So, in our earth under the earth or maybe the soil we are having plenty of heat energy. If we able to capture that heat energy through that we can able to generate the heat and if we able to flow the water through it. So, what will happen?

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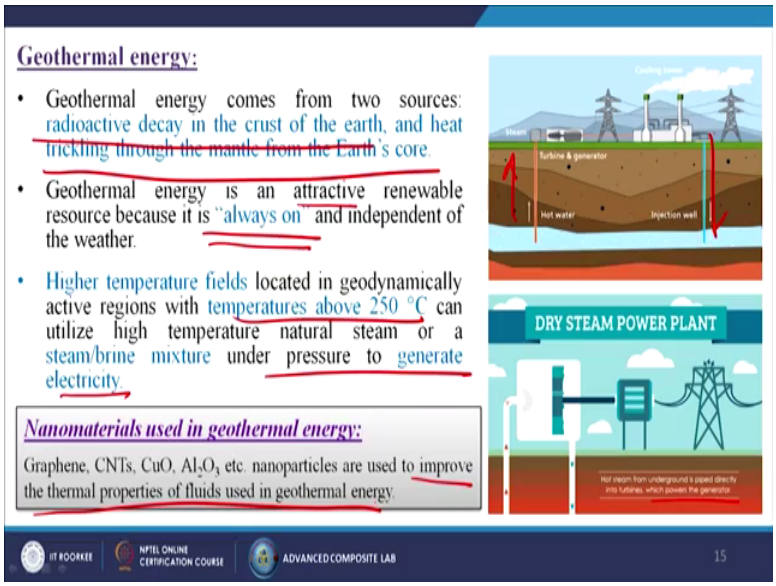

One side by injection well the cool water will go and another side the hot water will come. And the water when it will be heated up so, automatically it will be do the vaporization or may be the vaporize or may be it can generate the steam. So, if we are able to capture that steam by which we can rotate the turbine and through that we can generate the electricity by the generator itself.

So, now the geothermal energy comes from two sources; one is the radioactive decay in the crust of the earth another is the heat trickling to the mantle from the earth's core. Geothermal energy is an attractive renewable resources because, it is always on and independent of the weather. Higher temperature fields located in geo dynamically active regions with temperatures above 250 degree centigrade can utilize high temperature natural steam or a steam brine. Brine is nothing but, the some kind of salty water over there.

So, steam brine mixture under pressure to generate the electricity itself. So, in this particular case you can see hot steam from underground is piped directly into the turbines which powers the generator itself. Now what kind of materials? Basically graphene, carbon nano tubes, copper oxides, alumina etcetera; nanoparticles are used to improve the thermal properties of fluids used in the geo thermal energy.

So, whatever the water we are injecting inside it we are introducing this kind of nano fillers into the water system. So, that it can capture the more heat energy from the earth

surface and not only that it can with stand that temperature for a longer time. So, that the hot water will be very heated up and it can be able to generate the steam so, that continuously we can generate the electricity. Next one is called the thermal power plant energy.

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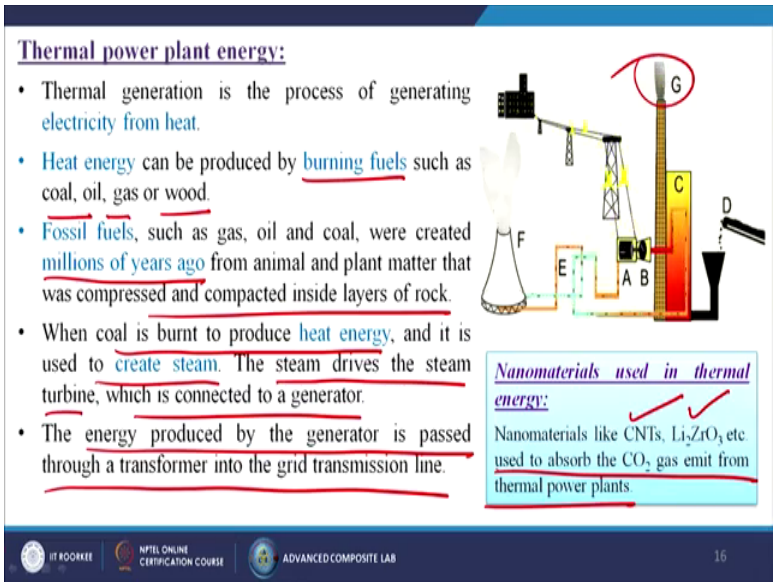

So, thermal generation is a process of generating electricity from the heat, but there is a problem. It is not good for the environment because we are burning some kind of petroleum products like coal or maybe some kind of oil which is generating the high heat over there. Due to that high heat we are heating the water to generate the steam and then we are generating the electricity.

So, automatically it is generating certain kind of toxic gases which is going to the environment. Not only that sometimes that coal particles very fine particles also come into the system or may be the environment which is not good for our health. Basically, heat energy can be produced by burning fuels such as coal oil gas or maybe the wood. Fossil fuels such as gas oil and coal were created millions of years ago from animal and plant matter that was compressed and compacted inside layers of rock. When coal is burnt to produce heat energy and it is used to create steam, the steam drives the steam turbine which is connected to a generator itself.

The energy produced by the generator is passed through a transformer into the grid transmission line. What kind of materials? Like carbon nano tubes, Li 2 Zr O 3 and used to absorb the carbon dioxide gas emit from thermal power plants itself.

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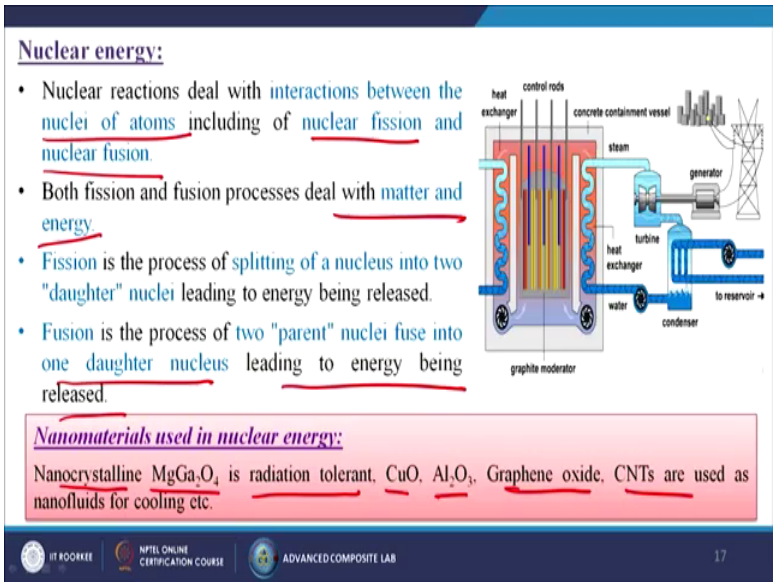

Next come to the nuclear energy; that means, we are using some kind of nuclear material to generate the temperature over there. So, nuclear reactions deals with the interactions between the nuclei of atoms including nuclear fission and the fusion. Both fission and fusion processes deal with matter and energy, fission is a process of splitting of a nucleus into two daughter nuclei leading to energy being released. So, in one case it is divided into two parts that is known as the fission and fusion is the process when two parent nuclei fuse into one daughter nucleus leading to energy being released.

So, one case it is divided into two parts another case the two parts is joint together to making the one. And they are both the cases they are releasing the energy itself. So, what kind of materials? Like nano crystalline MgGa 2 O 4 is radiation tolerant, copper oxide, alumina, graphene oxide, carbon nano tubes are used as nano fluids for the cooling systems itself. So, in this space particularly what is happening? This is acting as a energy generator so, we are having that control rods in which we are putting the nuclear materials over there.

So, continuous reactions is taking place and one side the cool water is coming and another side the hot water is going out. So, water basically is heated up into these

systems. So, cooling water is coming and just they are taking the temperature from here and the steam is generating then the steam is directly going to the turbine itself. So, till now we are discussing about the energy harvesting systems. Now, we are going to discuss about the energy storage systems.

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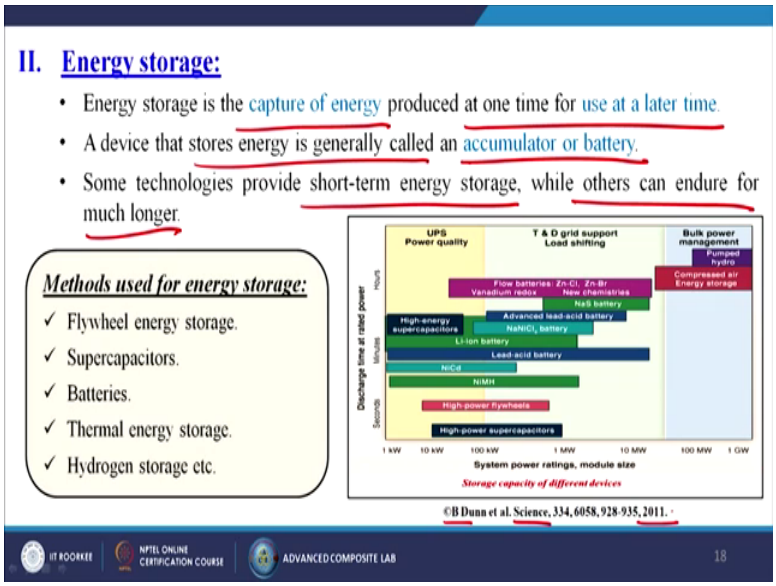

So, basically the energy storage is the capture of energy produced at one time for use at a later time. A device that stores energy is generally called as accumulator or maybe the battery. Some technologies provides short term energy storage, while others can endure for much longer. Now, there are also several methods are available for energy storage systems. One is called the flywheel energy storage, then supercapacitors batteries, thermal energy storage and the hydrogen storage systems.

Now, you can see by some scientist B Dunn who has published the papers in the Science in the year of 2011. He has shown as that how the energy generation is changing, earlier days when we are talking about the low energy storage systems. So, basically we are using the high energy super capacitors kind of materials, then after that we have moved to the grid output load shifting and last one is the bulk power management when we are talking about 100 megawatt to 1 gigawatt. So, basically you can see that there are several types of energy storage systems are available based on their capacity.

So, basically when we are talking about the super capacitor, it ranges from 1 kilo Watt to maximum 100 kilo Watt. So, what is that we can do it by the lithium ion battery, lead

acid battery, advanced lead acid battery, flow batteries. Flow batteries is nothing, but the it is also a one kind of material which is into the flowable conditions; that means, they are into the liquid state not into the solid state. Maximum cases we are using the solid state battery but, nowadays people are working on the flowable super capacitor or may be the flow able batteries. So, first is called the electrochemical energy storage which is nothing, but the batteries.

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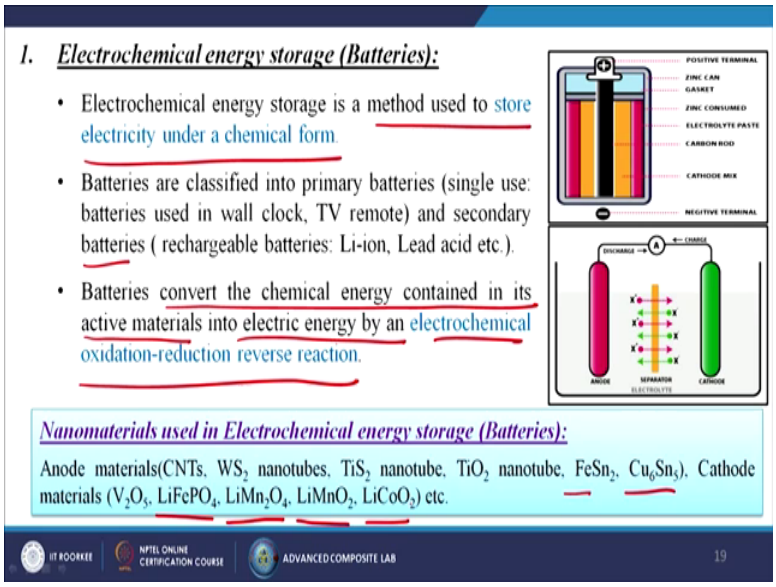

Electrochemical energy storage is a method used to store electricity under a chemical form. Batteries are classified into primary batteries that is single use as I told already. So, energy is already stored inside the system we are going to use it, when it will be finish we have through it out. There is no chance to use that particular battery for the second time. And the second one is called the secondary batteries which is nothing, but known as the rechargeable batteries like lithium ion, lead acid etcetera. Batteries convert the chemical energy content in its active materials into electric energy by an electrochemical oxidation reduction reverse reaction.

Nano materials used in electrochemical energy storage, what kind of materials? For anode materials we are using carbon nano tubes, tungsten disulphide nanotubes, titanium sulphide nanotube, titanium dioxide nano tube, FeSn 2, FeSn 2, Cu 6 Sn 5. For cathode material basically we are using the V 2 O 5, vanadium pentaoxide, then LiFePO 4, LiMn

2 O 4, LiMnO 2, LiCoO 2 etcetera. So, basically the chemical reaction is taking place and due to that we are storing the electricity. Next one is called the super capacitor.

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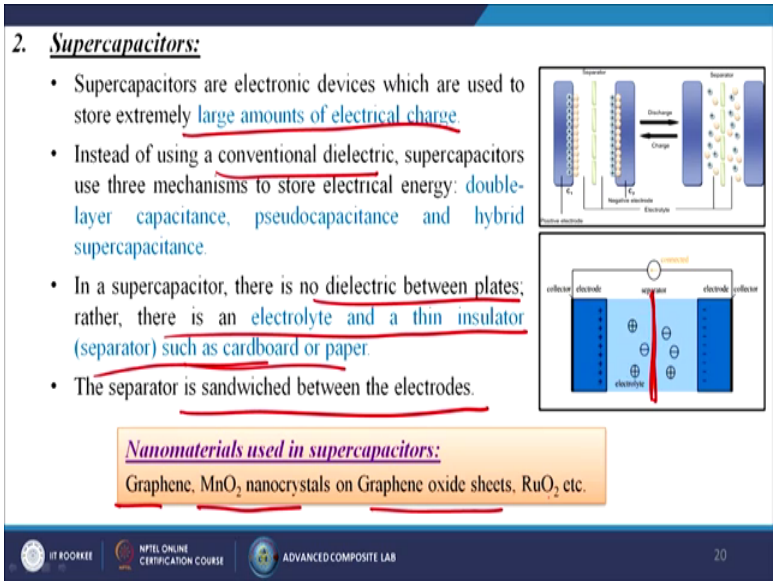

So, basically the super capacitor are electronic devices which are used to store extremely large amount of electric charge. Instead of using a conventional dielectric, super capacitor use three mechanisms to store electrical energy which is double layer capacitance, pseudo capacitance and another one is called a hybrid super capacitance. So, basically by these three mechanisms the super capacitor works. In a super capacitor, there is no dielectric between plates rather, there is an electrolyte and thin insulator which is nothing, but known as the separator; this one such as cardboard or maybe the paper. The separator is sandwiched between the electrodes.

What kind of nano materials basically we are using? We are using graphene, manganese dioxide nanocrystals on graphene oxide sheets then ruthenium oxide. So, these all are the material basically nowadays we are using.

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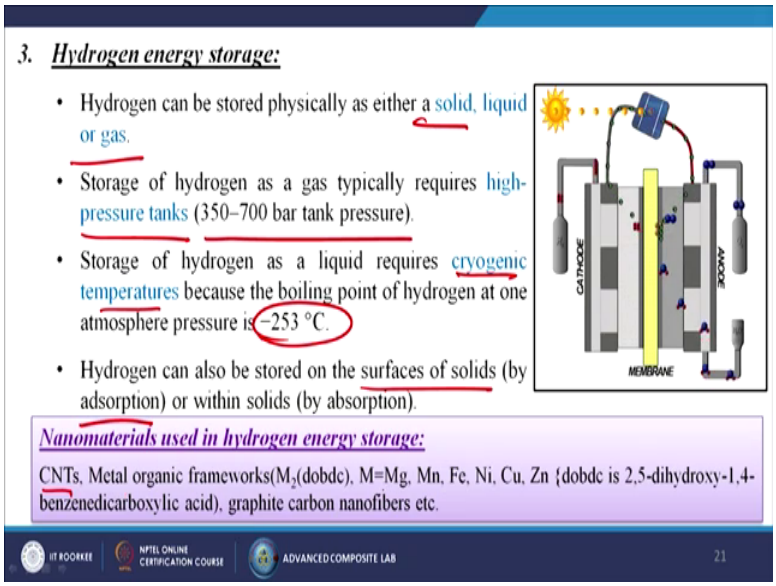

Next one is called the hydrogen energy storage, hydrogen can be stored physically as either a solid or may be liquid or may be the gas. So, nowadays people basically are using that people are trying to store the hydrogen as a solid materials. So, as and when it requires just give the heat or maybe load or pressure and simple convert that solid hydrogen into the liquid hydrogen or maybe the gaseous hydrogen. So, that we can be able to store the hydrogen in our near future. Storage of hydrogen as a gas typically requires high pressure tanks, that is also a one drawbacks for storing the hydrogen as a gas generally, 350 to 700 bar tank pressure requires.

Storage of hydrogen as a liquid requires cryogenic temperatures, because it goes up to minus 253 degree centigrade. Hydrogen can also be stored on the surface of solids by adsorption or may be within solids by absorption. Nanomaterials used in hydrogen storage systems is carbon nanotubes, Metal Organic Frameworks MOF's where M is nothing, but the magnesium manganese, iron, nickel, copper, zinc with some other materials. Other materials is this one and sometimes people are using the graphitic carbon nanofibers then graphitic carbon nano nitrides the g CN. So, these all are the materials nowadays people are using.

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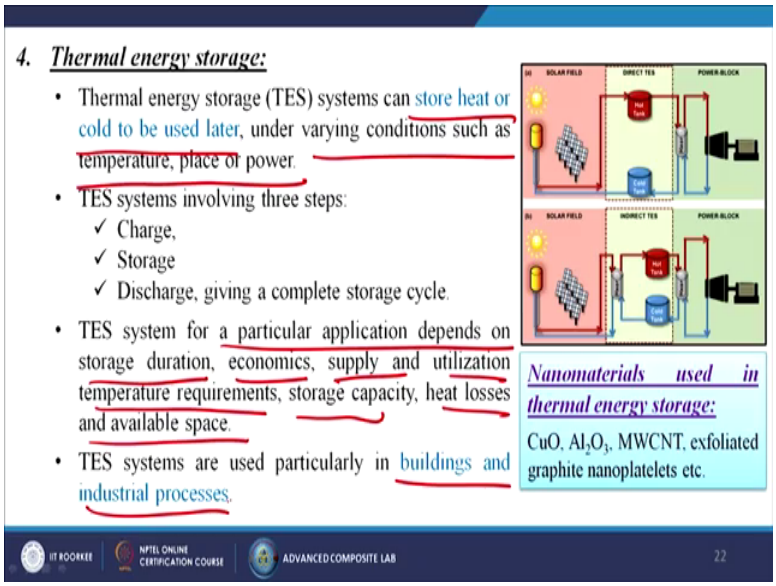

Next one is called the thermal energy storage so, basically the Thermal Energy Storage in short basically we are calling it as TES systems can store heat or cold to be used later, under wearing conditions such as temperature may be the place or maybe the power. TES also works on three different steps: one is called the charge, second one is called the storage and third one is the discharge or may be giving a complete storage cycle. So, TES system for a particular application depends on storage durations, economics, supply and utilization temperature requirements, storage capacity, heat losses and available spaces.

TES systems are used particularly in building and the industrial process. So, simple the temperature difference in between the two tanks: one is the cold and another one is the hot tank over there. So, automatically the water will flow from one side to another side and when the water will flow it will rotate the turbine and then through that we can generate the electricity. What kind of nanomaterials basically we can use?

We can use copper oxide, alumina, MWCNT: Multi-Walled Carbon Nano-Tubes, exfoliated graphite nanoplatelets or maybe some kind of other advanced kind of materials. Now, we can come to the last part of our lecture. So, in summary we can say that this is the introductory chapter of this particular lecture series, that is the nanomaterials for the energy harvesting and storage applications.

So, in this particular chapter we have shown basically that what the things we are going to cover throughout this particular chapter. So, basically first initial stage we are going to describe about the mechanisms by which we are going to generate the electricity or maybe storing the electricity or maybe the energy. And for doing those things what kind of nanomaterials nowadays people are using, how we are changing its efficiency, what can be the input parameters. So, that we can choose the nanomaterials and what can the modifications we can do so, that we can increase the efficiency.

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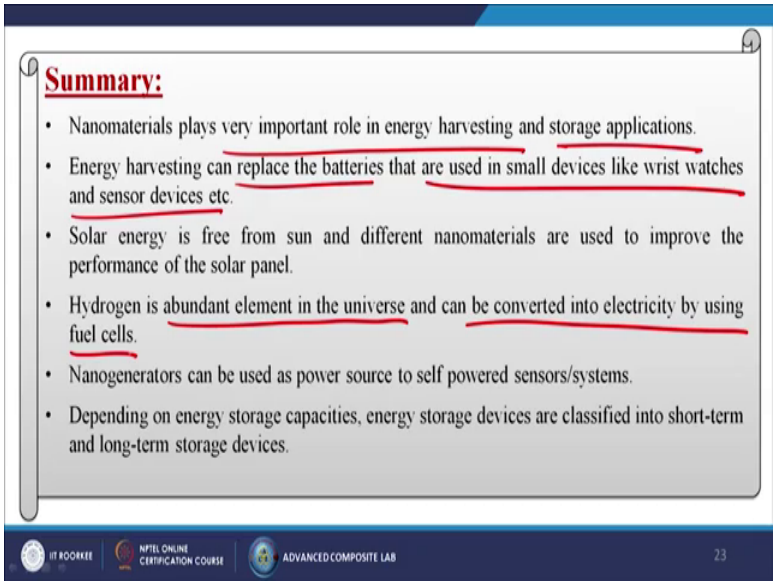

So, basically nano materials plays very important role in energy harvesting and storage applications. Energy harvesting can replace the batteries that are used in small devices like wrist watches and sensor devices. Solar energy is free from sun and different nano materials are used to improve the performance of the solar panel. Hydrogen is abundant element in the universe and can be converted into electricity by using fuel cells. Nano generators can be used as power source to self powered sensors or may be the systems. Depending on energy storage capacities, energy storage devices are classified into short-term and long-term storage devices for the short span of time or may be the long span of time.

Thank you.