Solar Energy Engineering and Technology
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Lecture 27
Concentrating collector technologies and working principles

Dear students, today we will be discussing about different solar concentrating technologies and principle which are used for power generation.

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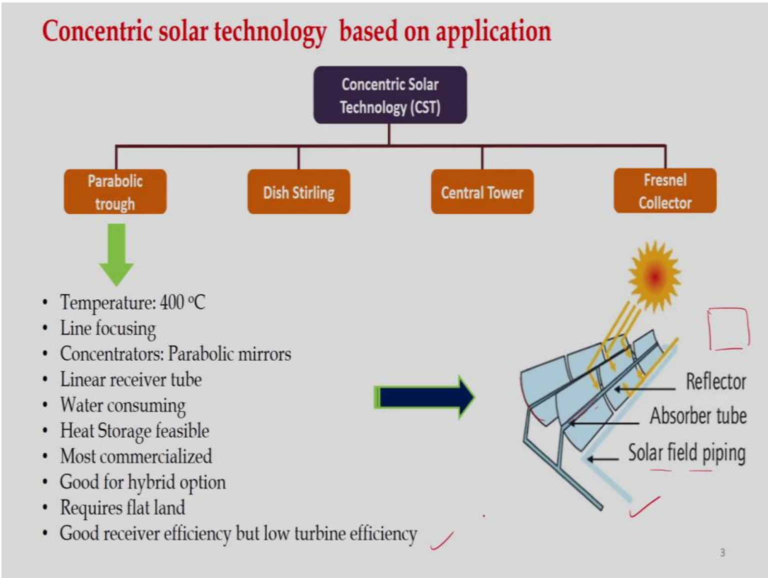

So, we have technologies like parabolic trough, dish stirling, central power receiver system, Fresnel collectors. So, if we talking about parabolic trough, as you can see, this is a configuration for a parabolic trough. It must have a reflector, this component is reflector, then absorber tube, then solar field piping. And, if we apply this kind of technologies, we can get a temperature of the fluid is about 400 ^{o}C and these kind of devices use line focusing system.

And concentrators are parabolic mirrors. As you can see, these are the concentrators, these are parabolic mirrors. And these are linear receiver tube. And this kind of system, it consumes lot of water, because sometimes water is also used as heat transfer fluid. Of course, some thermic fluids are used in most of the cases. And heat storage is feasible, because heat can be collected and we can have independent storage and that can be used as per the requirement.

And this technology is one of the most matured technology and commercially available technology. And this technology is very good for hybridized option. We can hybridize with other technologies, but it requires flat surfaces or flat land, so that this can be focused to a particular focal point on that particular surface. And it is a good receiver efficiency, but low turbine efficiency in this kind of arrangement. Let us study more on it.

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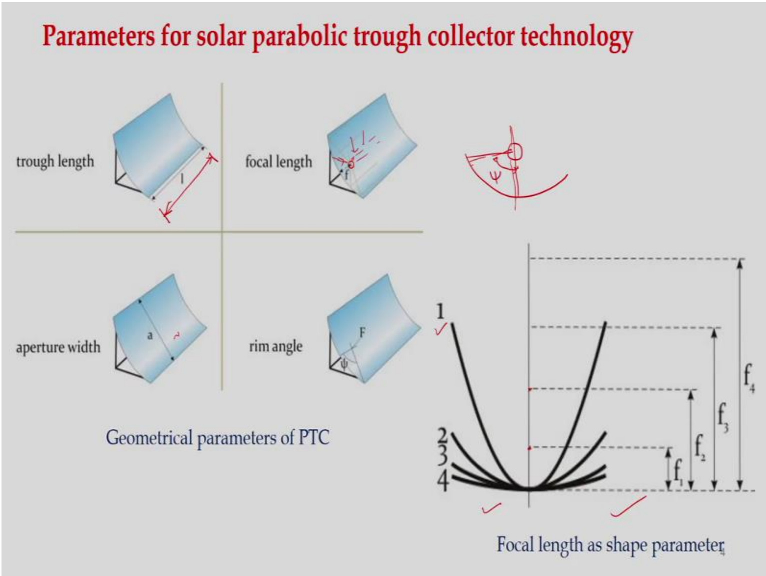

So, there are parameters for solar parabolic trough collectors. So, here we must know, what is trough length; already we have analyzed this system, we are already aware, but still I am emphasizing, some of the important aspects. So, this is the tube or trough length. And focal point is known here. So, solar radiation falls here and it will direct to this receiver system. So, this is an axis. In that axis, all the radiation will be received, after reflecting from the reflector. And we have the aperture, this is the aperture width, sometimes we represent in W.

So, this a is the aperture width. And rim angle, if we draw it something like this, and if we make this trough, so if we go to outer, outermost part and if we take this half of the trough, and this is nothing but rim angle. So, sometimes represent this ψ. And what you can see here, so if we use different arrangement, then we can have different focal points. So, for this kind of arrangement, say arrangement 1, so you can see, this focal point is here. For arrangement 2, this focal point is here. So, we can take the appropriate decision what kind of focal length is required, based on these devices used for reflecting the solar radiations.

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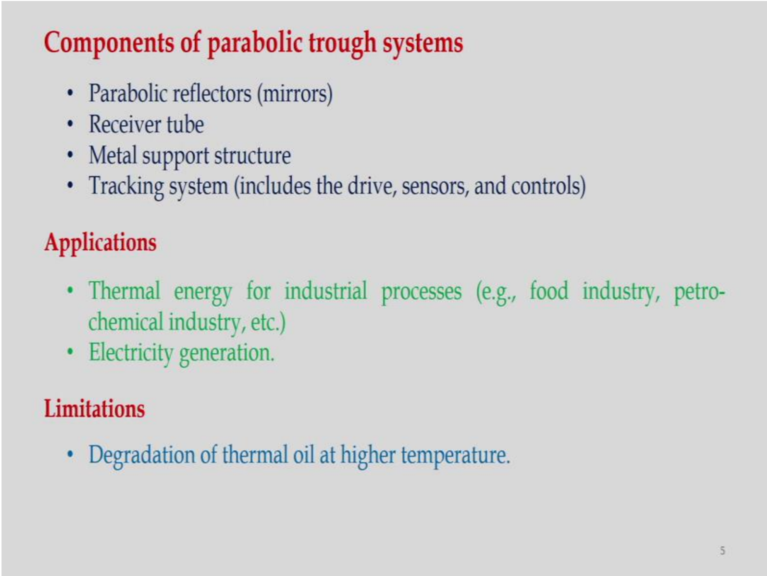

Now, what are the different components of a parabolic trough system? So, it has got mirrors or parabolic reflectors, then receiver tube, then metal support structure, then tracking system which includes the drive, sensors and control. And what are different applications of this kind of systems? So, we can use for generation of thermal energy for industrial processes, may be that can be applied in food industries, petro-chemical industries, or any other kind of industries.

And of course, we can use this kind of concentrator for electricity generation. Only limitation is, when we use thermic fluid, that fluid degrades with temperature. So, if we have to operate the system for a long with the same heat transfer fluid, so it degrades its capability or heat capacity.

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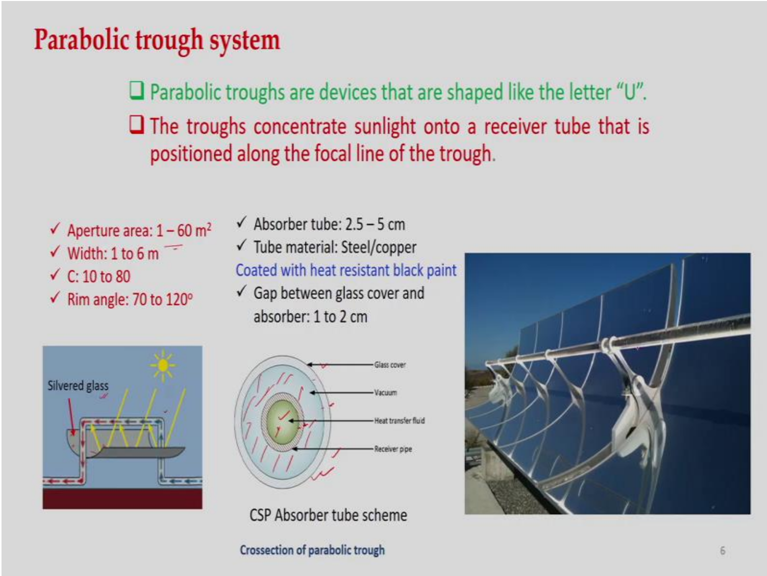

So, these parabolic troughs are devices that are shaped like U, letter U. The troughs concentrate sunlight onto a receiver tube, that is positioned along the focal line of the trough. So, as you can see, so this is the trough and solar radiation is falling in this concentrator and is reflected to this receiver where heat transfer fluid is flowing. So, initially what you can see, this is a blue line and finally what you can see, its a red line. So, that means temperature is increasing from inlet to the outlet.

So, this is the inlet, this is the outlet. And normally these reflectors are made of silvered glass to increase the reflectivity. Now, if we talk about this aperture area, normally this area varies from 1 to 60 m^2, it is a very large area. And width is 1 to 6 m, so this width is about 1 to 6 m. And this concentration ratio varies from 10 to 80. And rim angle, what we have defined, it varies from 70 to 120.

So, if we talk about this absorber tube now, so in this absorber tube, diameter varies from 2.5 to 5 cm. And tube material is normally steel or copper. And these tubes are coated with heat resistance black paint. Sometimes selective coating is also applied to increase the absorptivity of the solar radiation. So, in modern parabolic troughs, selective coatings are applied, which gives higher conversion efficiency. Normally, this gap between this glass cover and the absorber plate varies from 1 to 2 cm.

As you can see, so this is the absorber plate or absorber tube. And this is the glass cover, it is got thickness. In between, this is vacuum to reduce the heat losses. So, heat transfer fluid flows through this tube, and this is the inner diameter of the tube, this is the outer diameter of the tube. And this is for glass cover. So, sometimes, glass covers are not used, but in order to increase the efficiency, this kind of glass cover is very-very essential. So, this photograph shows the actual installation. So, this is, these are the tubes, these tubes are connected and this is the reflector.

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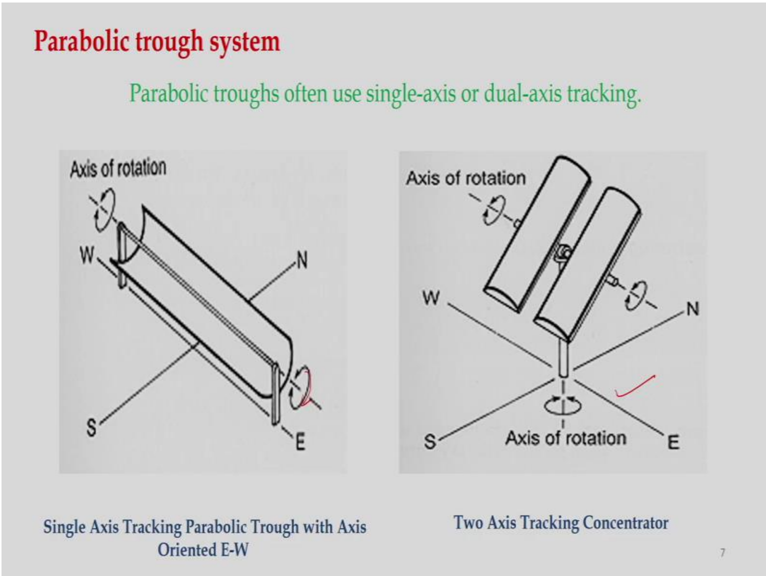

And in case of parabolic trough system, it maybe single-axis or maybe double axis or dual-axis tracking. So, we need to track the sun. So, this structure is rotated to track the sun, or if we are doing very precise calculation, or we want to capture all the solar radiations very-very efficiently, we have to go for dual-axis tracking or double axis tracking. So, arrangement of dual-axis tracking is something like that. So, at the bottom also, we can rotate and this side also, we can rotate, so that we can maximize the absorption of solar radiation.

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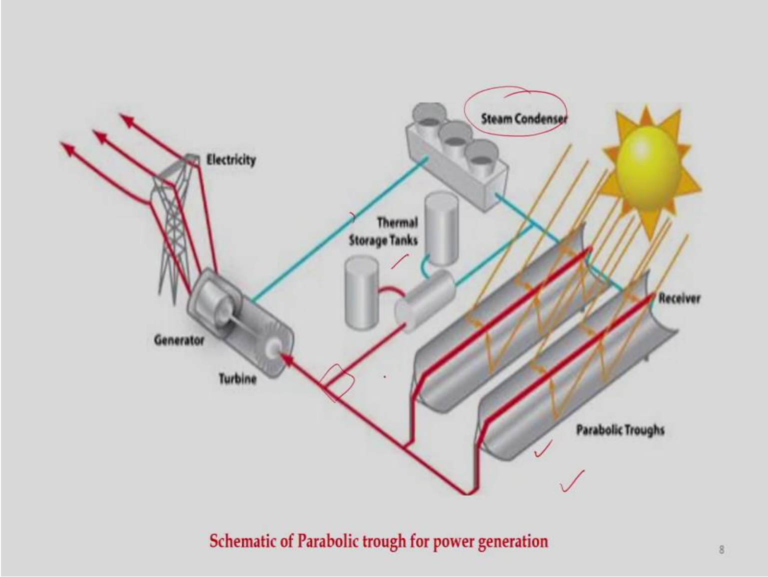

And this is a plant, how solar radiations can be used for heating the fluids and then that heat can be used for expanding in a turbine and we can generate electricity. We can couple a generator with a turbine shaft. So, if we use water, then straight way, the water will be at a very high temperature and that can be expanded in the turbine and we can generate electricity.

And then eject which is condensed and we have to do some kind of condenser, or we have to use some kind of condenser. Of course, we need some kind of tower, cooling tower. Once it is cool, then same fluid can be injected again to heat by using this solar energy or parabolic trough concept. So, we can use storage devices as well, when we are producing more energy. Then that can be stored and whenever required, that can be delivered.

So, this is the principle of working, by which this water can be also used as a heat transfer fluid for generation of electricity with the help of this parabolic trough concept. Of course, we can use other fluid, say thermic fluid, so then we need to use some kind of heat exchanger here. Then this will work in a close loop, with water. And this will work in a close loop which work on thermic fluid.

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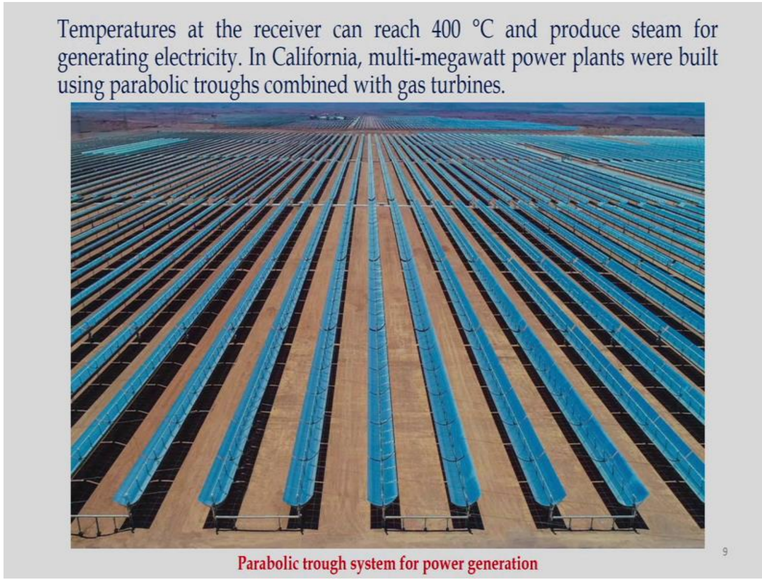

So, this picture shows about the installation of a parabolic trough system for power generation. As you can see, it has a flat surface and you see, how these troughs are installed. So, we can generate the fluid temperature at about 400 ^{o}C. So, that will produce steam and then we can generate electricity.

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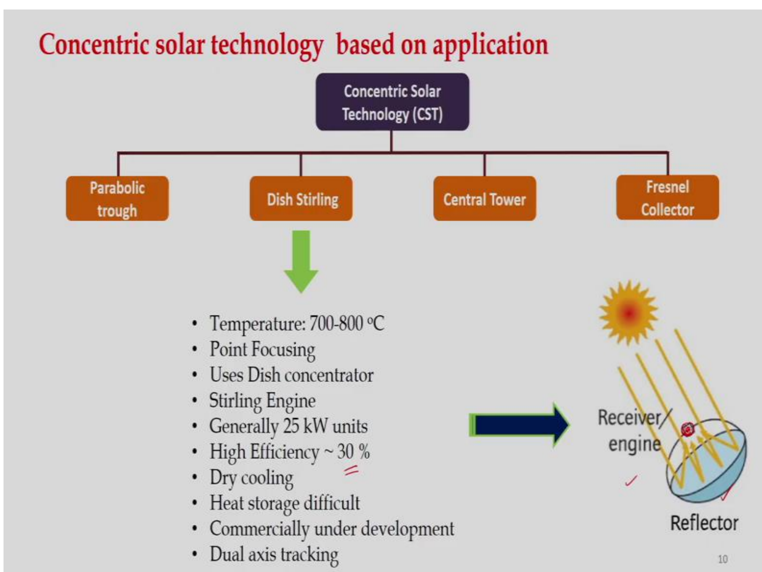

Now, come to the next technology called dish stirling. So, this kind of dish is used and solar radiation falls here and then it is concentrated on this point. This is the focal point. So, this is reflector and this is a receiver or engine. So, some different kind of engines are used, like external combustion engine or stirling engines are used here. So, in this technology, temperature can go up to 800 ^{o}C, and it is a point focus system, because it is pointing to a single point.

And this technology uses this concentrator, as you can see here, and of course stirling engines need to be used. And it provides an output of about 25 kW per unit. Single unit can be designed for generation of 25 kW. And its efficiency is quite high, it is about 30 %. And dry cooling arrangement is there in the receiver system. And heat storage is difficult, because this is a very single point.

So, it is very difficult to accommodate more number of devices. So here, engines are installed and then electricity can be generated. Of course, there are other arrangement if we look for some firm of this technology, then that has to be collected. And finally one engine will be there. So, this heated fluid will go to the engine, then engine will generate electricity. And this technology is commercially under development. And here dual-axis tracking is mandatory.

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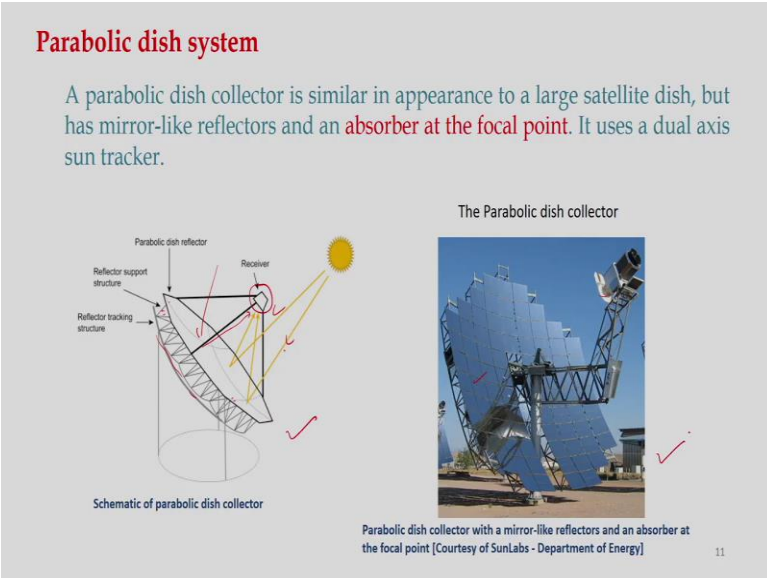

So, this parabolic dish collector is similar in appearance to a large satellite dish, as you can see here. But has mirror like reflectors. So, these are the mirrors. So, what you can see in this picture is a mirror like reflectors. And an absorber at the focal point. So, this is the absorber here. So, this is the absorber here or receiver here. So, of course, it has to use dual-axis tracking.

So, this is the receiver and this is parabolic dish reflector, solar radiation falls here, which is reflected to this point. So, as you can see here. And reflector support structure is here. And this tracking mechanism is here. So, it has to track in two axes mode. And, this figure shows the installation of a parabolic dish system.

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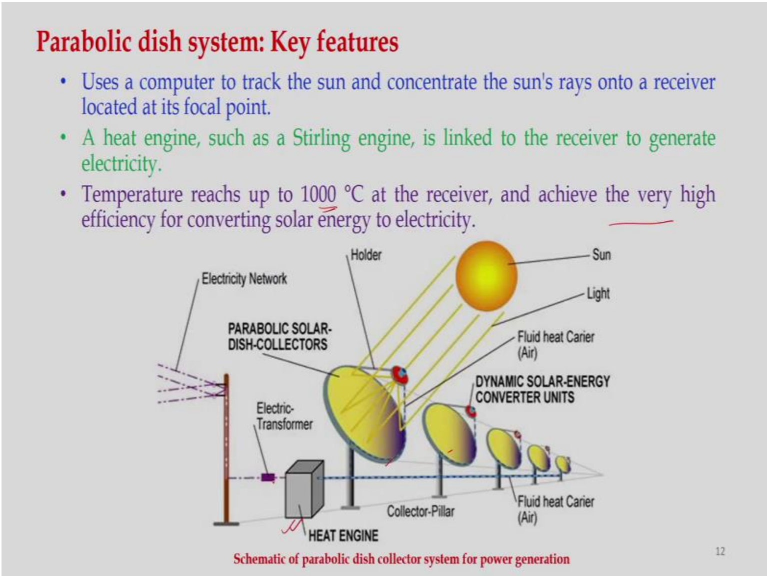

Now, there are some key features of this technology, like this technology uses a computer to track the sun. It is a very precision tracking system and concentrate the sun's ray on to the receiver located at its focal point. A heat engine such as a stirling engine is linked to the receiver to generate electricity. As we have already discussed, a very high temperature can be attained by using this technology. It is reported that 1000 ^{o}C can be achieved by using this technology.

And that is why, this efficiency is also very very high. Efficiency means thermodynamic efficiency is very high compared to other technologies. So, what we can see here, it is a farm. So, there are many this kind of parabolic dish systems are installed. Maybe 1, 2, 3, that maybe many more. And this heat is collected at the end and then finally, one heat engine is attached and then that will convert to electricity. If we couple a generator here, so this is the electricity generation. There are many more this kind of systems are connected in series.

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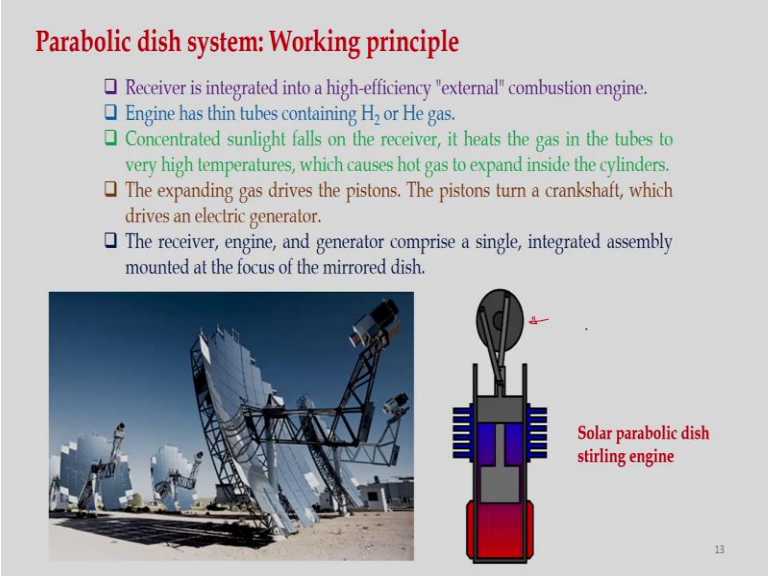

So, working principle goes something like, receiver is integrated into a high efficiency external combustion engine. An engine has thin tubes containing hydrogen or helium gas. This concentrated sunlight falls on the receiver, it heats the gas in the tubes to a very high temperature, which causes hot gas to expand inside the cylinders. This expanding gas drives the piston, and then the piston turns the crankshaft which drives an electric generator. The receiver engine and generator comprises a single integrated assembly mounted at the focus of the mirrored dish.

So, arrangement is something like this. So, fluid is here, once it is heated, it will actually expand. When it is expanded, so this is piston cylinder assembly is attached. Then it will move, once this piston cylinder is start rotating, means this will rotate, our shaft will rotate. And then finally, we can have mechanical energy and if we couple to a generator, then we can get electrical energy out of this parabolic dish system.

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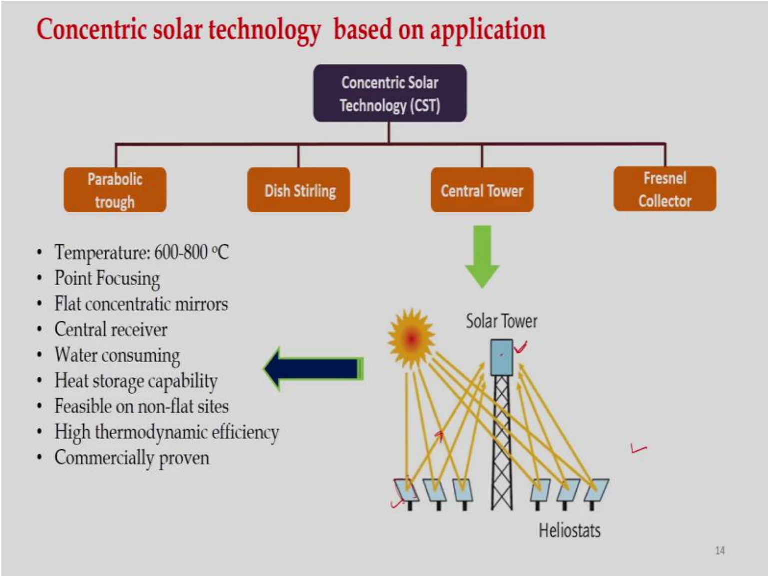

Now, come to the central power receiver system, which is quite common in many of the countries. So, here what happens, we can see one single tower will be there and one receiver will be there at the top. And these are the mirrors. Solar radiation falls here and then reflect back to this receiver. So, very very high temperature will be attained here and then that has to be carried by using some kind of arrangement, we will discuss.

So, in this kind of arrangement, temperature can go up to a value of 800 ^{o}C. Of course, it uses point focusing device. And also you can see, these are flat concentric mirrors, these are flat concentric mirrors are used. Of course, this systems can also be used for reflecting the sun rays. And it is a central receiver, only one receiver will be there. And water consumption will be very high in this kind of arrangement.

And heat storage capability is there in this technology, because while operating, it generates enormous heat that can be stored and same can be applied whenever required. And it is feasible on non-flat sites. We do not need very flat surface for installation of this heliostats or this mirror systems. And it has got high thermodynamic efficiency, because its operating temperature is higher. And it is commercially proven, already many installations are present across the globe.

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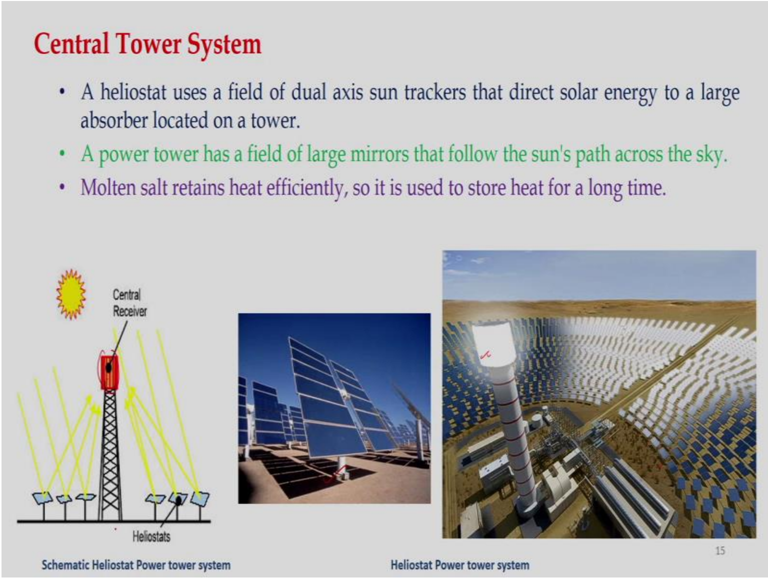

So, a heliostat uses a field of dual-axis sun trackers that direct solar energy to a large absorber located on a tower. So, this is a tower you can see which is very wide and bright. A power tower has a field of large mirrors that follow the sun’s path across the sky. As you can see, these are mirrors also known as heliostats. Single component can be known as heliostat. You can see the arrangement. So, all are reflected, the radiations and they are received at the top of this tower. And then heat has to be carried from the top to the bottom for electricity generation. So, if we consider a single heliostat, it looks something like this. So, this is something like this.

Many of the mirrors are attached in a single heliostat. So, all the radiations what is falling in this flat mirrors, that will be reflected to this single receiver, which is known as the central receiver. And, normally molten salt retains heat efficiently, because molten salts are used as a heat transfer fluid, as it is used to store heat for long time. So, we will draw one picture, how this heat can be stored for a longer period of time, that will be demonstrated. But what we should know, this is a single receiver and then this heat, what is generated here has to be carried from this top to the bottom, where power house is built. So, as you can see here.

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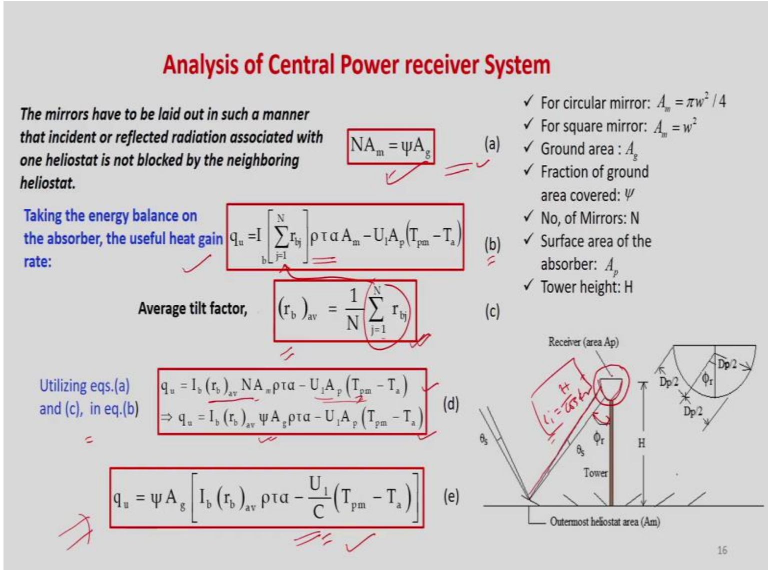

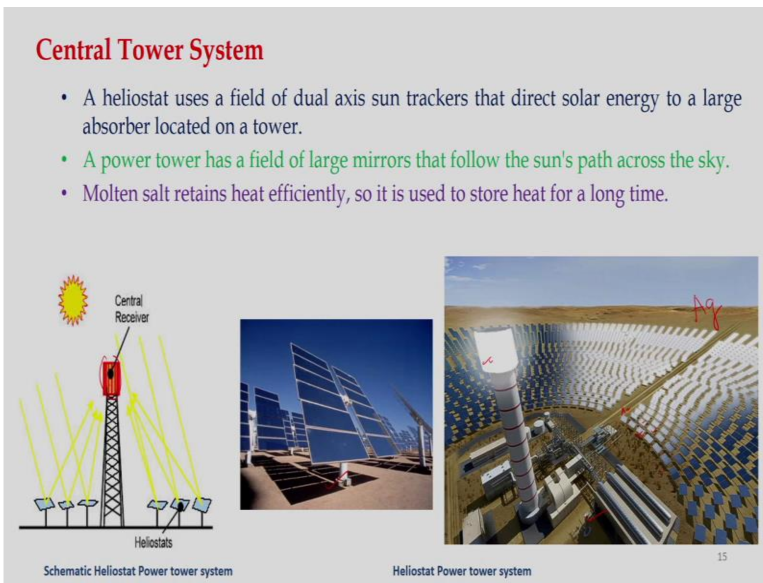

So, let us analyze the central power receiver system. So, if we consider, if we go back to the last slide, so these are the heliostats. See in between, gaps are there, because if shadow is there, means if this heliostat is shadowing the others, then what happens, we are losing the efficiencies. So, that has to be taken care. But what I mean to say, there is a gap in between the heliostats. That gap has to be maintained.

If we consider this area of a single heliostat is A_m and there are N number of heliostats. And if we consider the ground area, say ground area maybe A_g. And if gap, we maintain, or say gap is also measured, then we can incorporate the gap factor is ψ, then we can write this expression.

This $N A_m = \psi A_g$. What is N, N is the number of mirrors. And A_m is the area of the single mirror. And then A_g is the ground area. And this ψ is fraction of ground area which is covered by the heliostats.

So, the mirrors have to be laid out in such a manner that the incident or reflected radiation associated with one heliostat is not blocked by the neighboring heliostat. That we should keep in mind. Now, if we are interested to develop the energy balance on the absorber, then we need to develop this kind of expression. So, we want useful heat gain, q is the amount of energy which is received by the receiver minus losses. So, this part, this summation of j=1 to N r_{bj} is nothing, but average tilt factor.

So, if we have to write the average tilt factor, then it will be $(r_b)_{av} = \frac{1}{N}\sum_{j=1}^{N} r_{bj}$. So, if we use this r_{bj} and what is defined by this equation a and use in equation b, then what we will get is something like this. Just what we are doing, r_b average we are introducing. So, this expression multiplied by N, so if we multiply N both the sides, then what will happen, N× $(r_b)_{av}$. So, this part, what we have expressed in equation b, we can replace by this N× $(r_b)_{av}$.

That is why, this N× $(r_b)_{av}$. And this τ reflectivity absorptivity, all the information needs to be accounted. And then these are the loss factor. And T_{pm} is the mean temperature of the absorber. And we can use this expression, so $N A_m = \psi A_g$. So, we can now substitute here and we can modify this expression something like this. So, our expression will be something like this, if we define this concentration ratio. So, we need to define the concentration ratio now.

Before we define, let us see ϕ_r also, how this ϕ_r can be defined? So, here what happens, this is the height of the collector, central receiver system. And this is the receiver area. And solar radiation is falling here in the last heliostat and it is reflected to the absorber, where it makes an angle with this height of the collector or height of the central power receiver system. So, this angle is known as ϕ_r and which is also called rim angle. So, now what we are interested about this length. This length is nothing but imaging length, or if we have to write this L_i will be something like H by cos of $\bar{\phi}_r$. So this L_i, we need to know, again add something, that we will discuss now. But this length will be $L_i = \frac{H}{\cos\phi_r}$. And this configuration of this receiver is something different. So, it is somewhat spherical. But when we look from here, it is like a line.

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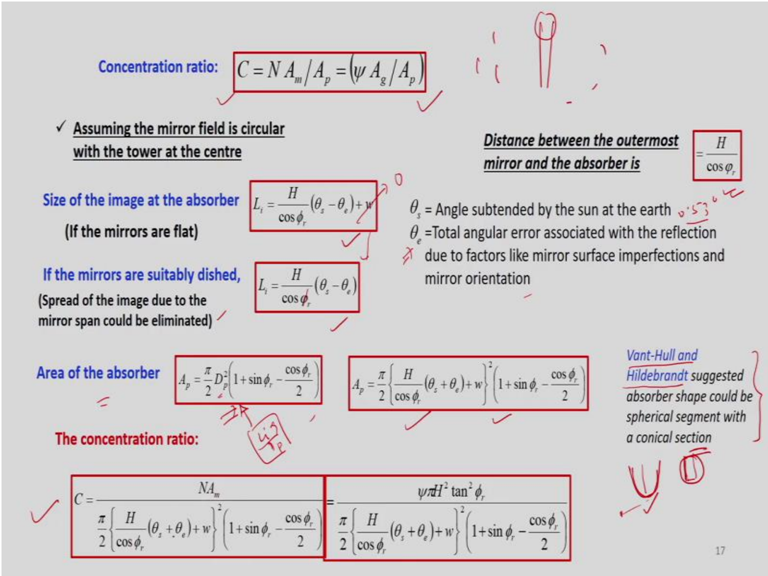

So, now let us define concentration ratio, which is nothing but $C = \frac{N A_m}{A_p} = \frac{\psi A_g}{A_p}$. So, we can use this expression, in the last q_u expression, and we can write useful heat gain in terms of concentration ratio. As we have defined the distance between the outermost mirror and the absorber is $\frac{H}{\cos\phi_r}$. So, when we are interested to investigate the size of the image at the absorber, then we must assume something. Like assumption is the mirror field is circular with the tower at the centre.

So, mirror field is circular, so all the mirrors are there and this will be at the centre, so receiver will be at the top. So, if the mirrors are flat, then expression, of this size of the image at the absorber can be expressed by a L_i which is nothing but $L_i = \frac{H}{\cos\phi_r}(\theta_s + \theta_e) - w$. So, this θ_s is the angle subtended by the sun at the earth which is fixed always; it is about point 53^o. This is fixed. And this θ_e is the total angular error associated with the reflection due to factors like mirror, surface imperfections and mirror orientation.

So, this has to be accounted in order to calculate the size of the image at the absorber. Now, if the mirrors are suitably dish, so dish system is there, then this w=0 in case of suitably dish mirrors. So, under that condition, our size of the mirror will be, or size of the image will be $L_i = \frac{H}{\cos\phi_r}(\theta_s + \theta_e)$, it should be ϕ. So, at what condition, we can remove this?

The spread of the image due to the mirror span could be eliminated in case of suitably dish system. If the mirrors are suitably dished. So, we can use this expression under this condition, where ω or say w=0. So, this area of the absorber can be calculated by using this expression, because this configuration is something different. So, these two researchers, they have suggested the absorber shape could be spherical segment with a conical section.

So, based on their suggestion, they have made the absorber something like that and they have calculated the absorber area to be something like this, which is $A_p = \frac{\pi}{2} D_p^2 \left(1 + \sin\phi_r - \frac{\cos\phi_r}{2}\right)$. So, if we substitute this L_i value here in D_p, so at what condition we can do it? Because when we see from the outer most mirror to this absorber, so it is sphere, but from here if we see, it is like a line.

So, this is something like L_i. So, this D_p can be replaced by L_i, so if we do it, then expression of A_p will be something like this. So, once we know A_p, as we know the expression for concentration ratio, we can substitute the value here and we can develop the concentration ratio for dished considered absorber system. This kind of absorber. So, this will be something like this. N A_m, then this expression, multiplied by this expression.

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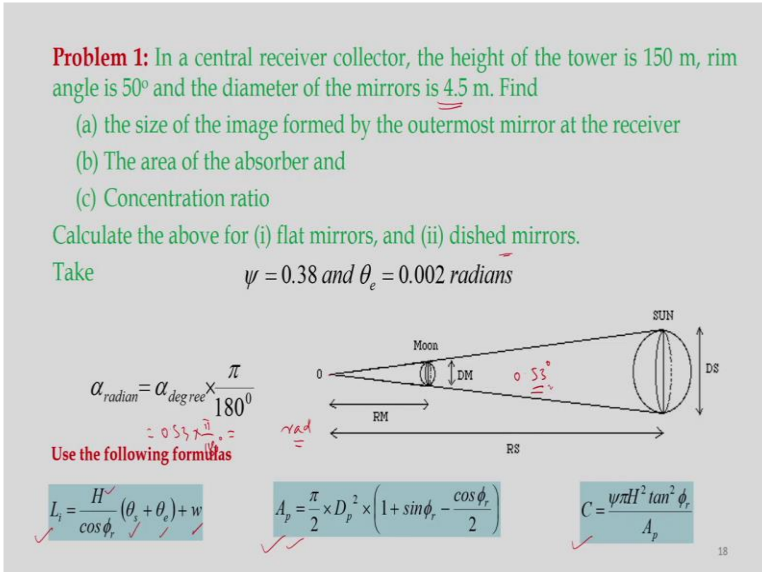

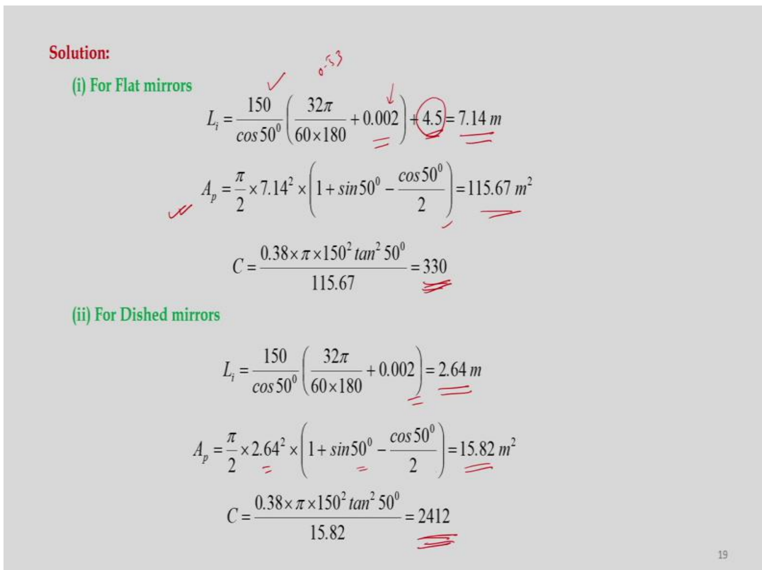

So, if we take a problem, say in a central receiver collector, the height of the tower is 150 m and rim angle is 50^o, and the diameter of the mirror is 4.5. So, we need to find the size of the image formed by the outermost mirror at the receiver. So, L_i need to be calculated. The area of the absorber and the concentration ratio need to be calculated. And this has to be calculated for two different cases, one for flat mirrors and other for dished mirrors.

So, when we need to consider dished mirror, then this diameter of the mirrors need to be eliminated. So, this is the sun, and this is the moon and then this is the receiver. So, this angle is 0.53^o, always. And once we know this degree, then we can convert it to radian, so this is (0.53^o × π/180), we can calculate what will be the radian. So, we can calculate the radian values.

So, we can use those equations what we have discussed now. So, L_i is known for us, $\frac{H}{\cos\phi_r}$. So, in order to calculate this L_i, we need the variable like H, θ_s, θ_e and w. w is nothing but the diameter of the mirror. Then area of that configurations, what proposed by the researcher, so same area need to be considered, because which is found to be the best for energy conversion. And concentration ratio expression is known to us. So, we will take case by case. So, let us consider the first case, for flat mirrors.

So, this L_i, if we substitute those values, H is known to us and this value 32/60 is nothing but ($0.53^o \times \pi/180$). And then this radian, this angle is always radian, which is given to us and diameter is given, then we can calculate the size of the image, when mirror is flat. And also, we can calculate what will be the area of the absorber by using the expression proposed by the researcher. So, we can substitute those values of L_i here and we can calculate and this found to be 115.67 m^2.

And if we calculate this concentration ratio, which is found to be 330. So, now we consider the second case for dished mirrors, so what will be the L_i here? Because this part will be not present in this expression. So, this Li = 2.64 m. Earlier it was 7.14 m. Accordingly, we have to calculate this A_p value. So, just we have substituted this L_i value here and then ϕ values, and this found to be 15.80 m^2.

Now next phase, we will calculate what is concentration ratio. So, this concentration ratio is found to be 2412. See the difference in concentration ratio, in the flat mirrors it was 330, and in case of dished mirrors, it is 2412. You can see, how much concentration we can increase. So, we can generate intense heat by using this dished mirror system, or dished mirrors. So, this is very very important problem to understand the difference between two mirrors and how we can increase the concentration.

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Power tower system with heliostats for power generation

Now, this picture shows the installation of a MW level power tower system. As we can see, these are the heliostat and this is the tower. Receiver is at the top, so radiations are reflected from here to here, here to here. So, this is heated up to a very high temperature.

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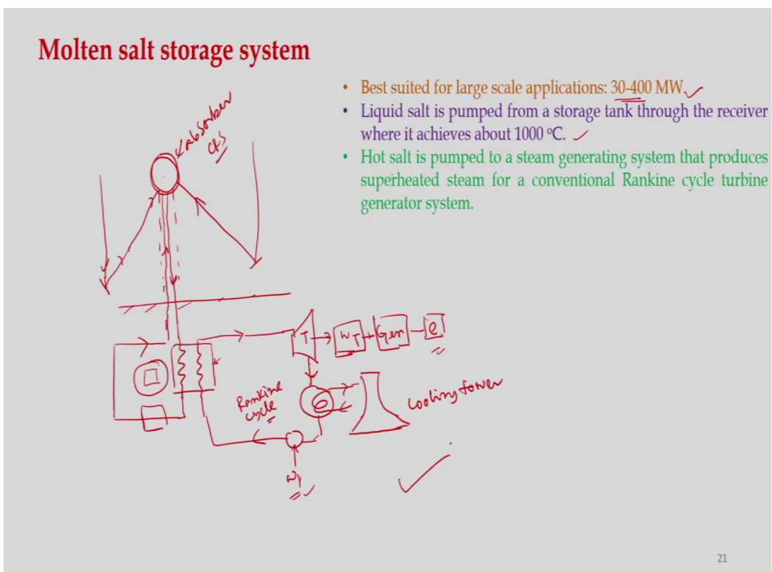

Now, if we have to understand this molten salt storage, let us draw one picture. So, maybe I will write this is an absorber. And I will draw this. And maybe this is a base, this is a tower. And fluid will flow and I will write two lines. Because one will heat carry and other will be cold fluids will be injected. And maybe this one, and this one, I will do. So, here we will write this kind of, draw a line and then we will have this.

So, these are the heliostats, solar radiation falling here, maybe solar radiations falling, it goes here, so it is falling here. This maybe here also. Solar radiation is falling maybe here and it goes there. So, when it comes here, then we need to have a heat exchanger. And of course, this heat has to be carried. So, maybe I can draw a this kind of block, this is a heat exchanger. And this will come here. And this will go to turbine, this will go to turbine.

And then we need to have condenser, we need to have condenser. And if we have condenser, then we need to have this kind of cooling tower. This maybe cooling tower. And we have to have a pump. And this will work in a close loop. And we can have storage as well, here somewhere. So, what I have shown here, this is a absorber of the central receiver system. And this is a Rankine cycle, the Rankine cycle, where water is used as heat transfer fluid.

So, this is pump, W_p is the work required and this is the W_t, is the turbine work. And if we have generator then, generator, then we can generate electricity. So, this is a mechanical power development. And then if you are interested to generator electricity, we need a generator and finally, we can have electricity. So, if we use molten salt, so we need to use some kind of pump to pump this cold molten salt and it will goes to the top of this receiver and it will be heated up to a very high temperature.

And then that has to be collected, then it will go through this heat exchanger. Then heat will exchange from here to here, where we have water as a heat transfer fluid in this circuit. Water flows and then heat developed here will carry by this water and then this is something like our boiler. So, steam will be generated which will be expanded in the turbine and electricity will be generated by using this generator. And then, this has to be ejected.

So, low temperature water will come here, and then condenser will be there to cool the fluid and that has to be pumped back, by using this pump. So, this molten salt, once heat is extracted from the molten salt, so electricity is generated, but it is cooling down. So, if sometime this electricity is not generating, then we need to have storage, or if even though electricity is generating, but we have generated enough heat, so that can be stored in a storage system.

And that can be utilized wherever or whenever required. So, this is best suited for the large scale applications, as we can say it is 30 to 400 MW, it is a big unit. And liquid salt is pumped from a storage tank through the receiver where it achieves about 1000 ^{o}C and hot salt is pumped to the steam generator, or steam generating system that produces superheated steam for a conventional Rankine cycle turbine generator system. That is what it is shown here.

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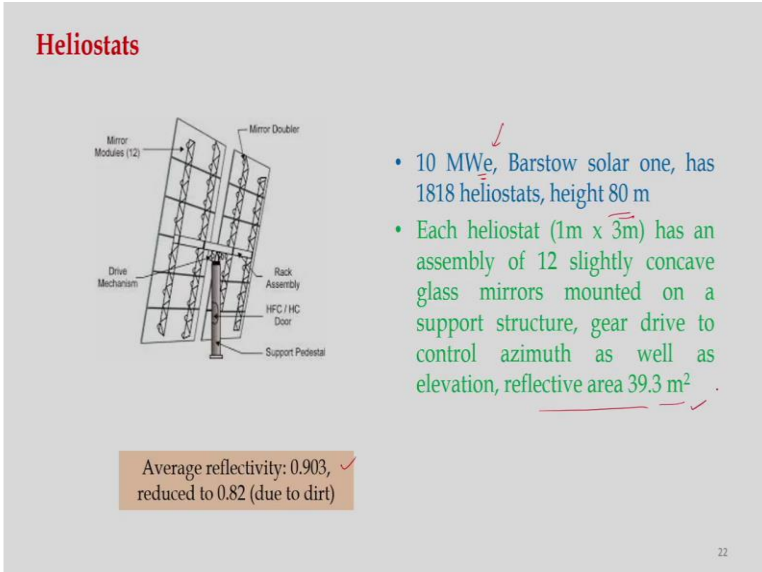

And if we talk about the particular heliostat, so it carries lot of mirrors, as we can see, there are mirrors, there are many mirrors, so about 12 modules of particular sized mirrors are hold by this structure. And this structure is known as heliostat. So normally, a reflectivity of this kind of heliostat is about 0.903, but due to this accumulation of dirt, this reflectivity reduces to 0.82. So, it is a concern.

And, in case of Barstow solar one, it has got about 1818 heliostats and height of the tower is about 80 m. And it can produce 10 MW of electrical energy. So, e stands for electrical energy. So, this each heliostat, that is 1m×3m is the dimension, has an assembly of 12 slightly concave glass mirrors, mounted on a support structure and gear drive to control azimuth as well as elevation. And, its reflective area is about 39.3 m^2. So, this is a heliostat. So, there are many heliostats will be there, in case of a central power receiver system.

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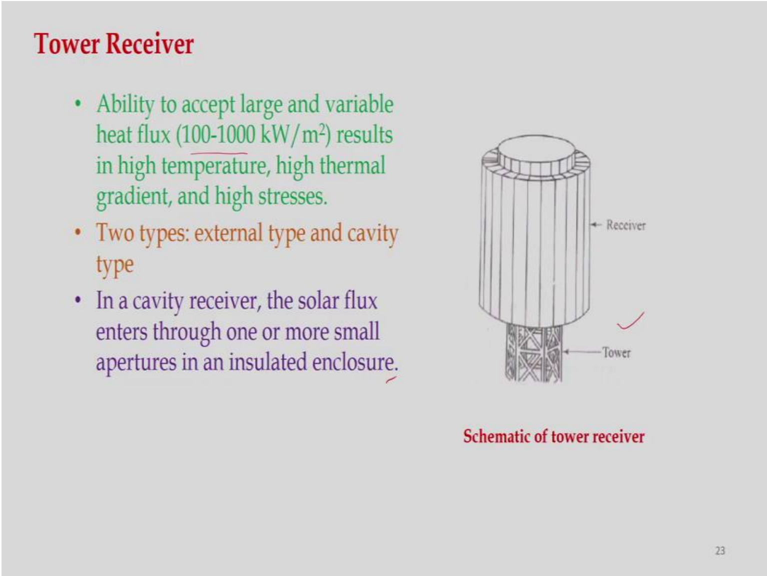

So, if we talk about the receiver, which is a very very important component of a central power receiver system. So, it has the ability to accept large variable heat flux. So, it must have the ability to accept heat flux in the range of 100 to 1000 kW/m^2. So, which results in high temperature, high thermal gradient and high stresses. You can see the receiver systems. There are many configurations of this kind of absorber.

Normally, there are two types, external type and cavity type. So, in a cavity receiver, the solar flux enters through one or more smaller apertures in an insulated enclosure. So, we can have higher optical efficiency in this configuration. And, of course, we can use different working fluid, not only molten salt and water. We can use air as well for this kind of arrangement.

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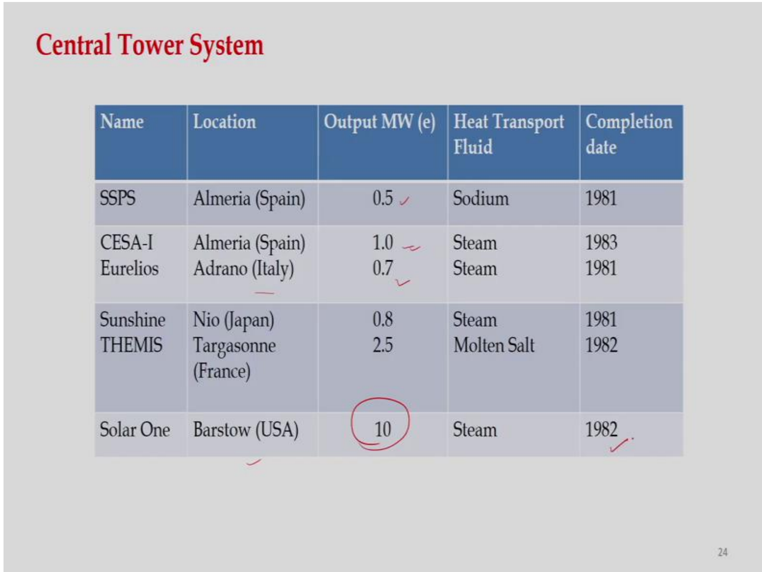

Central Tower System

Name	Location	Output MW (e)	Heat Transport Fluid	Completion date
SSPS	Almeria (Spain)	0.5	Sodium	1981
CESA-I Eurelios	Almeria (Spain) Adrano (Italy)	1.0 0.7	Steam Steam	1983 1981
Sunshine THEMIS	Nio (Japan) Targasonne (France)	0.8 2.5	Steam Molten Salt	1981 1982
Solar One	Barstow (USA)	10	Steam	1982

So, there are different plants which is already in operation. As you can see, this location is in Spain, there are two; Italy one, in Japan one and France and then USA, which is Barstow, which is one of the largest central power tower system. So, output power we can say, it is 0.5 MW. And Spain we have 1 MW. Then Italy, it is 0.7 MW. And largest one is at USA. So, that was installed in 1982. So, it was a operating well for a certain period of time. It was, had some issues. Then they have modified something and thereafter it was working for three and half years, and then it stopped working. So, but it is a very good technology to harvest solar radiation for power generation.

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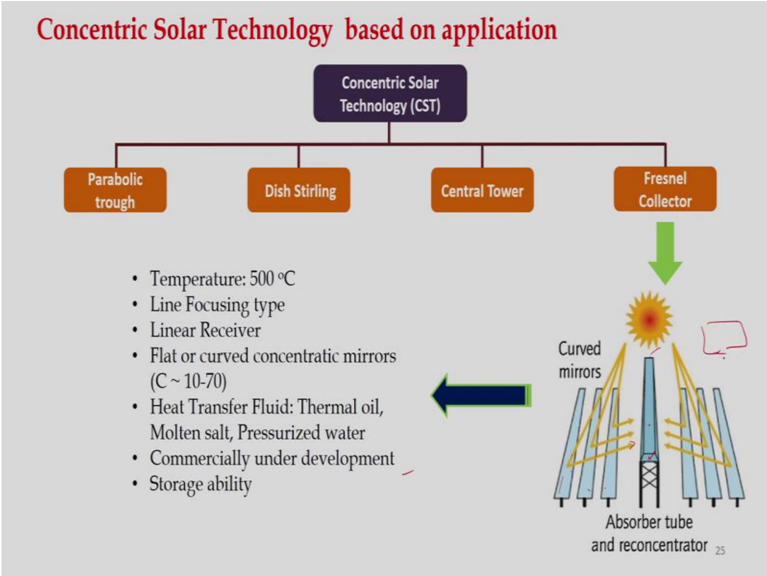

And let us discuss the last technology called Fresnel collector. So, as we can see, these are the curved mirrors and receiver is here. So, solar radiation received here and is reflected to the receiver. So, here the temperature can go up to 500 ^{o}C and it is a line focusing system, it is in line, no not the point, it is a line. And it is a linear receiver, as you can see, this is a linear receiver.

And flat or curved concentric mirrors can also be used and its concentration ratio varies from 10 to 70. And normally, as heat transfer fluid, thermal oil and molten salt and pressurized water are used. And this technology is commercially under development. And it has got storage ability, so storage can be done. Because heated fluid can be collected and we can have a storage and that can be used as per the requirement.

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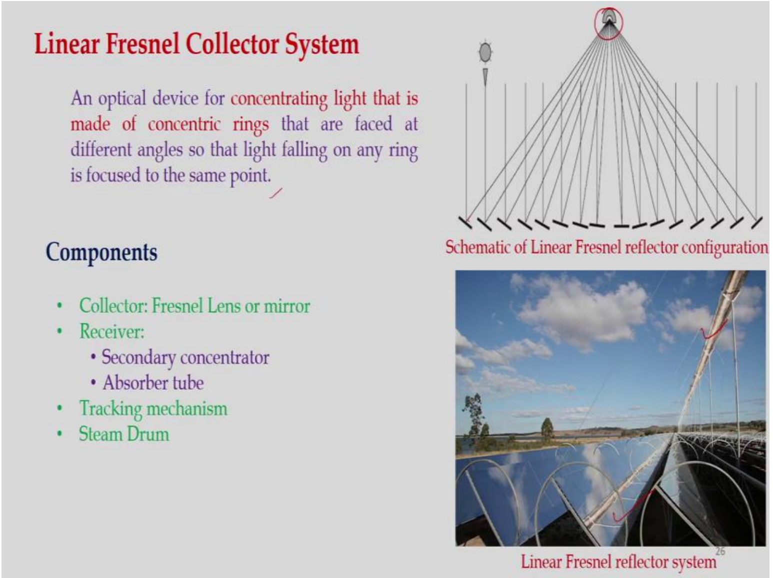

So, configuration of this linear Fresnel collector system is shown here. So, solar radiation is falling here and these are the mirrors, this is reflected and this is the receiver. So, these are segmented. So, an optical device for concentrating light, that is made of concentric rings, that are faced at different angles so that light falling on any ring is focused on the same point. So, this is very very important. So, photographs of this kind of installation is shown here.

And components, if we say, so collector is one component. This collector is nothing but Fresnel lens or mirrors. And receivers, we have secondary concentrator and absorber tubes. These absorber tubes are here, absorber tubes are here. And tracking mechanism and steam drum is required, because at the end, steam will be collected and that will be expanded in a turbine for electricity generation.

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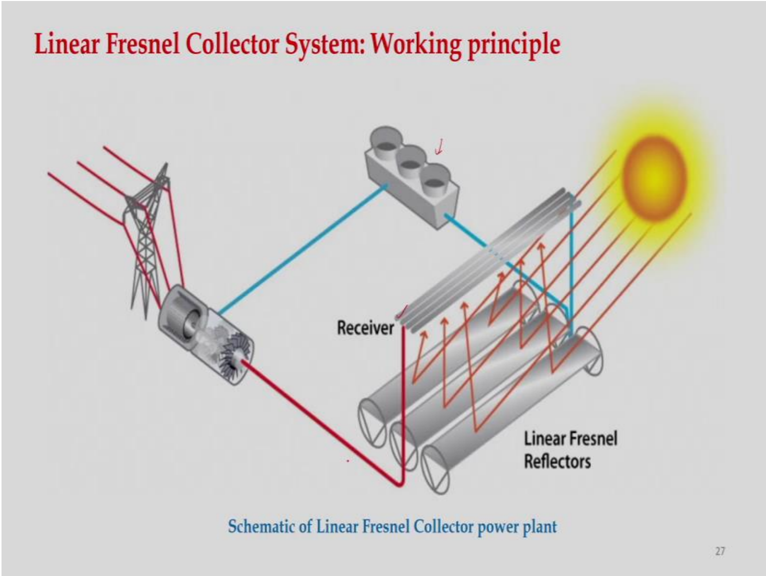

So, how it works, solar radiation fall on these mirrors and is reflected to this receiver. And receiver receives those energies and fluid is heated up and then if water is used, then water is expanded in a turbine. And then electricity is generated, if the shaft is connected with a generator. And then that has to be condensed by using a condenser and cooling tower. And same fluid can be circulated again and again for harvesting energy.

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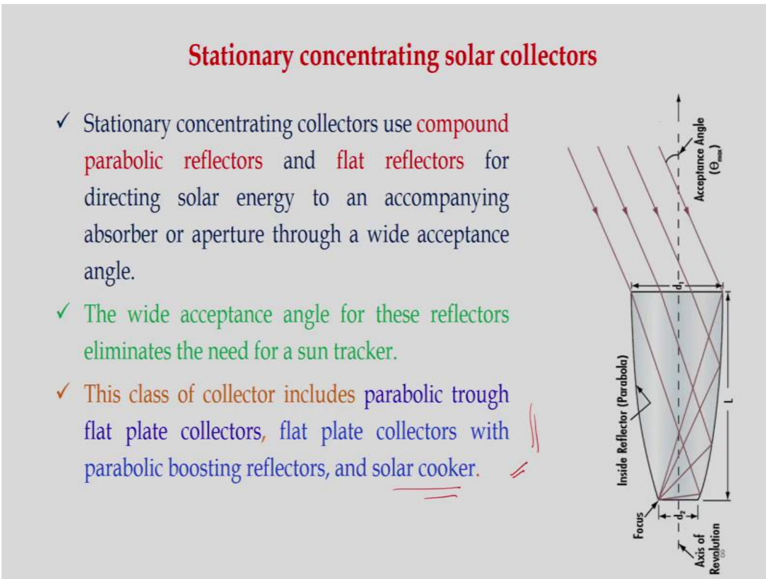

One more concentrating collectors which is stationary, you do not need any tracking devices. So, this stationary concentrating collectors use compound parabolic reflectors and flat reflectors, for directing solar energy to an accompanying absorber or aperture through a wide acceptance angle. As we can see, solar radiation falls here. And this is like a compound structure. So, it is a wide acceptance angle.

And once radiation is introduced, that cannot go out and that is utilized for energy generation. The wide acceptance angle for these reflectors eliminates the need for sun tracker. So, sun tracking is not required. So, this class of concentrator includes parabolic trough, flat plate collectors, flat plate collectors with parabolic boosting reflectors and solar cookers. So, these are the technology normally used for making this high heat production system. In this kind of technologies, concentration ratios can be improved, maybe up to 4 or 5.

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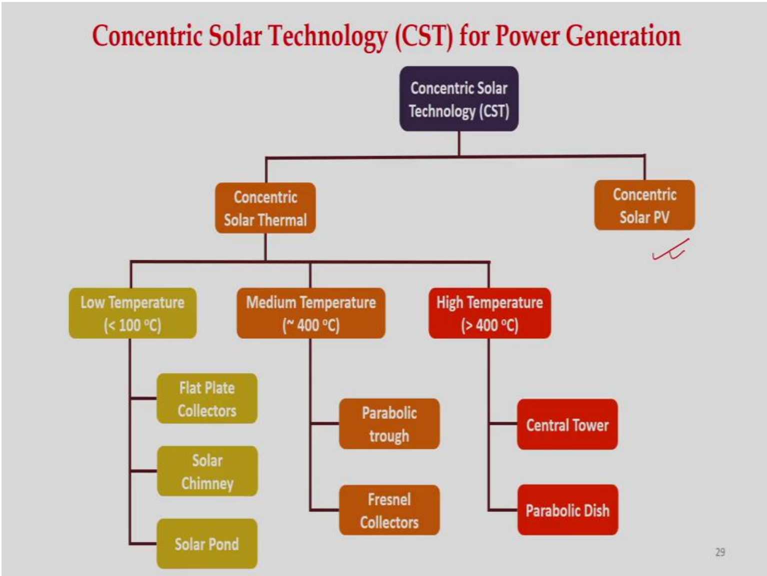

Also, we can see the different technologies which can generate electricity. So, we have two ways of generation of electricity. First way is to concentrate or concentric solar PV, solar PV technology. And second one is solar thermal. So, there are different categories again, like low temperature applications, moderate temperature application and high temperature application. So, as far as low temperature applications are concerned then we will go for flat plate collectors, solar chimney, then solar pond.

For medium or moderate temperature applications up to 400 ^oC, we will go for parabolic trough and Fresnel collectors. And for high temperature applications, we will go for central power tower receiver system and parabolic dish system. So, we can generate electricity by using thermal energy, by using these routes and we can generate direct electricity from solar energy by using solar PV technologies.

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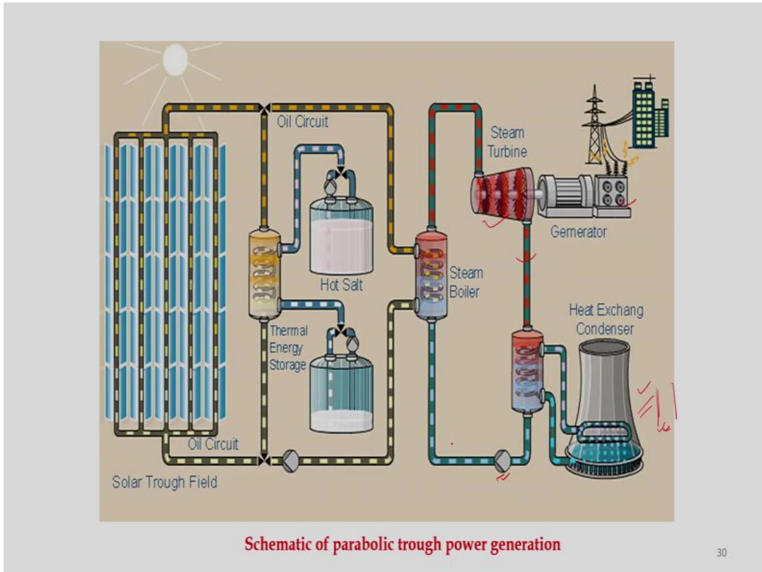

So, here it shows a schematic of parabolic trough power generation. So here, these are the parabolic troughs and these are thermal energy storage devices. So, hot salt will be collected here. And then we need a one heat exchanger to exchange these fluid with the secondary fluid, which is flowing in the circuit, this is nothing but water. And then once water is evaporated, it is expanded in a turbine and then if we connect this turbine to a generator, we can generate electricity.

And then, some amount of heat is to be rejected in the condenser. And then once we say condenser, this condenser is attached with this kind of cooling tower. So, normally in big power plants, this rivers are there, so rivers are also used as a release of cold water there. So, that water is used for cooling this condenser. And then we need a pump to circulate the fluid again and again in the close room.

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So, we have this technology, you can see, the large parabolic troughs are installed. And you can see the power plant, it is a big power plant for generation of electricity by using solar thermal technology.

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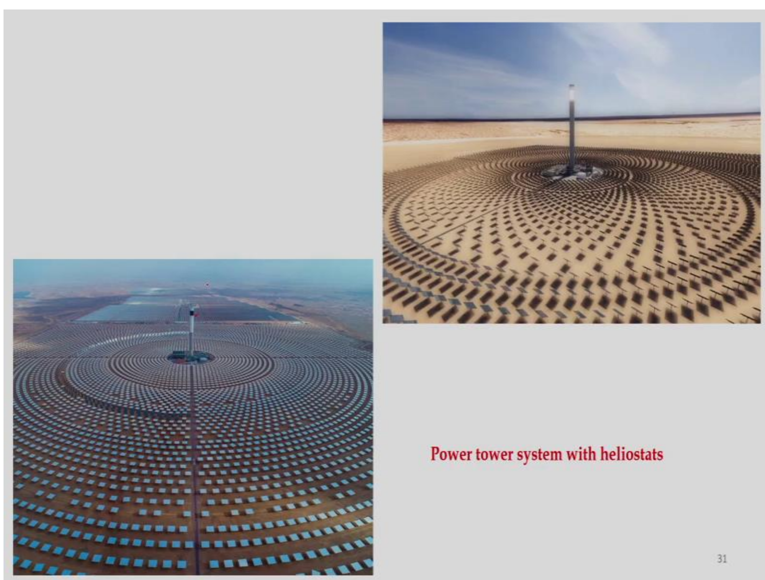

And as we can see, this is the figure for central power receiver system. See here, the circular fields are there. And then, these are the reflected rays and this is absorber. So, which is a big power plant for generation of electricity by using central power receiver system.

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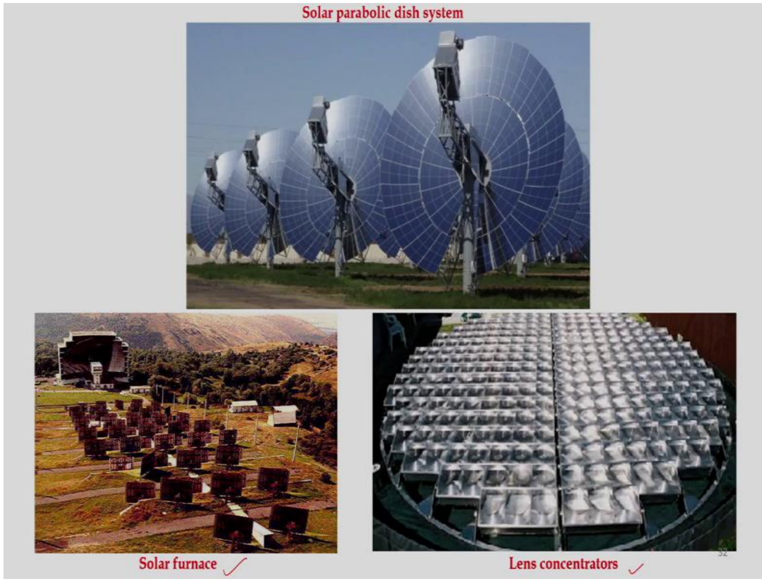

And this is for solar parabolic dish system. And we can see, sometimes solar furnaces are also used for different purposes we can say. So, this is the solar furnace, a very high temperature can be achieved. And this is called lens collectors. So, lens collectors are also used for generation of electricity by using thermal route.

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Key features of concentrating solar power technologies

	Parabolic Trough	Dish/Engine	Power Tower
Size	30-320 MW	5-25 kW	10-200 MW
Operating Temperature (ºC/ºF)	390/734	750/1382	565/1049
Annual Capacity Factor	23-50 %	25 %	20-77 %
Peak Efficiency	20%(d)	29.4%(d)	23%(p)
Net Annual Efficiency	11(d)-16%	12-25%(p)	7(d)-20%
Commercial Status	Commercially Scale-up Prototype	Demonstration	AvailableDemonstration
Technology Development Risk	Low	High	Medium
Storage Available	Limited	Battery	Yes
Hybrid Designs	Yes	Yes	Yes
Cost USD/W	2,7-4,0	1,3-12,6	2,5-4,4

(p) = predicted; (d) = demonstrated

And this slide shows the comparison of three most importantly used concentrated solar power technologies like, parabolic trough, it goes size from 30 to 320 MW. Then dish engine, it goes 5 to 25 for a single unit. And power tower can go 10 to 200 MW. Operating temperature, we can see here. So, dish system operating temperature can go up to 1382. In case of power tower, it is about 1049.

We can compare the annual capacity factor is 23 to 50 in case of parabolic trough. 25 % in case of dish system and for power tower, it is about 20-77 %. A peak efficiency is maximum in case of dish followed by power tower and parabolic trough. And if we talk about commercial status, so dish, dish has been demonstrated and parabolic trough is in already in place. And dish power tower is available for demonstration.

And we can hybridize this technology, parabolic trough technology with other technologies. And of course, dish can also be done and power tower can also be done. And cost wise also, we can compare. So, cost of this is somewhat higher compared to dish. And of course, power tower is also, also high. So, cost we have to compromise in those cases for generation electricity by using thermal routes.

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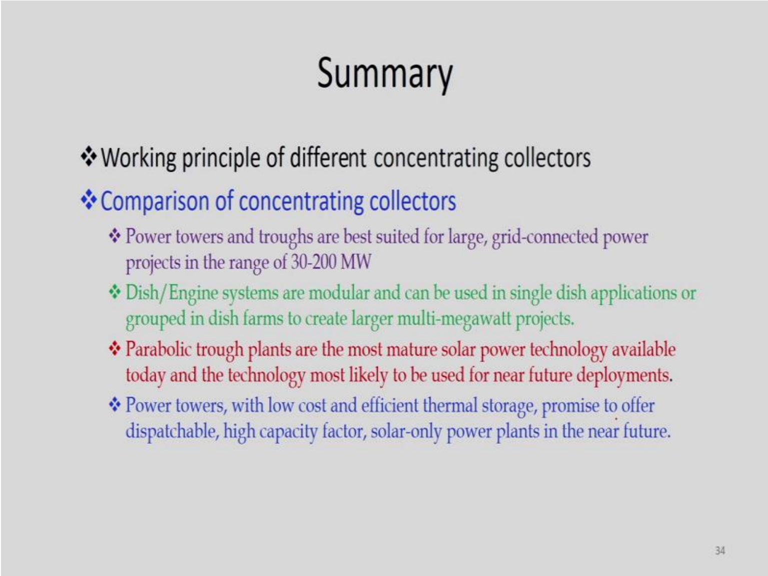

So, we can summarize what we have discussed today about this solar concentrating power technologies, its working principle and those technologies which are applied for generation of higher temperature. So, we have primarily discussed this principles of different concentrating collectors. And we have compared the technologies and it is found that, that power tower and parabolic troughs are best suited for large grid connected power projects in the range of 30 to 200 MW.

This dish or engine systems are modular and can be used in single dish applications or grouped in dish farms, to create large multi megawatt projects. The parabolic trough systems are the most matured solar power technology available today and the technology most likely to be used for near future deployments. The power tower systems with low cost and efficient thermal storage promise to offer dispatchable high capacity factor, solar-only power plants in the near future. So, hope you have enjoyed this lecture. So, thank you for watching this video.