Physics of Renewable Energy Systems
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Lecture 21
Thermal Energy Storage

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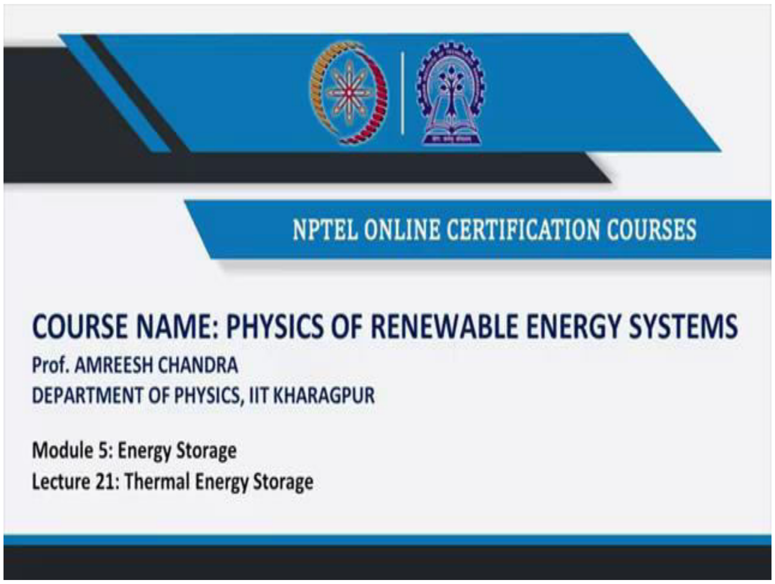

Welcome again to a new lecture on the course where we are dealing with the Physics of Renewable Energy Systems. In the previous lecture, I gave you an introduction towards the need of energy storage technologies, why do we need energy storage technologies in most of the renewable based energy landscape and we are also going to use these energy storage technologies in various other applications.

You have already seen that electrical energy storage such as batteries and supercapacitors are extensively used in mobile technologies. But there are various types of energy storage technologies which were presented to you in the previous lecture. We had talked about the sub-classifications such as thermal energy storage, chemical energy storage, mechanical energy storage and electrical energy storage. And in today's lecture, let us start with our discussion on thermal based energy storage systems.

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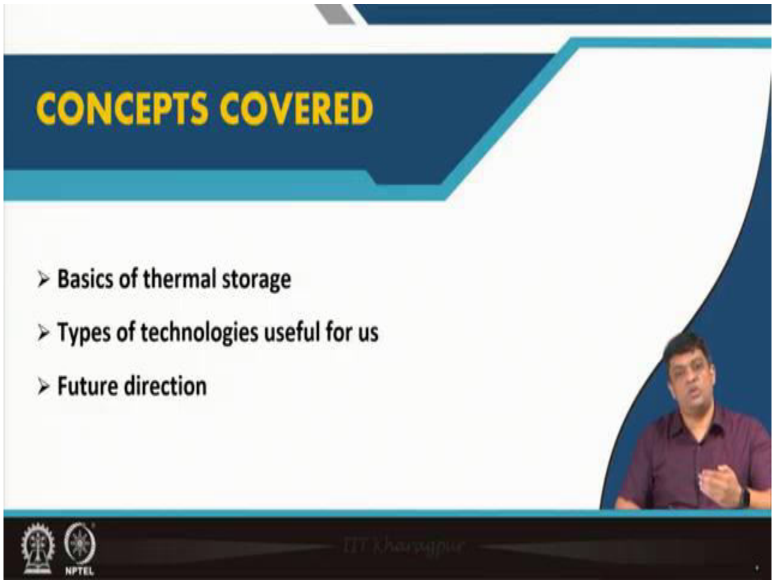

Today, I would like to cover these three concepts. We will spend most of the time in this lecture in building the knowledge about the basics of thermal energy storage systems. There are various types of energy storage systems and different scientists, researchers or even countries are promoting various types of thermal energy storage technologies, but we should talk about the technologies which are going to be useful for us, that is for Indians. And by the time I finish this lecture we will also like to give you the future direction where this technology is headed towards.

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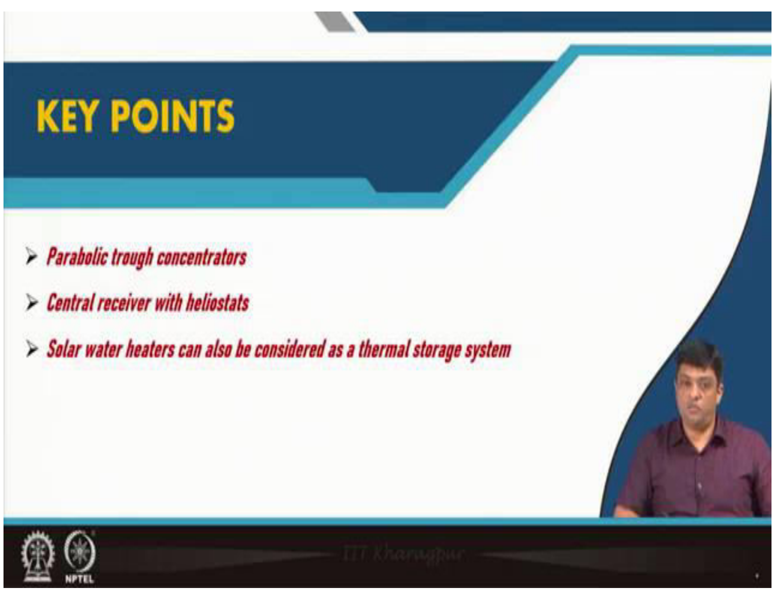

Hopefully, you will understand the construction, working and also develop interest to develop or fabricate some of these thermal based energy storage systems. We will talk about parabolic trough concentrators. You will see they are very easy and the physics involved is also very easy is just the engineering aspect which has to be tackled carefully and then these parabolic trough concentrators are quite easy to install and use. We will also talk to you about the central receiver with heliostats attached to them and how they are working as thermal based energy storage systems.

You will see that the topic which we covered in module 3, where we had talked about solar based systems, we had talked to you about solar water heaters and these solar water heaters can also be considered as a thermal storage system. This I had also mentioned in that lecture where we said that you can consider the solar based water heaters as also storage technologies. So, that concept will become furthermore clear to you after the discussions that will be made during this lecture.

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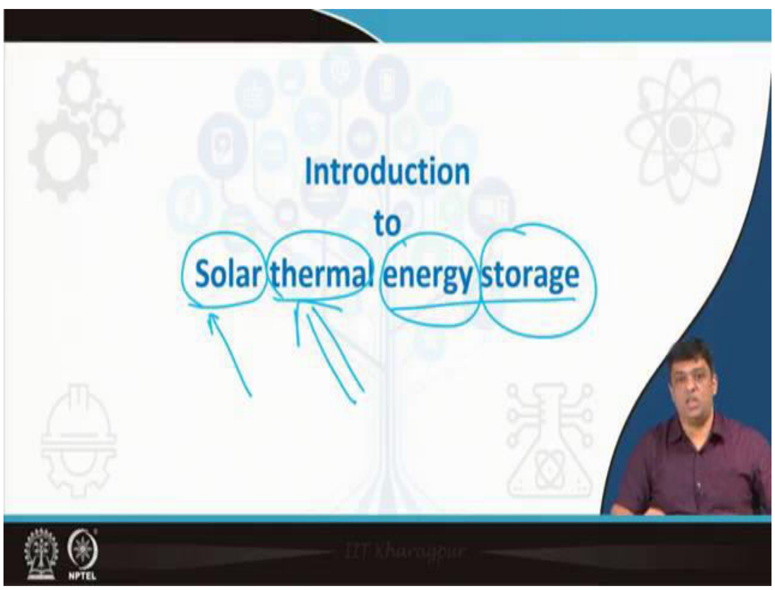

There are various types of energy storage technologies. This is clear by now. Now, the moment I say solar based thermal energy storage technologies, there are two words which are indicating at this very moment the direction which we are heading towards in today's lecture. What does it indicate? It clearly indicates that we are going to use solar energy.

What is the second term indicating? The second term is indicating that probably we are going to talk about the strategies where we modulate the temperature and by the variation in the temperature we reach to a condition where we say that the whole system is now acting as a storage for energy.

So, at this very introductory title slide I think you will be understanding what are we going to do. We will use solar radiation, heat the system and then store the energy. These are the things which we are going to talk for next couple of minutes or 10 to 15 minutes when we are talking about the details about the technologies.

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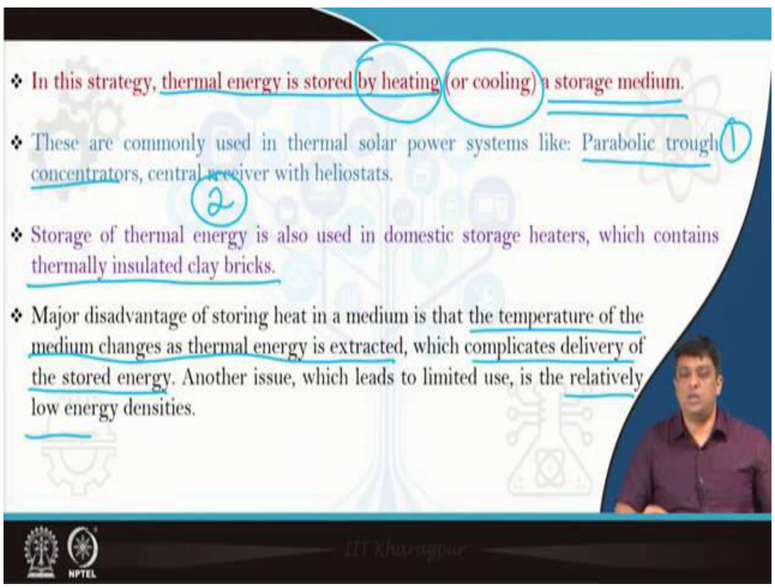

So, in this strategy, as I mentioned, a thermal energy-based system is used to store energy by heating or cooling a storage medium. These are commonly used in thermal solar power stations such as number one parabolic trough concentrator and the second is the central receiver with heliostats. So, we will also talk about these two systems in detail.

In the earlier modules, we have already talked about the storage of thermal energy using what, we had talked about using solar based water heaters. You can also use technologies to store thermal energy for various other domestic storage heaters and these are primarily using thermally insulated clay bricks. They are simple to design. They are simple to understand. They are simple to fabricate. But there are certain limitations which are still restricting the large-scale use.

If you are able to counter these limitations, you will be able to have simpler designs, but with higher efficiencies, whereby making this technology more viable for this societal and industrial use. The major disadvantage of storing heat in a medium is what is that the temperature of the medium changes as the thermal energy is extracted. So, what do we mean?

So, you have heated the medium, but when you are going to use this stored thermal energy what are you going to do, you are going to extract this energy. And when you extract this energy, this complicates the whole process and leads to losses, be it be related to the thermodynamic properties, be it be related to the transmission or any other issues related to conduction, convection, radiation losses. So, there are various losses which come into picture. And this complicates the delivery of the stored energy to the end user.

Along with that, the storage is such that the energy densities are still relatively low. Relatively low with respect to what? Relatively low with respect to the other technologies which we will be talking about later, such as mechanical base energy technologies or even electrical or chemical based energy storage technologies compared to them, the energy densities of these thermal based storage technologies are much lower and that is another disadvantage which needs to be kept in mind while designing the whole system.

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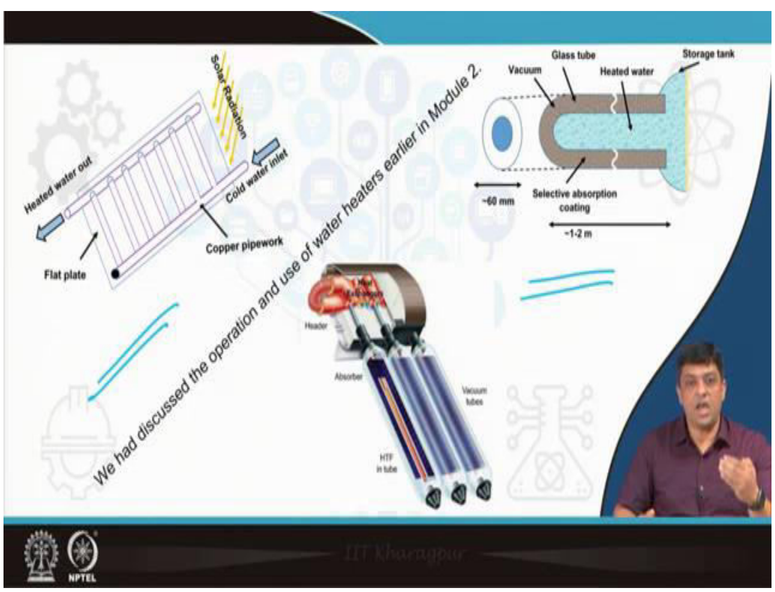

Earlier, we have seen three kinds of thermal storage in terms of water heaters. We had seen the flat plate, we had seen the vacuum tube collectors and we had also seen the thermal exchangers.

So, we had seen these kinds of heaters which were used. And what were they storing, they were leading to the storage of hot water in a tank. We had seen that the losses had to be minimized and for that the design of the storage tank was very critical.

We had also seen that if the fluid which you were heating was reaching to very high temperatures, then you were using heat transfer fluids to carry the heat and then maybe transfer that heat to the fluids such as water which can be used in water heaters. So, that those technologies were also forms of thermal based energy storage systems. So, keep that in mind.

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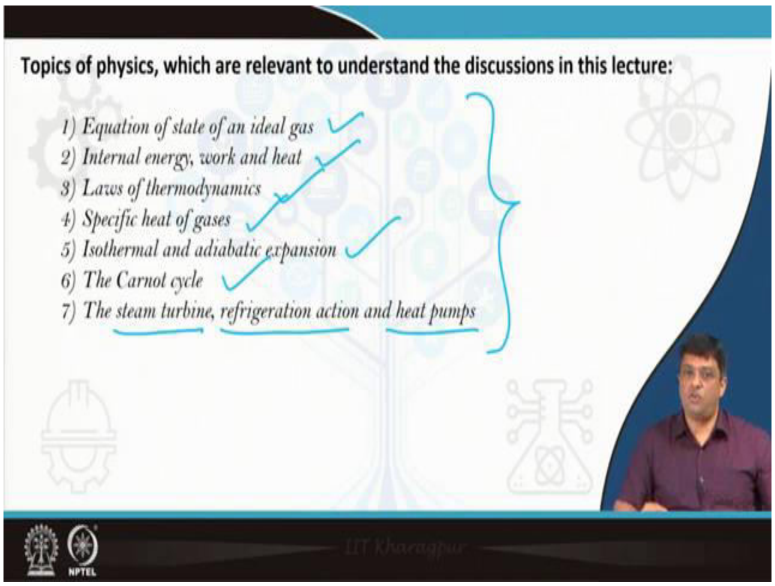

As we have been proceeding in all the lectures, before we start the topic in detail, we talk about the laws of physics which are very relevant to these technologies and how physics is contributing in the field of energy. For today's lecture, it will be clear that the topics which would be relevant are the following; the first equation of state of an ideal gas. You need to heating up the fluids, then you talk about the internal energy, work and heat principles.

The whole process is thermodynamically controlled. And therefore, the laws of thermodynamics become critical. As we talk about the exchange of heat, therefore, specific heat of gas is important. The moment we talk about the system that means it is being heated and then you are extracting the heat you are talking about processes and there you are going to use the concepts of isothermal and adiabatic expansion.

The moment you have the concepts of isothermal and adiabatic expansion immediately the whole cycle that is the Carnot cycle is becoming critical to understand and then implement its consequences to determine the efficiency of the system. As we said, solar based systems, what are you going to do?

You are going to use the solar energy to store this energy either by heating or by cooling the system. Hence, you are going to talk about steam turbines or refrigeration action or heat pumps. So, the basics of thermodynamics once again become extremely critical if you want to make the solar based energy technologies or solar based energy storage technologies useful for end user.

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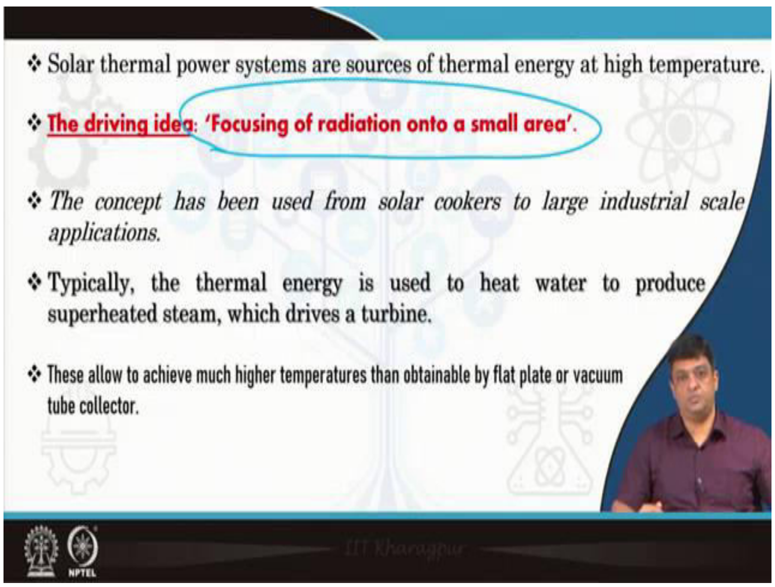

The driving force in the technologies which we are going to discuss now is, you collect the radiation and then focus it at one point. So, you collect from various places and if you concentrate at one point, then the temperature can be made to increase rapidly and then the fluid may be heated. So, focusing of radiation on to a small area is the driving force behind what we are going to discuss in next two applications after this slide.

The concept has been used from solar cookers to large scale industrial applications, you must think about it and how you have been using it. Typically, the thermal energy is used to heat water to produce superheated steam which drives a turbine. I will ask you a very simple question. You need to produce superheated steam and you have solar radiation. Now, just by solar radiation falling on water do you see the production of superheated steam? I do not think so.

So, what you can do that increase the temperature of a smaller area and then you can produce superheated steam. And for that what will you do, you have to focus a lot of solar energy at one point. The moment I say that you focus a lot of solar energy at one point, there comes the use of the driving force. Behind this idea, you need to focus radiation onto a small area so that you can increase the temperature and by increasing the temperature you will immediately be able to produce superheated steam, which will then drive the turbine.

The moment I am talking about the operation of a turbine what are we going to get we are going to probably talk about the generation of electricity simple as that. This concept allows you to achieve much higher temperatures than you had talked about while you were talking or discussing about the production or heating of water using flat plate or vacuum tube collectors. There you were just heating the flat plate and the tubes, but you were not concentrating the heat at one place and there the reason was that you were not going to produce steam there only you were, you going to use water heaters for domestic use.

But now I have to talk about the production of superheated systems or production of superheated steam which will drive the turbine and hence I need to go to higher temperatures, and therefore, that can be achieved by increasing the temperature. I have repeated few things a couple of times, because this concept should be clear at this very moment before we produce the details of this technology in front of you.

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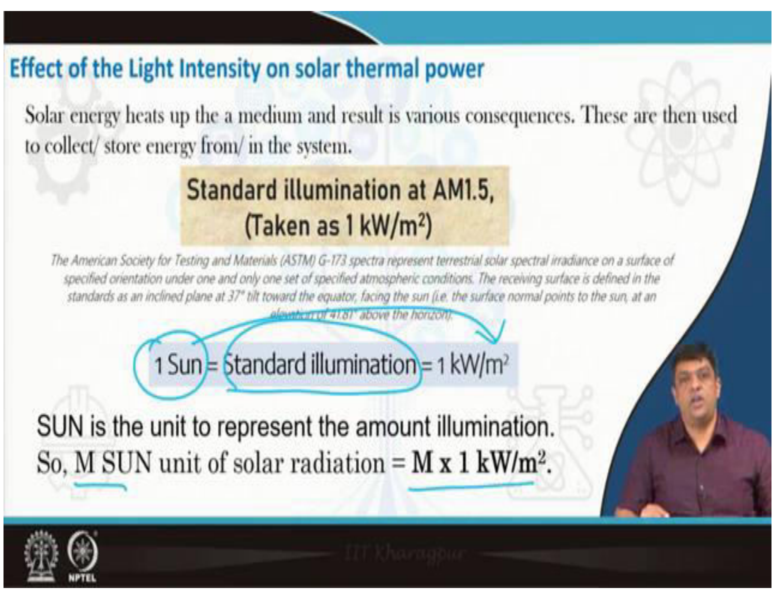

Before we move to the actual design, please remember that all these discussions will be based on the condition where we are talking about the AM 1.5, air to mass 1.5 condition which is at under this solar radiation irradiance condition, we take that you have 1 kilowatt per meter square irradiance and this is sometimes written as the term 1 Sun which is the standard illumination and therefore 1 Sun equals 1 kilowatt per meter square.

So, if somebody says that you have 1 Sun illumination then what are we talking about? We are talking about that per meter square you have 1 kilowatt of illumination. So, M Sun means you have solar radiation equals to M into 1 kilowatt per meter square that is what we are going to use.

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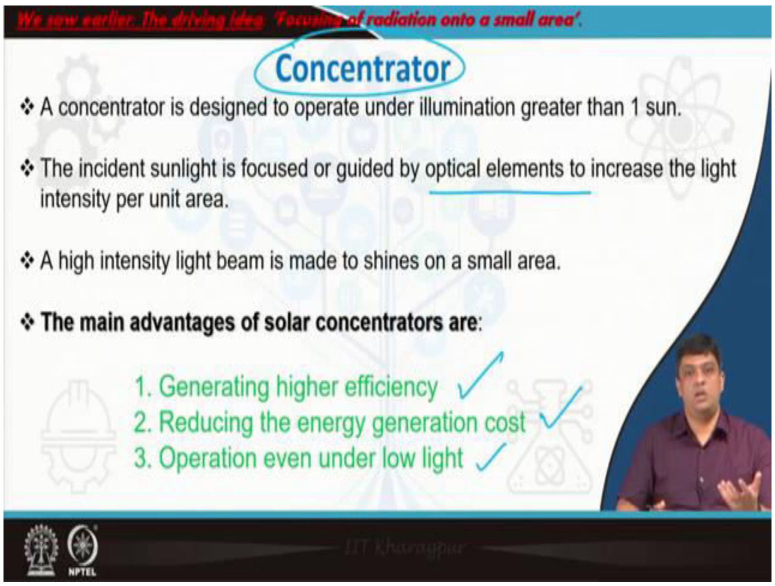

Now, we have been repeating this point for the last 5 minutes that you will be focusing, you will be focusing radiation at one point. If you have focusing at one point, the concentration at that point would increase and hence, you have the concept of concentrators. This concentrator is designed to operate under illumination greater than 1 Sun. So, obviously, if you are focusing lot of radiation at one point the illumination will increase and then you are talking about illumination which is more than 1 kilowatt per meter square, because you are collecting from surroundings and then focusing at one point.

What is the reason? The reason is the incident sunlight is focused or guided to that point. Now, how do you want to guide that solar radiation at a particular point? This is obtained by using optical elements those can be mirrors of various shapes. Immediately I have introduced the concept shapes. And in the next slide, if I say parabolic solar concentrator, I think it will become clear to you that the shape of the optical element or the mirror is most probably in the form of a parabola. So, optical elements are used to focus light onto a small area.

The main advantages would then become, you will be able to have higher efficiencies, reduce the energy generation cost and because you are focusing light from different areas to small area, it means that most probably you will be able to operate the whole system even under low light condition and that is a massive advantage which comes when you are using solar concentrators and you will find in many of the institutes you have solar based concentrators already installed.

You can see in IIT Madras, you can see in places in IIT Kharagpur, and there are many more such institutes where such concentrators have been installed and lot of research is going on to improve the efficiencies and also designing so that you can reduce the size of the concentrators without losing on the advantages.

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Collectors are of different shapes and forms as I mentioned. You can have Fresnel lens. This comprises of concentric rings that are placed at different angles and this results in light falling on any ring is then focused at the same point.

The second is the parabolic trough concentrator or the collectors. These are fabricated using trough that is covered with a highly reflective surface. This surface leads to focusing of sunlight onto a small receiver or onto an absorbing fluid and the shape of this collector is parabolic.

Another design which is becoming quite prevalent is the central receiver or power tower. Here, you use simple mirrors, but they are so installed that there are two axis tracking mirrors. What does these mirrors which are installed on these two axes do? They actually move with the sun so you are having the tracking. So, you are also using the concept of trackers or solar trackers. These kinds of mirrors are known as heliostats.

What do they do? They reflect the sun rays towards tower mounted thermal receiver. So, you have mirrors which are moving. They are, so either they can be moving in horizontal axis or along the axis of the plane in which they are installed. So, with this motion, they actually are able to focus the light on the tower and there you have a receiver that receives the heat and you, that heat can be transferred to a heat transfer fluid or to water or molten salts and then that receiving fluid or salt is stored at a higher temperature and when you want to extract the heat then you let the system to transfer this heat to the turbine and then generate the electricity.

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So, let us start with the first topic that is the parabolic trough concentrator. It is a high temperature concentrator which is working above 360K with the capacity of tracking the sun using one axis of rotation.

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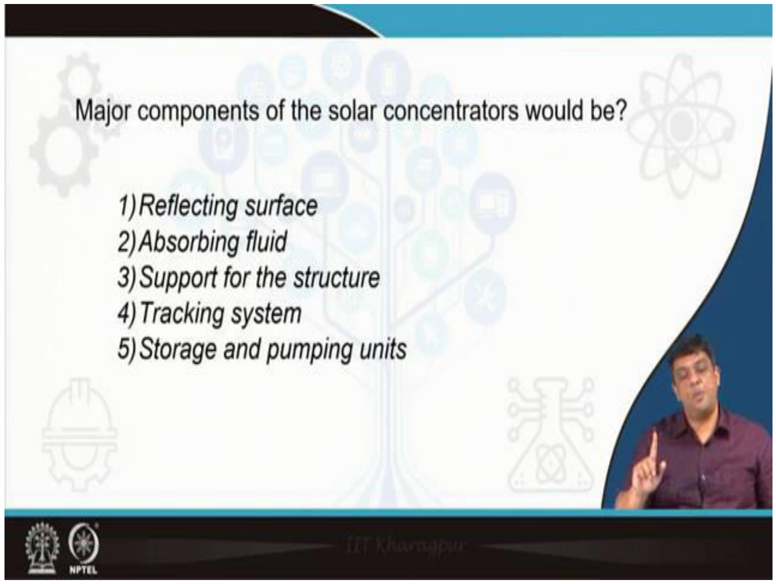

Major components of the solar concentrators would then be, you would have the reflecting surface, the absorbing fluid. Where would you install the whole structure? You cannot just let it lie on the ground. So, they have to be properly installed on a support structure which can also be used to have the inbuilt capacity of tracking the solar radiation that is the movement of the sun.

Hence, you will be having additional component that is the tracking system. Finally, you have heated a fluid and then you need to store it, hence you will have a storage system and also the pumping units which would then transfer the heat from one point to the other.

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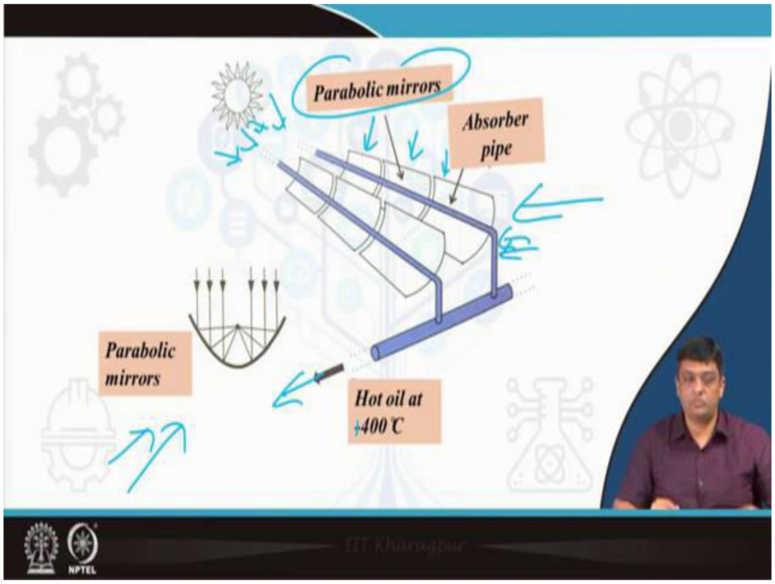

This is a typical design of a parabolic trough concentrator. You can clearly see what are they made of? They are made up of parabolic mirrors. Now, these parabolic mirrors are going to receive the sun rays and then focus the radiation on to the absorber pipes. So, they will focus the radiation on the absorber pipes.

If you have the oil or the fluid which is going to receive that heat and transfer it, then that heat will get heated. In this case, let it be hot oil and this hot oil is then heated up to 400 degrees and it can move towards the storage facility. So, parabolic mirrors receiving the heat, you have the absorber pipe at the focal points or if you have large number of parabolic mirrors then you are going to have these mirrors with same focal points, otherwise your focusing would be lost. Simple design, absolutely simple.

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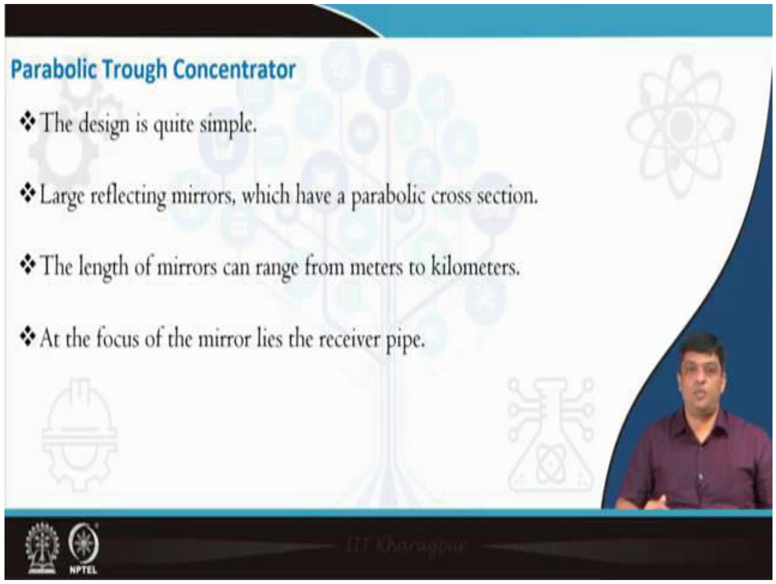

As I said, design is quite simple. You need large reflecting mirrors so that you can collect lot of solar radiation. These mirrors have a parabolic cross section. In reality and they have been actually investigated and installed in various test fields, the length of the mirrors can range from meters to kilometers if you are drawing the parabolic mirrors. And at the focus of the mirror lies the receiver pipe.

Can you please immediately think about the limitations? Before I list them, I would ask you that do not go to the next slide and just think it over. What is the major limitation? The major limitation would be that all the parabolic trough concentrators would have to be the ones with same focal or focus. Is it easy? You are talking about reflecting mirrors which are meters or kilometers in length and then you are talking about each and every curvature so designed that the focal point is the same for all the mirrors that is where the engineering comes into picture.

I have a parabolic shape and then now I need to cover them with extremely high reflecting materials or you have to have this inner surface which is extremely reflecting surface. So, you have to ensure that the coating of the internal surface with the reflecting material is uniform, but how do you ensure the coating of these reflecting materials on these flexible or the substrates which have been designed in the form of a parabola. So, these are the limitations, I guess, you will be able to immediately think when you think about the operation of these systems.

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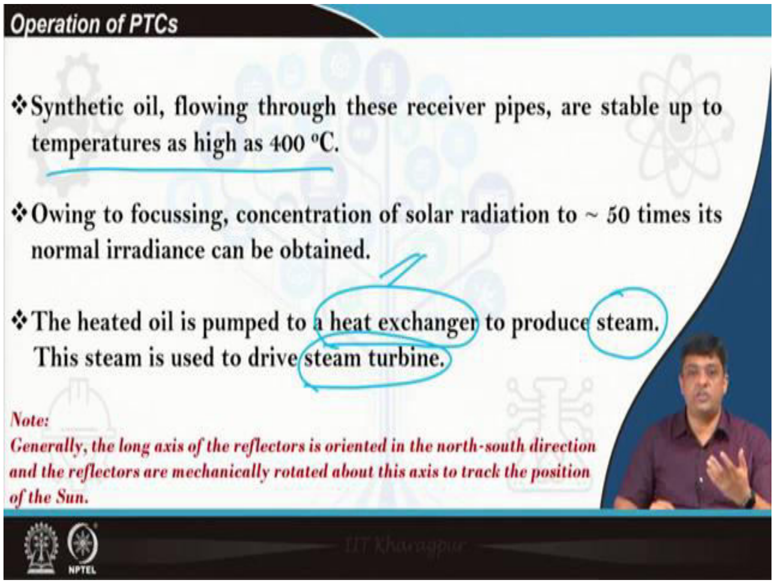

In addition, you will have to use heat transfer fluids which can sustain very high temperatures. Here we have talked about the use of synthetic oil which is flowing through the receiver pipes. And why are we talking about the use of synthetic oil, because they are stable up to temperatures as high as 400 degrees.

You clearly understand now that because of the concentration you can have much higher irradiance at a small area than compared to what you had in the initial condition if you are not focusing the solar radiation onto a small area. Once I have designed everything, I have heated the oil, what are we going to do? The heated oil is pumped to a heat exchanger. What is this heat exchanger going to do? It is going to produce steam. The moment I have super saturated steam production, this can easily drive the steam turbine.

So, the overall design is very simple and it is the engineering aspect which comes into picture. You will find that most of the research activities in the field of solar concentrators are therefore being pursued in departments of mechanical engineering in various institutes.

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The next design which actually looked into the limitations and then said, let us reduce the size of the mirrors, let us remove the condition that we have to have a parabolic mirror and talk about the use of mirrors such as the flat mirrors and also the size of these individual mirrors are much smaller and that is called a central receiver with heliostats, the mirrors. These are heliostats mirrors.

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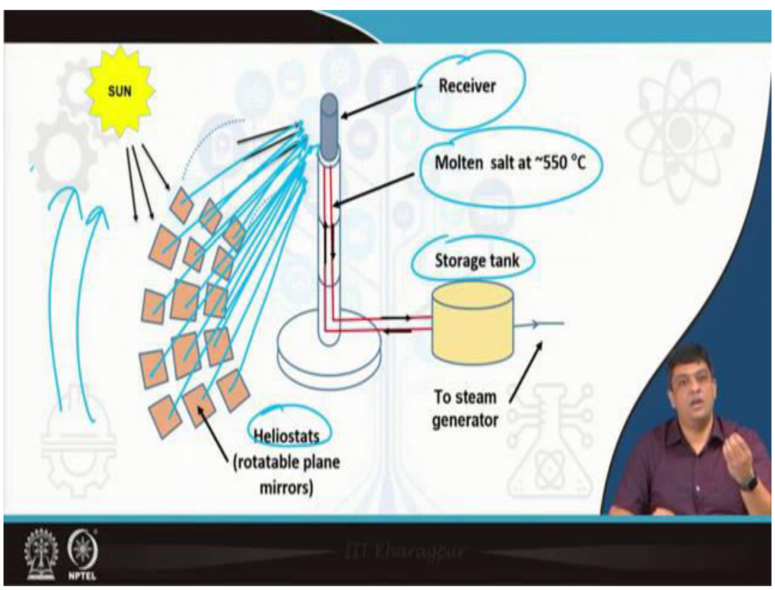

This is a typical schematic used to explain the operation of central receiver based on heliostats. You have heliostats, the plane mirrors, which can track the motion of the sun. So, you can track the motion of the sun. What are these mirrors going to do? They have to be so made that they, all these mirrors will reflect the solar radiation towards the receiver. This is what you are going to.

So, you have two types of motion, one in the horizontal axis and then along the plane. So, you also have the tracker, while the mirrors have to be rotated so that the focus of these mirrors is such that all the rays are hitting the receiver. Because you have a large number of mirrors, the irradiance is much higher, and therefore, you will reach to very high temperatures. If you reach very high temperatures, you have to use the heat transfer fluids which are able to sustain such high temperatures, and hence, you generally use molten salts.

Once you have these heat transfer fluids or materials, you heat them and then store it in a storage tank. Once this is stored, you have to generate electricity what you will do, you will use the stored heat, transfer it to the fluid which is going to produce the steam and that steam will then drive the turbines in the generator and you will be able to receive the output, and what is the output, you have the electricity as the output.

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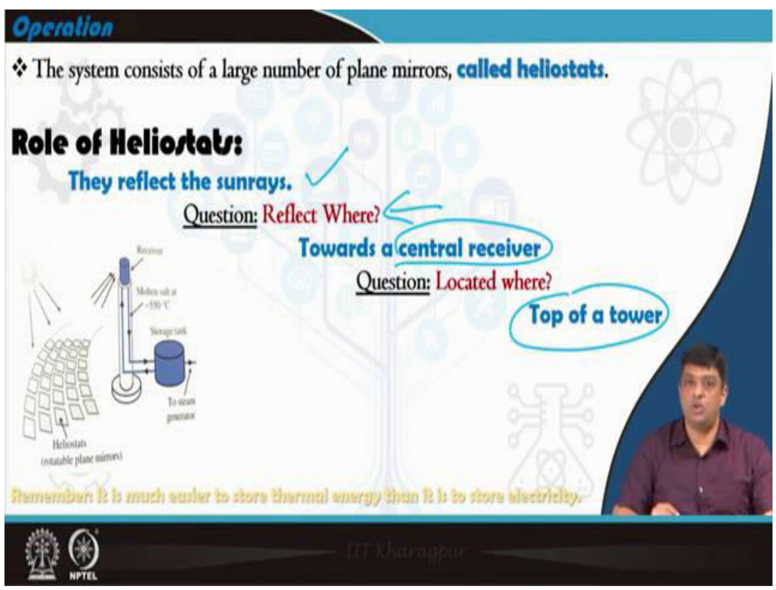

Hence, the role of the heliostats become critical, because they reflect the sun rays. Where do they reflect the sun rays? They reflect towards the central receiver. Where is this receiver located? At the top of a tower, and hence the name central receiver heliostats. Why this technology is becoming so useful, because it is much easier to store thermal energy than it is to store electricity.

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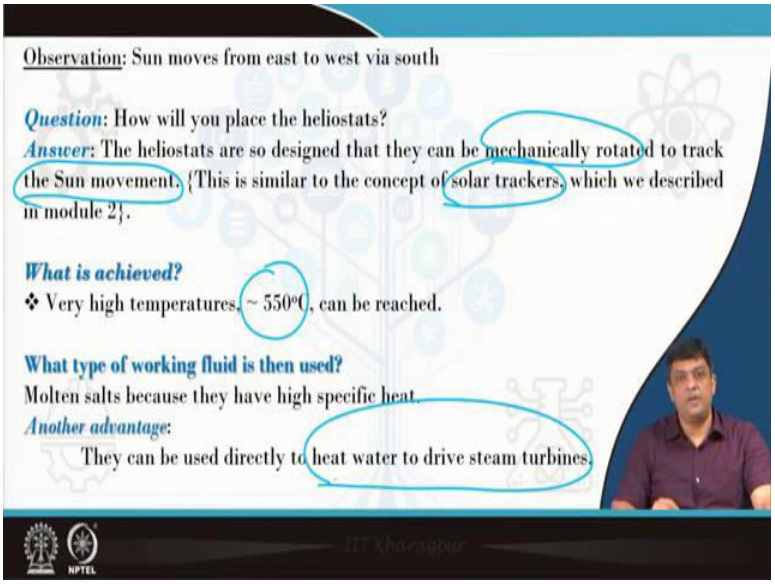

We know sun moves from east to west via south. What will you then be looking at? You are talking about how will you place these heliostats. You will place these heliostats so that they can be mechanically rotated to track the sun movement. This is the similar concept of solar trackers which we have discussed in module 2 and 3.

Because of this tracking, you are able to continuously focus the solar radiation onto these receivers. You can obtain very high temperatures. Because of this, you need to use the suitable heat transfer fluid or material. These can then be directly used to heat water and production of steam that will drive the steam turbines. Hence, you have to choose the heat transfer fluid very carefully.

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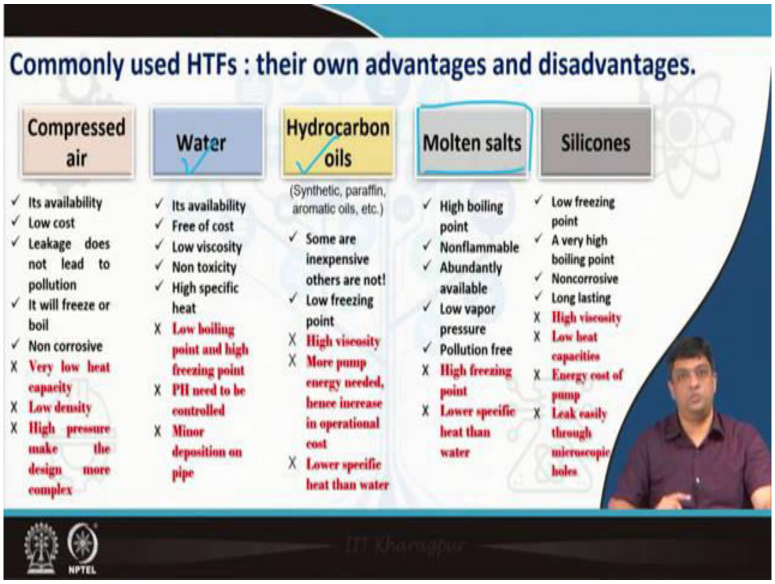

This is the same slide which we used in module 3 when we were talking about solar heaters, where we had talked about the use of water and hydrocarbon oils and we had said that the use of molten salts should not be ignored because there are technologies which are also based on solar and are using molten salts quite regularly. And I hope that sentence is now much more clear to you.

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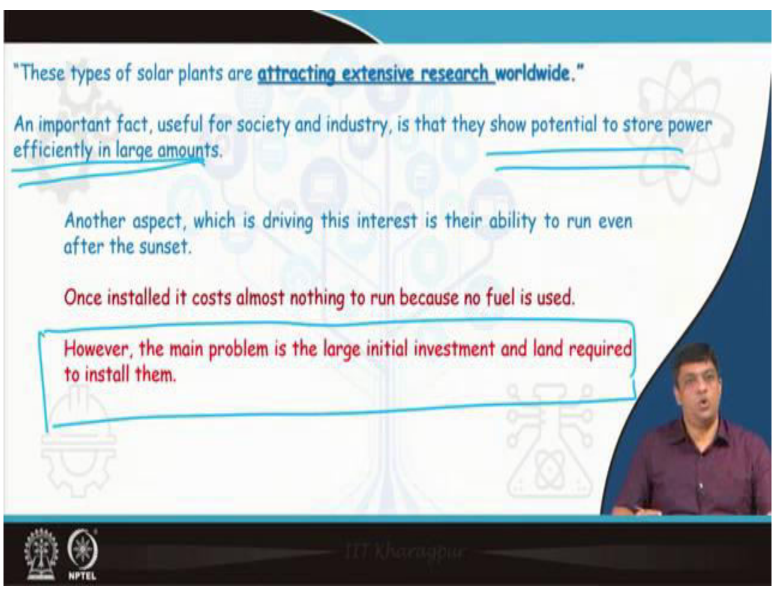

These types of solar plants are attracting extensive research worldwide. The fact that is driving interest both in society, in academia or in industry is that these technologies have the potential to store power efficiently and also in large amounts. They are able to operate even under low light conditions. That is very important. Once installed, the maintenance cost is low and the running cost is also quite minimal.

The major disadvantage which is still there is because of the size of the mirrors and the associated tower or the generator units. In many countries where line is not available for any kind of use, they are quite premium, the problem comes in that you have to have large areas where these technologies can be installed. And also, the initial investment is quite large.

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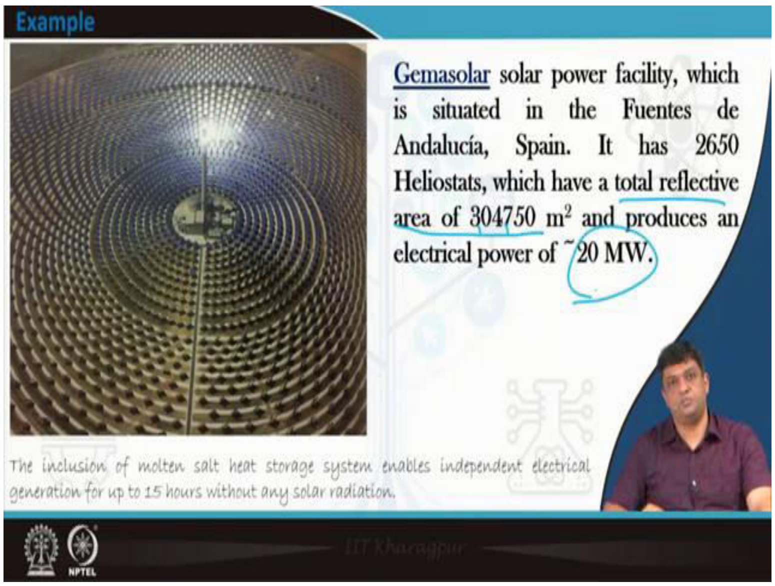

These are some of the examples which are there and are being used. For example, the Gemasolar in Spain with a total reflective area of more than 304750 meter square, is able to produce electrical power in the order of 20 megawatts.

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You have other examples. You have the Solar One in California or you have PS20 solar plant in Seville, Spain. And you can see the kind of area which is used to develop this power station and that one of the major limitations.

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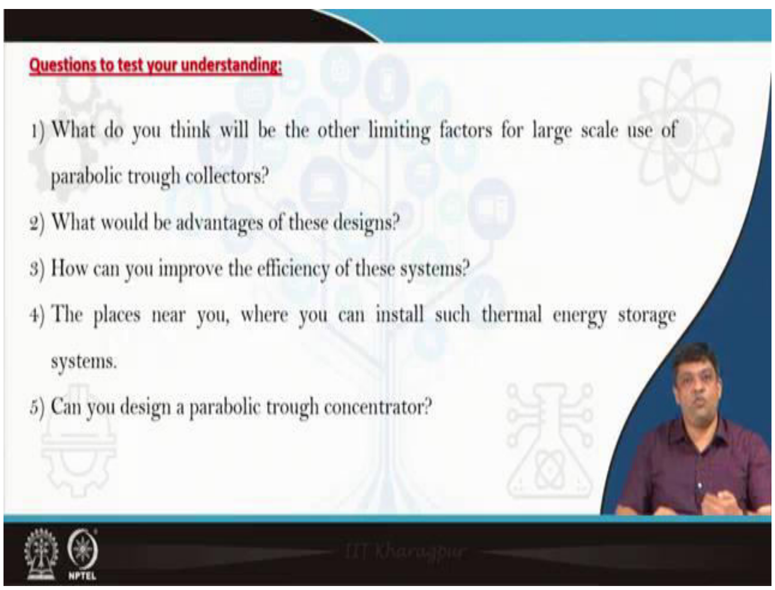

Let us ask some fundamental questions at this point to just to check how much we have understood in today's lecture and you can write the answers and see whether the answers are correct by revisiting the slides where these points were discussed. What do you think would be the other limiting factors for large scale use of parabolic trough concentrators? What would be the advantages of these designs?

Let me give you a hint. Can you install at various places, can you install on the roofs, can you install in desert area or can you install in one of the areas in villages or other places which are let us say at a corner and not routinely used by the villagers, can you efficiently use that land and area. Think it over.

How can you improve the efficiency of these systems, the thermodynamics, Carnot engine kind of heat transfer processes? And if these systems are so easy, can you pin point some of the places which are near you and those are the places where you can propose as the sites or installation of such trough concentrators.

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These are the major references which were used in today's lecture.

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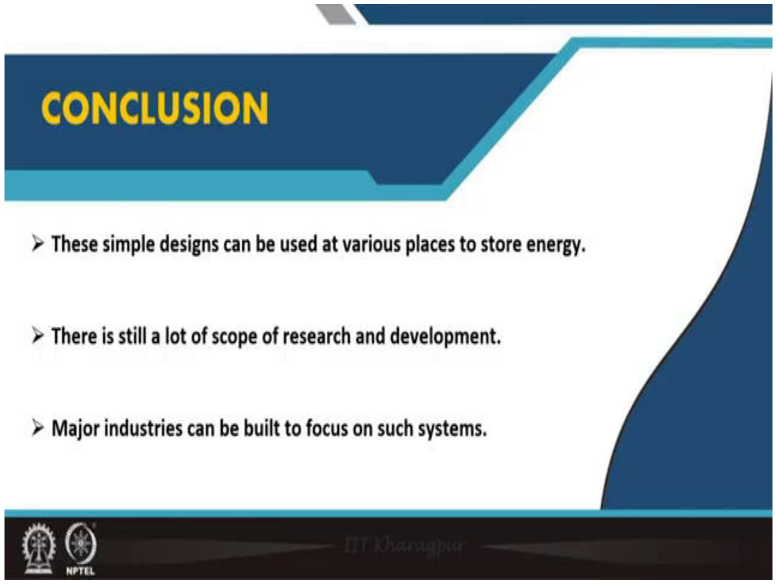

And hopefully you have been able to understand that whole process and also realize the fact that these are very simple designs. They can lead to highly efficient storage systems. But there is a large scope of further research and development. If we are able to do that, then even in our own country major industries can be built to focus on such systems.

I thank you for attending today’s lecture. And in the next lecture we will move to the next classification of the energy storage technologies, and that is the mechanical based energy storage technologies. Thank you very much. Have a nice day.