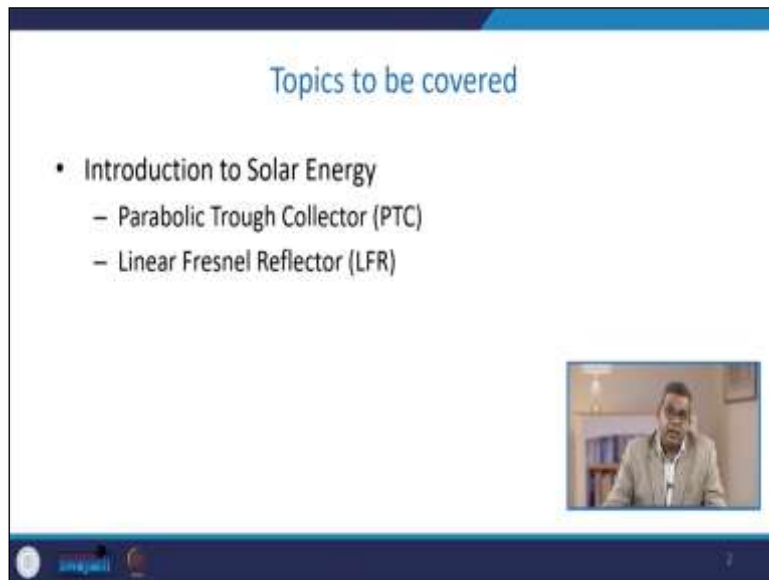


Chemical Process Utilities
Prof. Shishir Shina
Department of Chemical Engineering
Indian Institute of Technology, Roorkee

Lecture – 9
Solar Energy-I

Welcome to the next lecture on solar energy. We are discussing the various types of heat transfer media or heat transfer fluid. Under the heat transfer media or fluid, you can see the wide application in the solar panel. When we go for this solar panel anatomy, we need to go a small amount of knowledgeable approach with respect to solar energy. So, in this particular lecture, we will discuss some of the small concepts of solar energy.

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There are two major topics we will cover: the introduction to solar energy and then the different types of parabolic trough collectors or PTC and the linear fresnel reflectors LFR.

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Introduction

- India is a hot country having 200-250 days of bright sunshine with direct normal irradiance (DNI) of about 4-7 kWh/m²/day.
- Solar thermal energy is created when incident solar radiation is caught and transported as heat to perform different beneficial uses.
- With depleting resources of crude, it is becoming essential to think about alternative renewable and direct sources of energy.
- Technologies available to obtain thermal energy from sun as a free source of heat, getting up to 3000 °C temperature output.



See that India is a relatively hot country, and we have very good opportunities attributed to solar energy. Usually, in the Indian context, we do have 200 to 250 days of bright sunshine with normal, you can say direct normal irradiance of about four to seven-kilowatt hour per meter square per day, which means a huge opportunity huge avenues with respect to the solar energy.

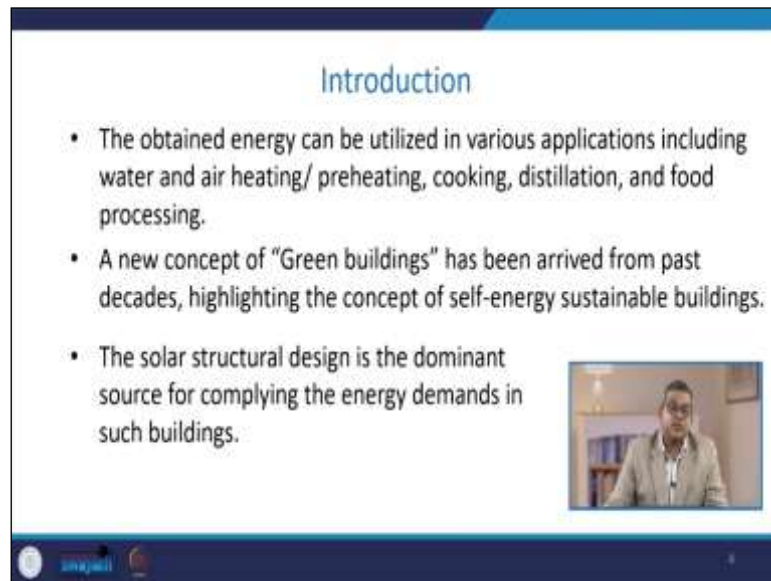
Solar thermal energy is usually created when the incident solar radiation is caught and transported as heat to perform different beneficial uses. With the depleting resources of crude sometimes it is a very challenging aspect, and that is why various government organizations are giving more and more importance or impetus to the use of some alternative energy sources, and solar energy is one of the best candidates.

So, while we consider the things that the crude or natural resources are depleting, it becomes essential to think about various alternative renewable or direct sources of energy or, above all, low-cost energy. Technologies available to obtain thermal energy from the sun as a free source of heat, getting up to 3000 degree Celsius temperature output, and solar energy is available in abundance.

See when we see a lot of opportunities avenues quantum etc. So, the obtained energy can be utilized in various applications, including water and air heating, preheating, cooking, distillation, food processing etc. Furthermore, a new concept of green building is coming up. For past decades past couple of decades, various regulatory bodies have been

introducing this kind of concept basic objective of this particular concept is to have self-energy sustainable buildings.

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The slide is titled "Introduction" and contains the following text:

- The obtained energy can be utilized in various applications including water and air heating/ preheating, cooking, distillation, and food processing.
- A new concept of "Green buildings" has been arrived from past decades, highlighting the concept of self-energy sustainable buildings.
- The solar structural design is the dominant source for complying the energy demands in such buildings.

A small video inset in the bottom right corner shows a man in a light-colored shirt speaking.

So, the solar structural design is the dominant source of complying with the energy demand in such buildings. The national institute of solar energy has an estimated country's solar potential to be 748 gigawatts, assuming that solar photovoltaic modules cover three percent of the wasteland area. So, you can analyze and imagine how much potential we do have with respect to solar energy.

Solar energy has been prioritized in India's national action plan on climate change with the national solar mission being one of the primary missions. So, keeping in view of this particular fact, a lot of revenues low-cost availability etc. January 11, 2010 the national solar mission was started.

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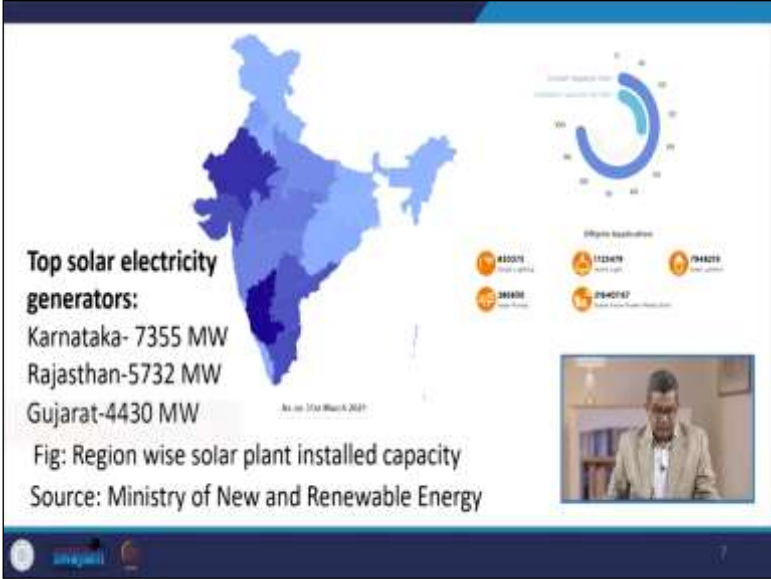
Introduction

- The National Sustainable Development Mission (NSM) is a significant project of the Government of India, with strong participation from states, to promote ecologically sustainable growth while addressing India's energy security issues.
- It would also represent a significant contribution by India to the global effort to address the concerns of climate change.
- The Mission's goal is to position India as a global leader in solar energy by fast establishing regulatory conditions for solar technology dissemination across the country.



The national sustainable development mission is a significant project of the Government of India with strong participation from states to promote ecologically sustainable growth while addressing India’s energy security issues. Sometimes, it would also be a significant contribution by India to the global effort to address climate change concerns. The mission's goal is to position India as a global leader because of the avenue because of solar energy opportunities by quickly establishing regulatory conditions for solar technology dissemination across the country.

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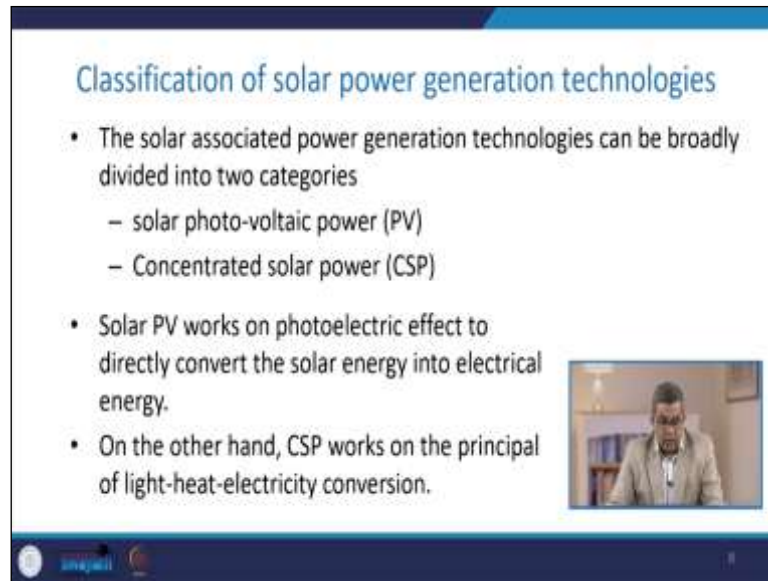
Top solar electricity generators:
 Karnataka- 7355 MW
 Rajasthan-5732 MW
 Gujarat-4430 MW

As on 31st March 2021

Fig: Region wise solar plant installed capacity
 Source: Ministry of New and Renewable Energy

Here you see some of the statistical information. As on March 31st 2021 these are the top solar electricity generators Karnataka 7 355 megawatts, Rajasthan 5732 megawatts, Gujarat 4430 megawatts. The figure shows the region-wise solar plant installed capacity, and the reference is the ministry of new and renewable energy.

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Classification of solar power generation technologies

- The solar associated power generation technologies can be broadly divided into two categories
 - solar photo-voltaic power (PV)
 - Concentrated solar power (CSP)
- Solar PV works on photoelectric effect to directly convert the solar energy into electrical energy.
- On the other hand, CSP works on the principal of light-heat-electricity conversion.

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When we talk about the potential of solar power generation, the question arises: how can we classify all these solar power generation technologies. So, the solar-associated power generation technology can be broadly divided into two categories: solar photovoltaic power, i.e., PV, then concentrated solar power, a CSP. So, solar photovoltaics work on the photoelectric effect to convert solar energy into electrical energy directly into electricity.

On the other hand, the concentrated solar power system it works on the principle of light heat electricity conversion.

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Classification of solar power generation technologies

- The absorbed heat is first utilized to produce steam using a solar collector. The produced steam drive the turbine to generate electricity.
- Solar PV is a well-studied field, but it contains some technical issues unresolved.
- PV panels used in such systems pose environmental concerns associated to their manufacturing and recycling steps.

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The absorbed heat, whatever is absorbed through the sun, is first utilized to produce steam using a solar collector. The produced steam drives the turbine to generate electricity. Solar

photovoltaic is a well-studied field, but it contains some unresolved technical issues. The photovoltaic panels used in such a system pose environmental concerns associated with their manufacturing and recycling steps.

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Classification of solar power generation technologies

- Second, it does not generate power reliably as it is directly related to the intensity of upcoming sun rays and the angle of incidence, both changes throughout the day, leading instability in the grid.
- The serious wastage of light is observed in these systems.
- One way to resolve such issue is the use of storage devices for smoother operations, but it reasonably increases the cost of cost of production.
- Hence, the use of batteries are not widely accepted in market.

The slide also features a small video inset in the bottom right corner showing a man speaking, and a footer with a logo and the number 11.

Second, it does not generate power reliability as it is directly related to the intensity of upcoming sun rays and the angle of incidence—both change throughout the day, leading to instability in the grid. In the morning, the intensity of the solar radiation may be on the lower side, and then it may be peaked during the middle of the day. And during the evening it gradually goes down and similarly the direction because sun usually moves in a different direction.

So, it creates a lot of instability. The serious wastage of light is observed in various systems one way is to resolve such an issue is the use of storage devices for a smoother operation. But when we are using the storage devices, we have the storage batteries, which reasonably increases the cost of production. Therefore the use of batteries is not widely accepted in the market nowadays.

Concentrated solar power can overcome these limitations providing a stable electricity generation system with minimal harm to the environment. The use of a costlier battery is also not required due to its unique heat storage assembly and auxiliary electricity generation parts it integrates the energy storage and electricity generation within the system.

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Classification of solar power generation technologies

- CSP can overcome these limitations, providing a stable electricity generation system with minimal harm to the environment.
- The use of costlier batteries is also not required due to its unique heat storage assembly and auxiliary electricity generation parts.
- It integrates the energy storage and electricity generation within the system.
- Moreover, if the adjustment parameters ensures smoother operation and longer grid life, improving the reliability of these systems.



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Moreover, the adjustment pattern ensures smoother operation and longer grid life, thereby improving the reliability of these systems.

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Classification of solar power generation technologies

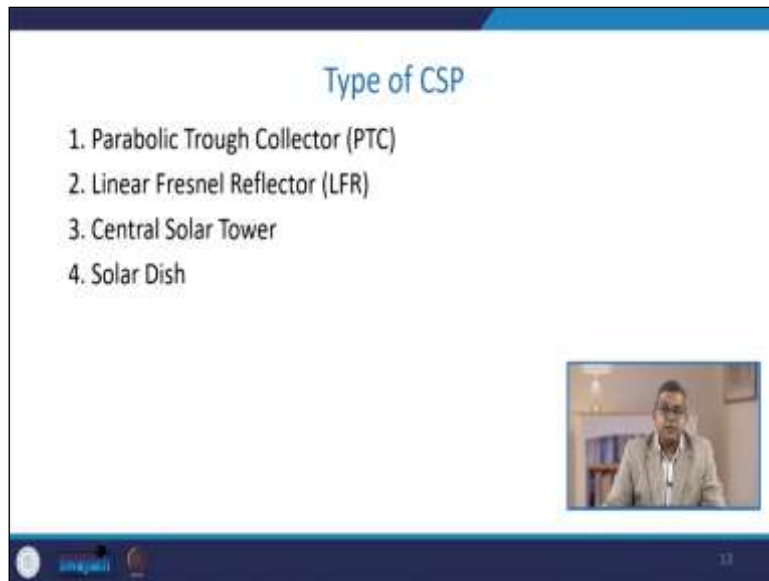
- CSP in near future can help to improve the power generation through free and green Sun energy, helping to reducing the carbon footprints.
- However, at present adoption of CSP seems challenging, mostly because of its higher cost as compared to other resources such as solar PV.



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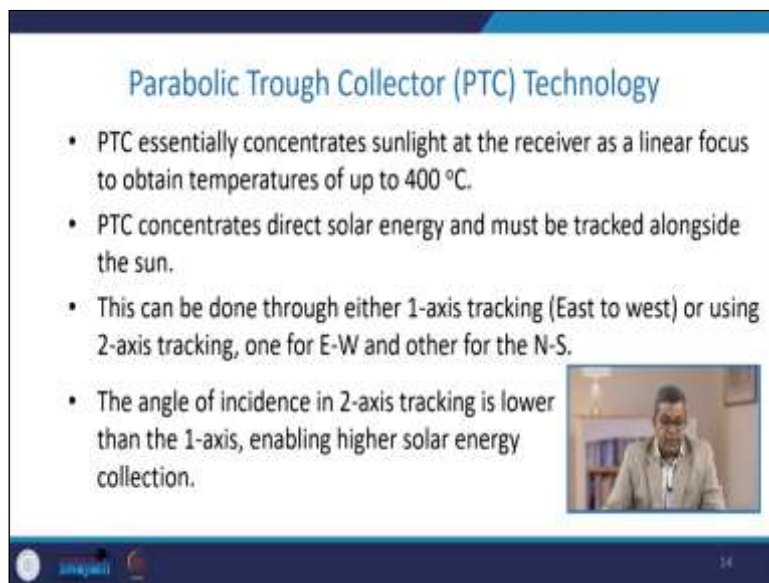
In the future, the CSP can help improve power generation through free and green sun energy, helping reduce the carbon footprint. The adoption of this CSP seems challenging mostly because of the higher cost compared to the other resources, one of the resources solar photovoltaic system. Let us discuss the different types of CSP's.

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One is the parabolic trough collectors (PTC), then linear Fresnel reflectors (LFR), then central solar tower, and solar dish.

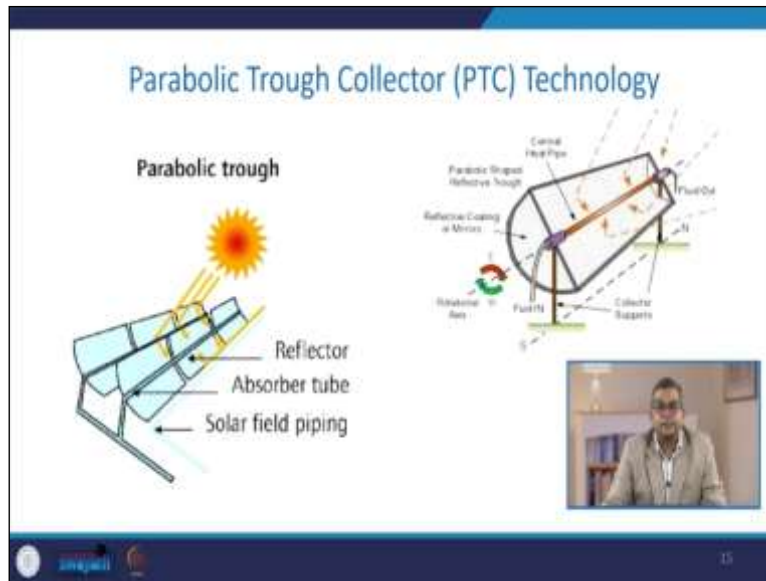
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So, first is the parabolic trough collectors technology PTC. The PTC essentially concentrates sunlight at the receiver as a linear focus to obtain a temperature up to 400 degrees Celsius. It concentrates direct solar energy and must be tracked alongside the sun. So, the moment alongside the sun needs to be tracked. This can be done by either one axis tracking east to west or using two excess trackings, one for east to west and the other from north to south.

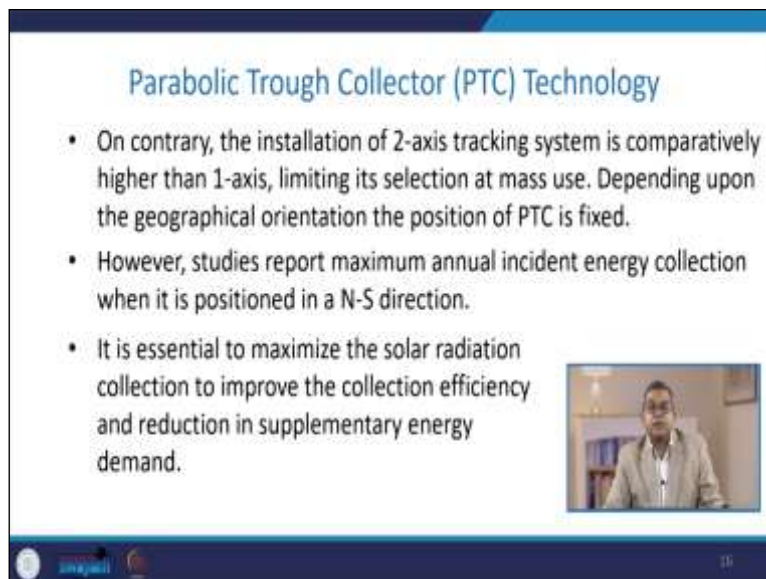
The angle of incidence in two-axis tracking is lower than one axis enabling higher solar energy concentration.

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Here you see this parabolic trough. These are the parabolic reflectors, where sun rays impart and get reflected towards the absorber tube. So, these are the reflectors, the absorber tubes, and the solar field piping. Here you see the anatomy of this parabolic shape reflecting trough, this is a central heat pipe you see the reflective coating mirrors, and this is the rotational axis you see that which we are discussing the east to west and north to south and these are the supports.

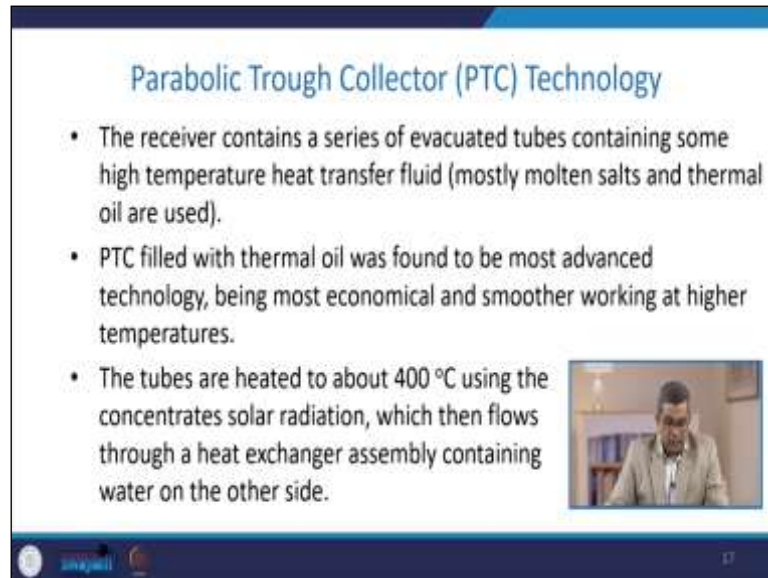
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On the contrary, installing a 2-axis tracking system is comparatively higher than one axis, limiting its selection at mass use. Depending upon the geographical orientation, the PTC position can usually be fixed. However, studies report the maximum annual incidence to incident energy collection when it is positioned in the north to south direction.

It is essential to maximize the solar radiation collection to improve the collection efficiency and reduction in supplementary energy demand.

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Parabolic Trough Collector (PTC) Technology

- The receiver contains a series of evacuated tubes containing some high temperature heat transfer fluid (mostly molten salts and thermal oil are used).
- PTC filled with thermal oil was found to be most advanced technology, being most economical and smoother working at higher temperatures.
- The tubes are heated to about 400 °C using the concentrates solar radiation, which then flows through a heat exchanger assembly containing water on the other side.

The receiver contains a series of evacuated tubes containing some high-temperature heat transfer fluid. This can be a molten salt, thermal oil, or synthetic oil. Depending on the use and how much heat transfer capacity you require, it can be used. These are filled with thermal oil, the most advanced technology, and the most economical and smoother working at high temperatures.


These tubes are heated to about 400 degrees Celsius using the concentrated solar radiation which then flows through a heat exchanger assembly containing water on the other side. So heat transfer can take place the high pressure superheated steam is thus produced using this particular approach. Whatever steam you produce is then passed through our conventional steam turbine power generator to produce the electricity. So, it is clubbed with the power generation unit.

So, first, the concentration of solar irradiation then heats the thermic fluid and then passes on the absorbed energy or heat to the water to generate the steam, and the steam then used as the power generation plant to the power to generate power or to generate electricity. So, whatever steam is used in the course of time, it can be cooled to the condenser to improve the pumping efficiency on the compression cycle.

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Parabolic Trough Collector (PTC) Technology

- A high pressure superheated steam is produced using this approach.
- The produced steam is then passed through a conventional steam-turbine power generator to produce the electricity.
- The used steam is then cooled through the condenser to improve the pumping efficiency on compression cycle.
- The compressed water is then again recirculated through the series of heat exchangers. The cycle continues and a stable electrical output can be obtained through this process.




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The compressed water is then again recirculated through the heat exchanger series, and the cycle continues and stable electrical output can be obtained through this process.

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Parabolic Trough Collector (PTC) Technology

- The advantages of PTC system are associated to its lower operational cost, easy scale-up and integration, handy operation, and wide acceptability in Indian perspectives.
- Several innovations are underway pertaining to a domestic use of PTC in cooking and heating applications.



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The advantages of this PTC system are associated with its lower operational cost you can easily scale up and integrate it is very handy to operate, and has wider acceptability in a local perspective. Several innovations are still occurring in the domestic use of PTC in cooking and heating applications because a sizeable quantum of energy is being consumed in these two domestic operations.

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Parabolic Trough Collector (PTC) Technology

Some commercial uses of PTC technology include;

- 50 MW PTC based Solar Thermal Power Plant was commissioned in Rajasthan
- A grid-connected solar thermal power plant was commissioned at Gurgaon, New Delhi.
- It generates a high pressure steam at 350 °C and 42 bar, generating electricity up to 220 MWh/month with a capacity of 1 MWe (megawatt electric) at direct normal irradiance of 600 W/m².



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There are some commercial uses of the PTC technology, including the 50 megawatts PTC-based solar thermal power plant commissioned in Rajasthan. A grid-connected solar thermal power plant was commissioned at Gurgaon, New Delhi. Usually generates high-pressure steam at 350 degrees Celsius and 42 bar, and it can generate electricity up to 220 megawatts with a capacity of one megawatt electric at direct normal irradiation of 600 watts per meter square.

Let us discuss the linear fresnel reflectors technology LFR. The term fresnel in the LFR technology comes from the name of a fresnel lens, which consists of multiple reflecting planes which help to enhance the concentration of light coming from different direction in different angles.

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Linear Fresnel Reflector (LFR) Technology

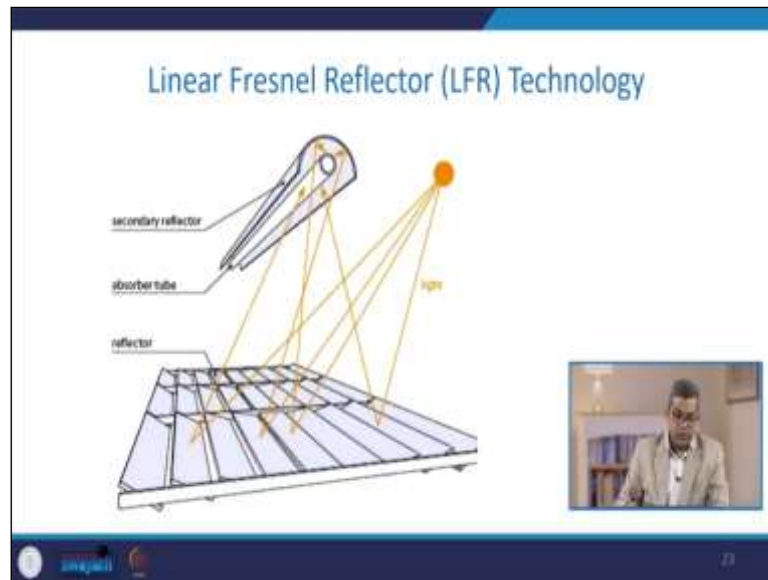
- The term Fresnel in the LFR technology comes from the name of Fresnel lens which consists of multiple refracting planes which helps to enhance the concentration of light coming from different directions in different angles.
- Later, this technology was modified to obtain a linear and a two-axis tracking Fresnel steam-generation system.
- LFR works as mixed power tower and PTC system, containing a fixed receiver pipe whereas mirrors tracks using control devices.



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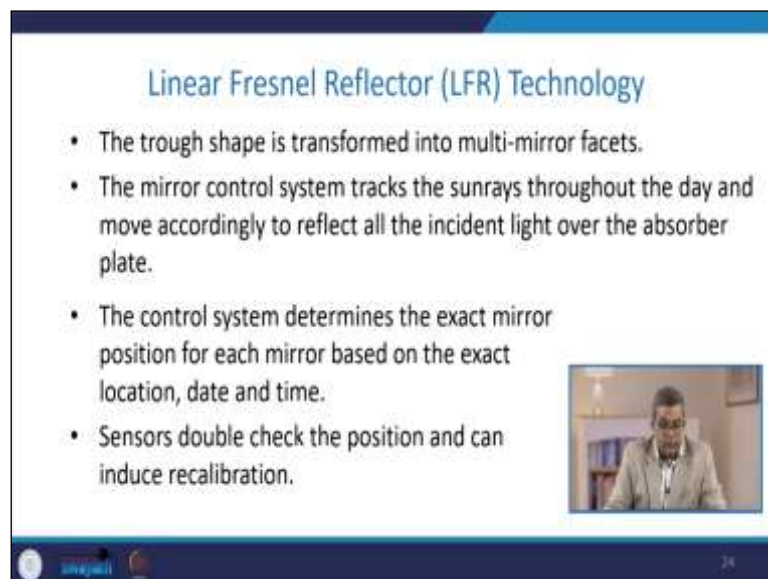
Later on, this technology was modified to obtain a linear and two-axis tracking of the fresnel system, which helped the steam generation system. This LFR works as a mixed power tower and PTC system containing a fixed receiver pipe whereas mirror tracks use control devices.

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Here you see that these are the LFR technology. We have the reflectors, and there are secondary reflectors which comprises of absorber tubes. So, when light passes on these first-hand reflectors, it goes to these secondary reflectors, and whatever the thermic fluids are there, it can get absorbed the solar energy.

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So, this trough surface is transformed into a multi mirror facet. The mirror control system tracks the sun rays throughout the day and moves according to the reflection accordingly

to reflect the incident light over the absorber plate. The control system determines the exact mirror position for each mirror based on the exact location, date, and time. Sensors usually be double check the position and can induce recalibration.

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Linear Fresnel Reflector (LFR) Technology

- All mirrors are in a different angle as the relative position (sun – mirror – absorber tube) is different.
- The mirrors can be flat or slightly curved, reflecting the light rays towards the linear collector containing SS absorber tubes.
- The collector can be a fixed absorber tube placed at a common focal line of the reflecting mirrors.
- The reflectors can have a single or dual axis tracker, allowing maximum collection of solar radiations in a day.

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So, whatever mirrors are being used in this LFR technology are at a different angle as the relative position that is a sun mirror, or absorber tube is different. These mirrors can be flat or slightly curved, reflecting the light rays towards the linear collector containing stainless steel absorber tubes. The collector can be a fixed absorber placed at a common focal line of the reflecting mirror.

The reflectors can have a single or a dual-axis tracker allowing maximum collection of solar radiation in a day. The secondary concentrator is also used to place the rays according to the accepting angle the radiation missing the absorber tube hits the secondary reflector, which again concentrates the radiation on the absorber tube.

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Linear Fresnel Reflector (LFR) Technology

- A secondary concentrator is also used to place the rays according to the accepting angle. The radiation missing the absorber tube hits the secondary reflector which again concentrates the radiation on the absorber tube.
- The receiver is surrounded by secondary compound parabolic collector (CPC) reflector which directs the concentrated reflected beam to the absorber tube.





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And usually, the receiver is surrounded by a secondary compound parabolic collector (CPC), which directs the concentrated reflected beam to the absorber tube.

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Linear Fresnel Reflector (LFR) Technology

- Whole system consisting of CPC reflector and receiver with two SS tubes are walled in glass casing. This unit can be evacuated as the vacuum reduces the heat losses from the absorber pipe.



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The LFR technology whole system consists of a CPC reflector and receiver with two stainless steel tubes walled in a glass casing. You can see this tube, and this is the glass casing. This unit can be evacuated as the vacuum reduces the heat loss from the absorber pipe. So, these are the absorber pipes, and if you put a vacuum, the heat loss can definitely be minimized.

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Linear Fresnel Reflector (LFR) Technology

- The absorber tube having recirculating heat transfer fluid is heated to produce superheated steam which then finally used to produce electricity through steam-turbine generator.
- The fluid transports the heat to a process where it transfers the heat via heat exchangers. Later it is re-circulated through the absorber tube.



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The absorber tube has the recirculating heat transfer fluid, which is heated to produce superheated steam, which is then used to produce electricity through steam turbine generators. The fluid transports the heat to a process where it transfers the heat via heat exchangers, and later it is recirculated through the absorber tube. The modified LFR system allows water to act as a transfer fluid or heat transfer media.

This produces steam as high as 285 degrees Celsius inside the absorber tube, and by this way, you can reduce the cost of additional heat exchanger assembly.

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Linear Fresnel Reflector (LFR) Technology

- Modified LFR system allows water to act as a transfer fluid, producing steam as high as 285 °C inside the absorber tube, reducing the cost of additional heat exchanger assembly.
- The produced steam can be directly used to move turbine and generate electricity.



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The produced steam can be directly used to move the turbine and generate electricity. So, you may eliminate the requirement of the additional heat exchanger.

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Uses and limitations of LFR

- The LFR is a low temperature rising system with less efficiency and reduced performance as compared with other CSP systems.
- However, simplified design and standalone operation makes it a cheaper alternative and allows its use in small scale and remote areas.
- The use of flat mirrors and fixed CPC unit makes it economical in installation perspective.



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There are certain specific uses and apart from this limitation of LFR. This LFR is a low-temperature rising system with less efficiency and reduced performance as compared to other CSP systems. Simplified design and standalone operation make it a good candidate because it is a cheaper alternative and allows its use in small-scale and remote areas. The use of flat mirrors and fixed CPC units make it more economical from the installation perspective. So, it is economically feasible in this respect.

It also provides the enhanced land consumption than linear to, and a power tower system, and it can be combined with the working of a fossil fuel production system for energy generation throughout the day.

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Uses and limitations of LFR

- Moreover, it provide enhanced land consumption than linear trough and power tower systems and can be combined with working fossil fuel production systems for energy generation throughout the day.
- There is neither a (optional) vacuum nor metal-glass sealing requirements in LFR.
- Also, due to the reduced wind load on the reflector plates, its width can be increased to about three times as compared to the parabolic troughs.



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There is neither a vacuum no matter glass sealing requirement in LFR, and also due to the reduced wind load on the reflector plate, its width can be increased to about three times as compared to the parabolic row. However, we have other technologies. So, when compared with the PTC technology, the power per unit of land area in LFR is smaller. Therefore, it opens a new avenue because it offers more revenue for the research and more research is needed in this field to utilize more areas, such as the reason beneath the collector.

The industry is a significant energy user, especially the chemical industry accounting for over 30 of the total final energy consumption process heat accounts for approximately 67% of overall industrial energy consumption. Sometimes a significant portion, approximately, you can say 57% of the total process heat demand is in the medium temperature range, that is around 400 degrees Celsius.

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The slide is titled "Uses and limitations of LFR" and contains the following text:

- However, when compared with PTC technology, the power per unit land area in LFR is smaller. Hence, more research is required in this field to utilize more area such as the region beneath the collector.
- Industry is a significant energy user, accounting for over 30% of total final energy consumption.
- Process heat accounts for approximately 67% of overall industrial energy consumption. A significant portion, approximately 57% of total process heat demand, is in the medium temperature range (400 °C) and may be met using LFR technology.

A small video inset in the bottom right corner of the slide shows a man speaking. The slide also features a blue header and footer with some logos.

And maybe met using this LFR technology.

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Uses and limitations of LFR

- In industrial processes, process heating is a major consumer of heat energy.
- It is typically provided using heat exchangers from a distribution grid, allowing uncontacted heat transfer with sustained purity.
- Steam is the most common heat transport fluid used in industries.
- An industrially adapted LFR collector may directly create saturated or superheated steam.




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Industrial processes process heating is usually a major consumer of heat energy usually are typically provided using heat exchangers from a distribution grid, allowing uncontacted heat transfer with sustained purity. Steam is the most common heat transport fluid used in this particular industry. The industrially adopted LFR collector many directly created create saturated or superheated steam, and thereby it can be used in the steam power generation plant.

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Uses and limitations of LFR

- Thermal oil or pressurized water can also be utilized as heat transfer fluids, and both are well-suited for integration into solar process heat solutions.
- Solar cooling solutions are also available to compensate the cooling requirements.
- Similarly, areas with DNIs (Direct Normal Irradiation) greater than $1,500 \text{ kWh/m}^2$ are best suitable for solar process heat applications using Industrial Solar Fresnel collector technology.



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Thermal oil or pressurized water can also be utilized as a heat transfer fluid, and both are well suited for integration into solar process heat solution. So, solar cooling solutions are also available to compensate for the cooling requirement. Similarly, when we talk about the direct normal irradiation which is greater than 1500 kilowatt-hour per meter square at

the best suitable for solar process heat application using the industrial solar phenol collector technology.

So, at the outset, we discussed the solar energy different types of solar system solar energy production systems being used.

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For convenience, we have enlisted for references. Further reading is needed then you can have a look at these references, thank you very much.