

Lecture 19: Solar Thermal Energy

Course: MECH-422 – Power Plants

Instructor: Kashif Liaqat

Term: Fall 2021

BUITEMS – DEPARTMENT OF MECHANICAL
ENGINEERING

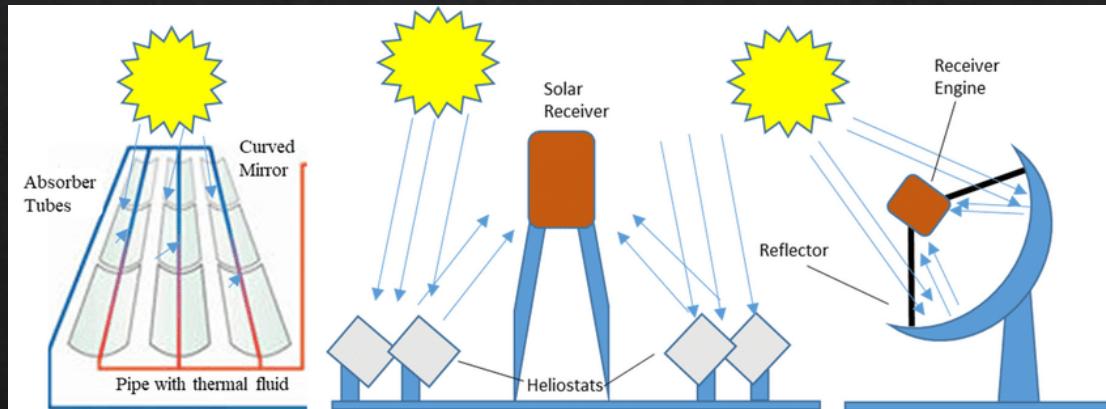


What is Solar Thermal?

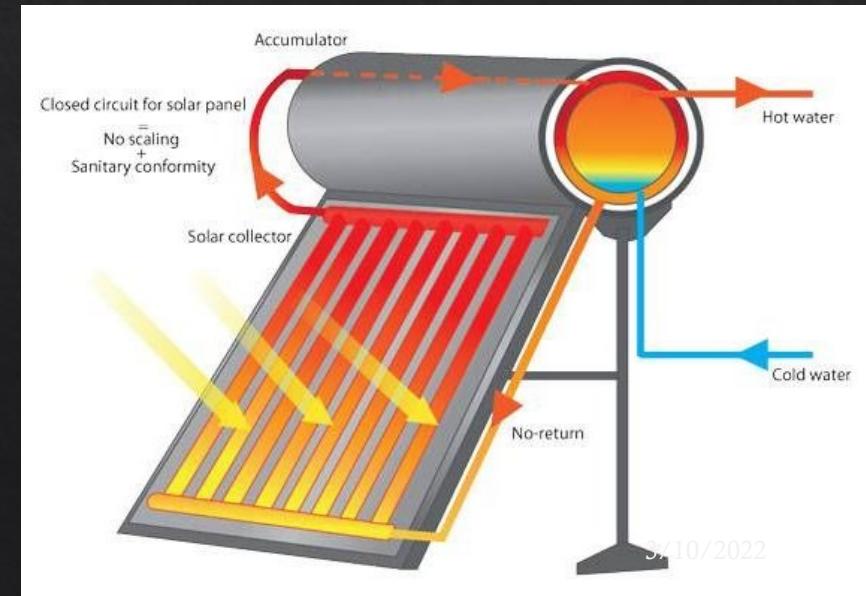
- ❖ Solar radiation can be converted either into thermal energy (heat) or into electrical energy.
- ❖ Solar thermal generates energy indirectly by harnessing radiant energy from the sun to heat fluid, either to generate heat, or electricity.

Solar collectors

- ❖ Solar collectors are the devices used to absorb the energy from the sun and repurpose it for direct or indirect human consumption.
- ❖ As solar collector designs have improved two main classification for solar thermal collectors have emerged.
 1. Non-concentrating collectors
 2. Concentrating collectors



Concentrating collectors



Non-concentrating

Types

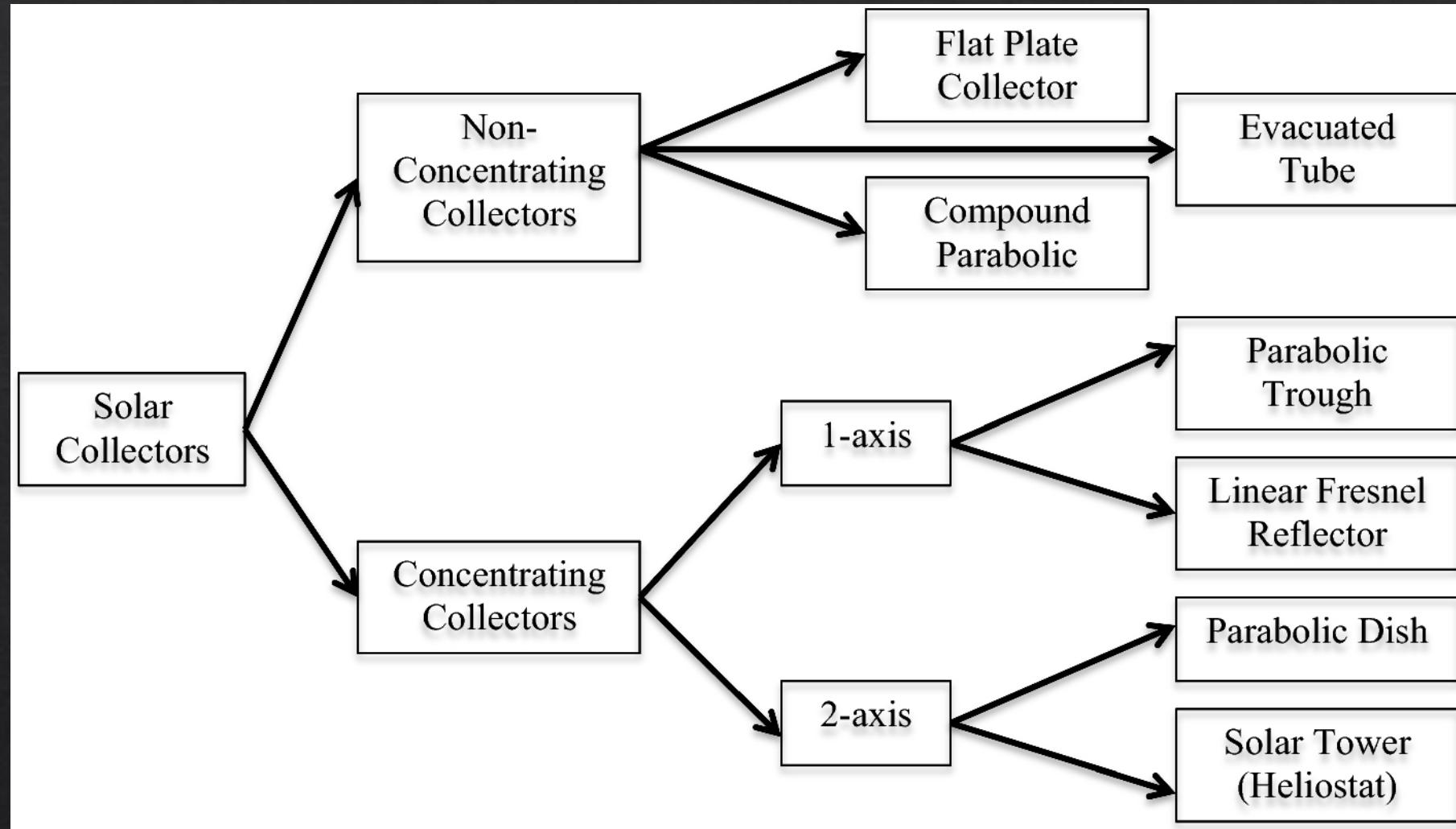
Non-Concentrated (Uses both diffuse and direct components of solar irradiance)



Concentrated (Uses the direct component only)



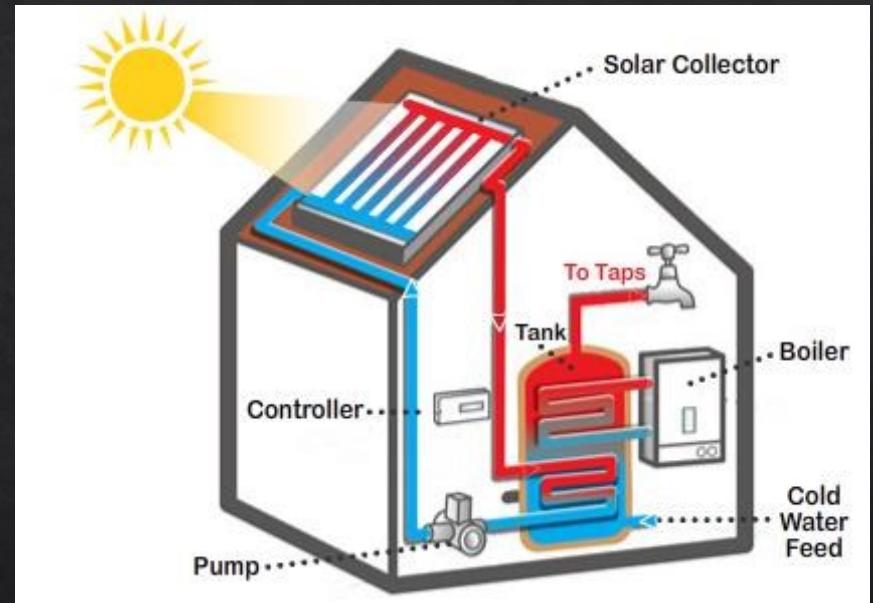
Solar concentrators are the devices that collect **solar** radiation and concentrate at a single focal point.



Non-Concentrated

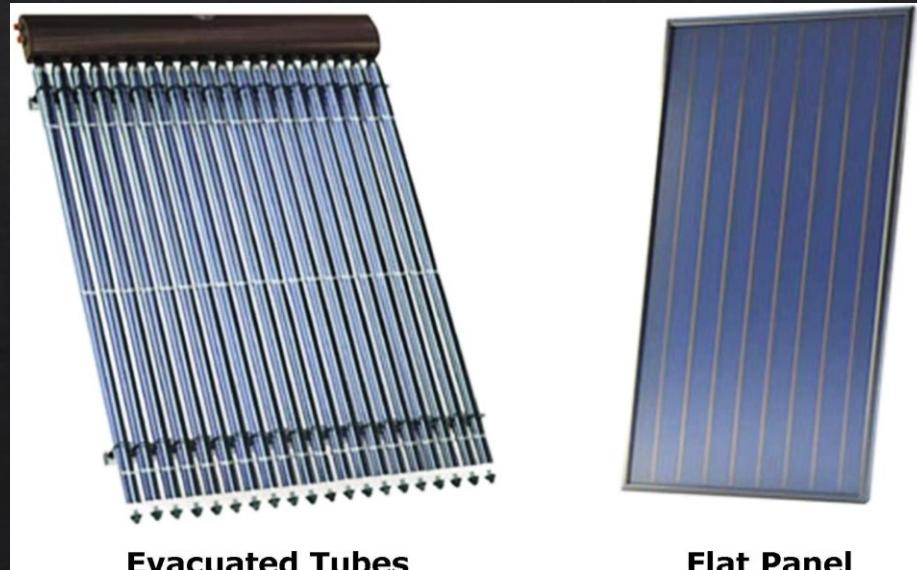
Solar Water Heaters

- Solar Thermal is a clean, highly efficient means of using energy from the sun to provide hot water for domestic, commercial and industrial process.
- Example if you place a container full of liquid in the garden on a sunny day, in a short time the contents of the container become warm.
- Solar Collectors work in much the same way but are very more efficient.



Non-concentrating collectors

- ❖ Evacuated tube collectors (ETC) and flat plate collectors (FPC) and are the main commercial non-concentrating collectors.
- ❖ The working fluid temperatures can range between 303 and 423 K depending on the collector system.
- ❖ Widely used for solar heating systems

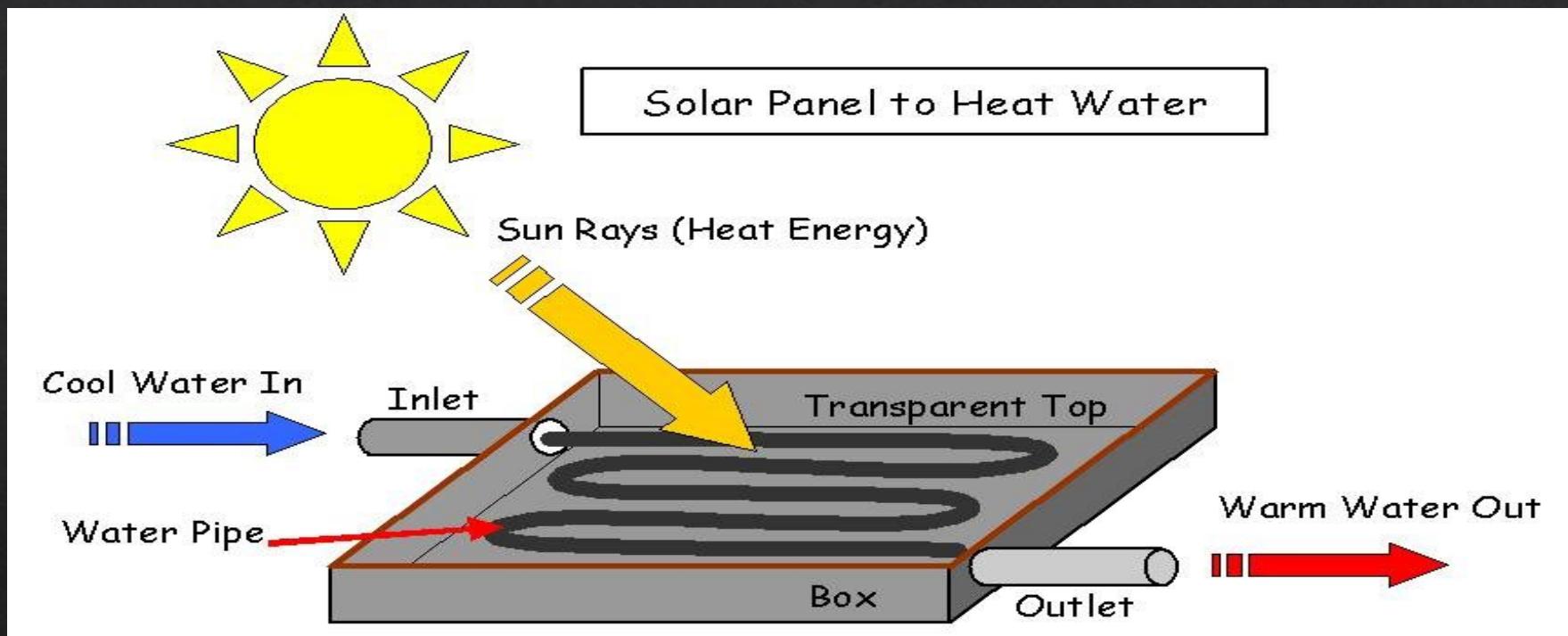


Flat Plate Collector

- It can easily achieve a temperature 60-80°C above ambient temperature.
- It uses both beam and diffuse radiation.
- Does not require tracking.
- Requires little maintenance.
- Efficiency: ~ 45% at 80°C
- Applications: air heating, water heating, industrial process heating, passive air conditioning.

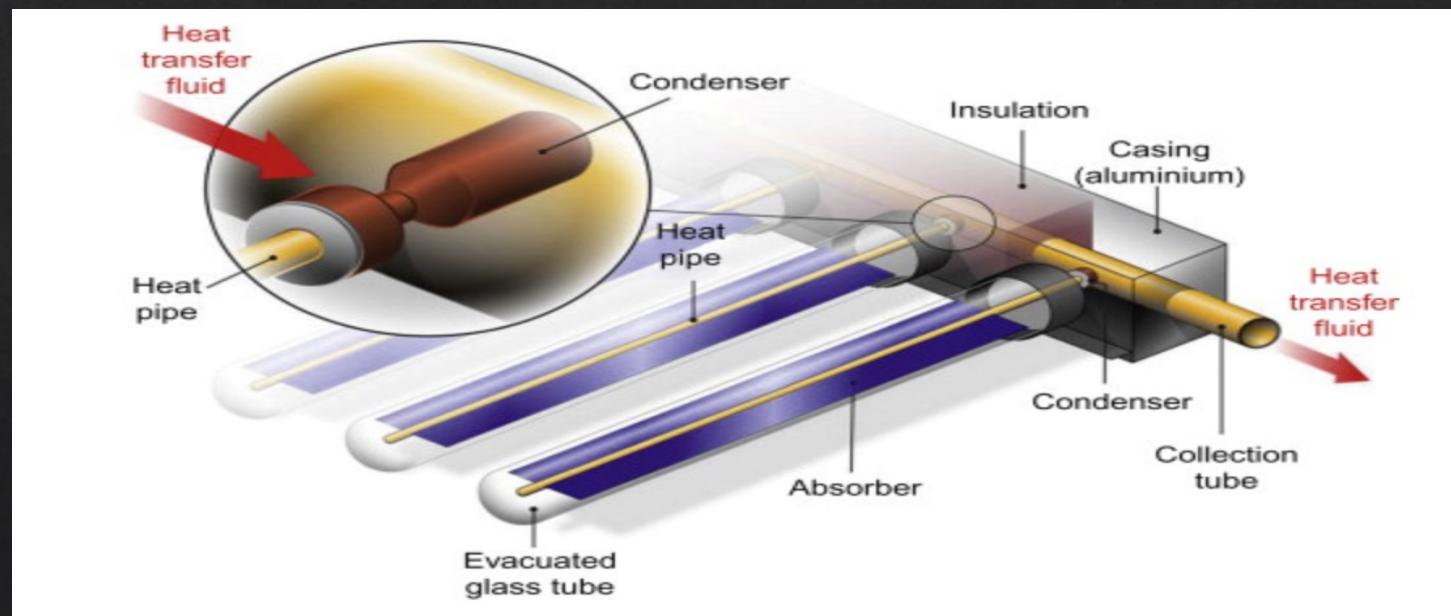


Flat Plate Collector



Evacuated Tube Collector

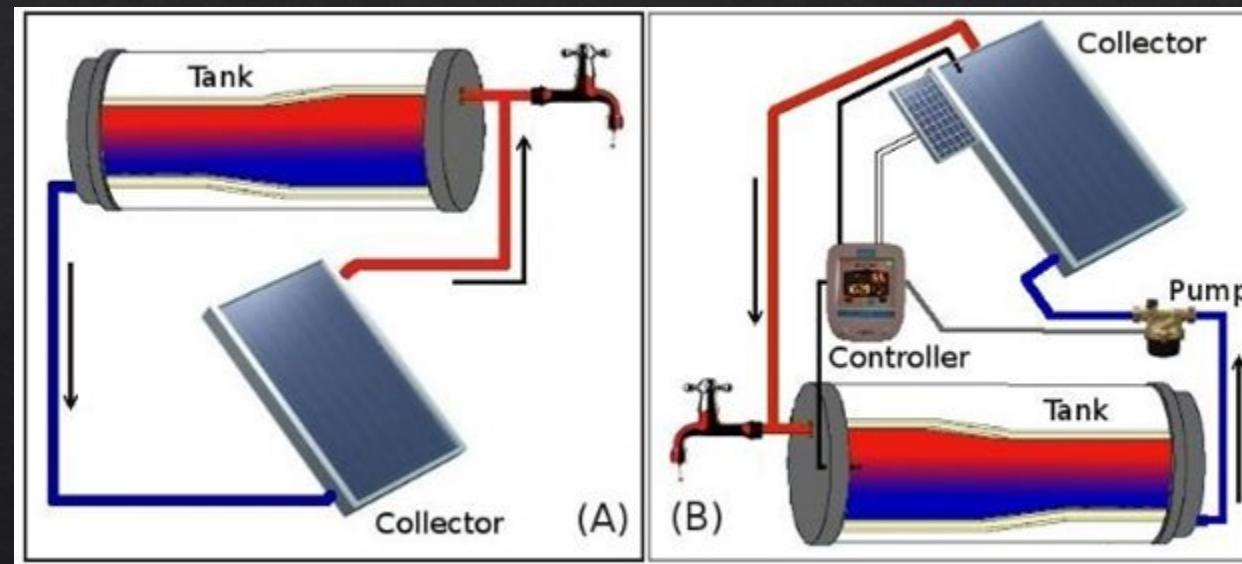
- ◊ An evacuated-tube collector consists of a set of modular tubes, where convective heat losses are minimized by virtue of the vacuum in the tubes.
- ◊ Compared with FPCs, ETCs have better performance in producing high temperatures.



Active/Passive solar water heater

(A) Passive System: Uses Thermosiphon effect

(B) Active System: Uses Pumping system





A natural-circulation solar water heater (SWH). (By Gilabrand at English Wikipedia, CC BY 2.5, <https://commons.wikimedia.org/w/index.php?curid=7954929>)



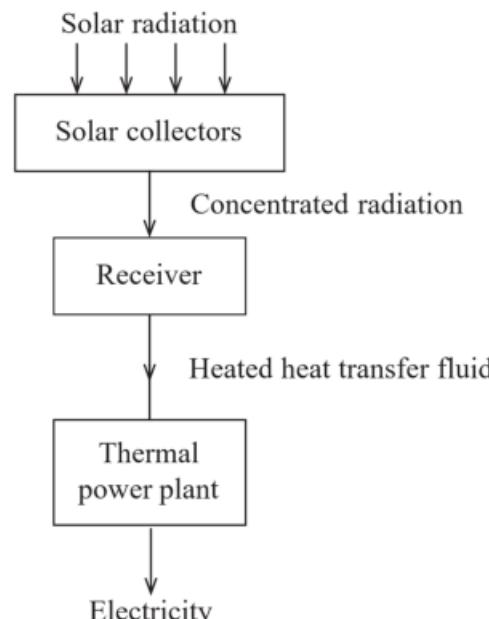
An evacuated tube SWH. (Image by Vijaya Narasimha from Pixabay, <https://pixabay.com/photos/solar-water-heater-shimoga-india-331314/>)

Concentrated

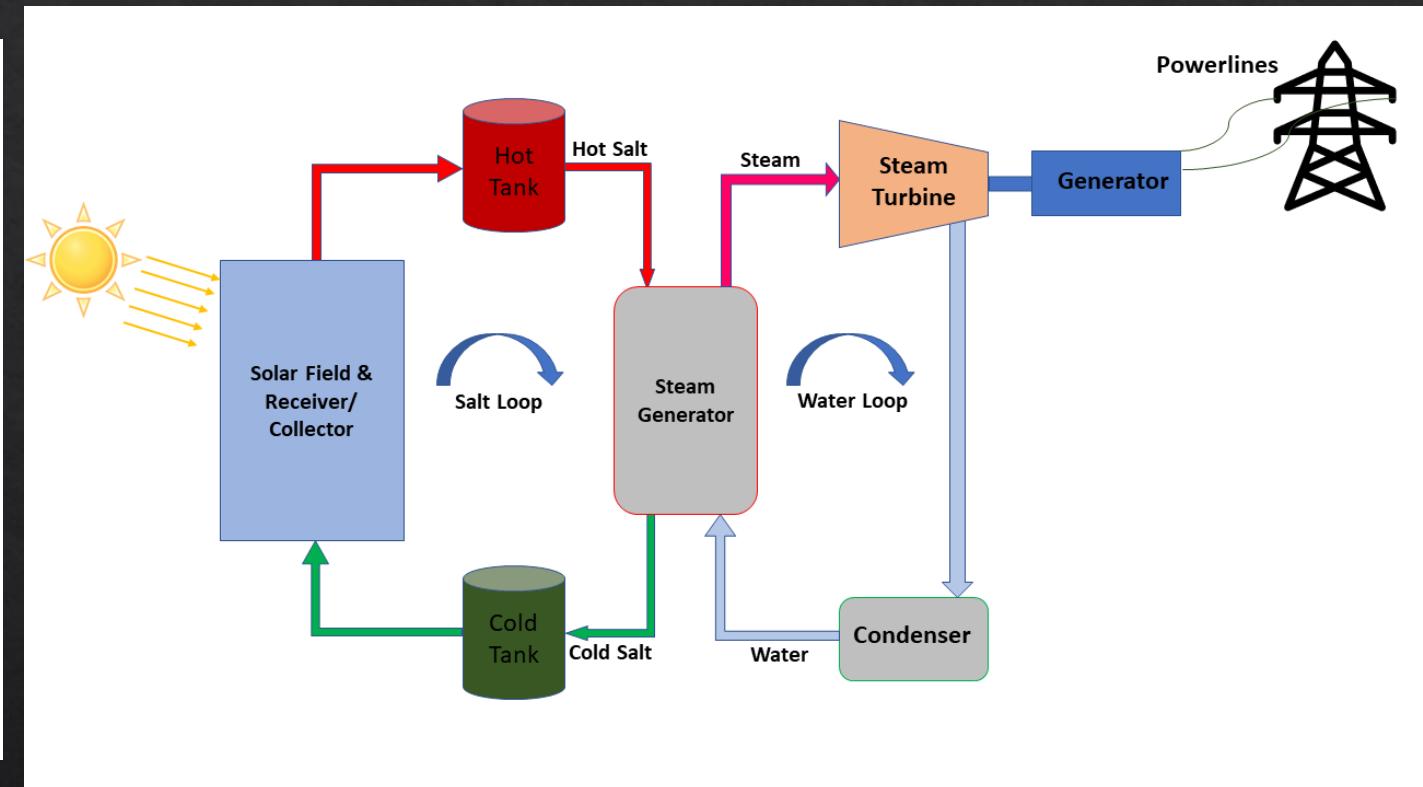
Concentrated Solar Power (CSP)

- ❖ Concentrating Solar Power (CSP) is a type of renewable energy (RE) that uses the sun's energy to generate electricity and process heat.
- ❖ Solar Thermal Power Plants are large scale renewable energy infrastructures using heat produced by contracted solar beams.
- ❖ The produced heat with temperatures of 400°C to 1000°C can be used directly, be transformed into electricity or stored.
- ❖ CSP Plants can remain in operation for almost 40 years and thus demonstrate its durability and reliability.

CSP Power Plants

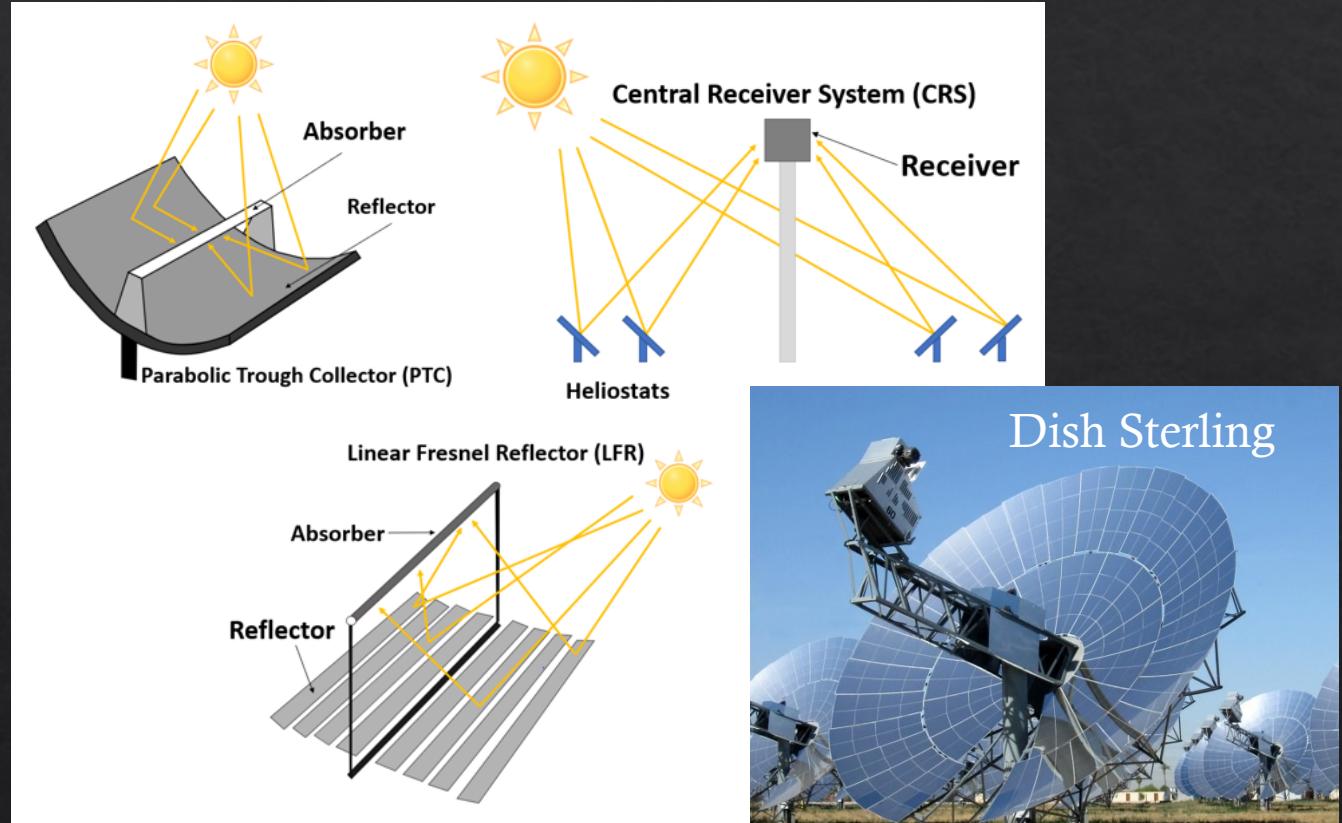


Parts of a solar thermal energy power plant

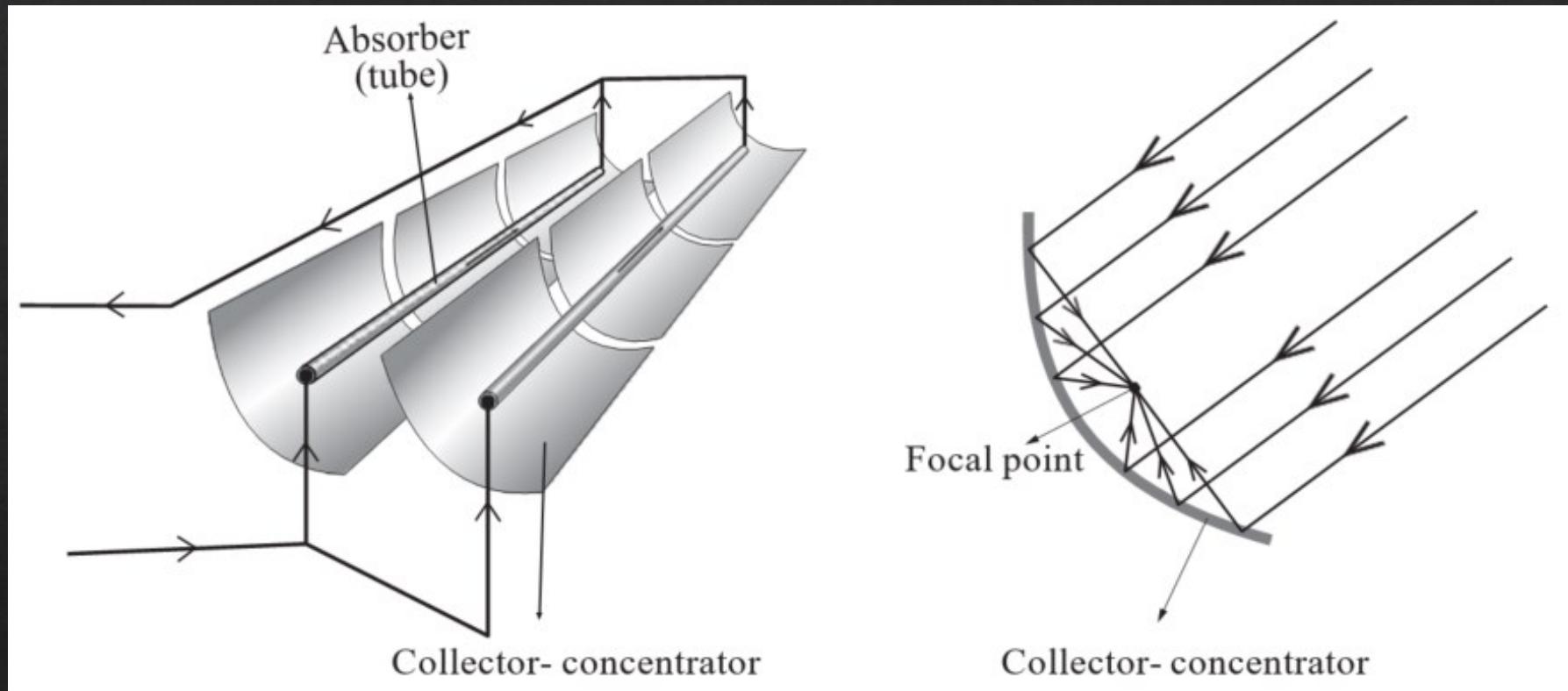


CSP Technologies

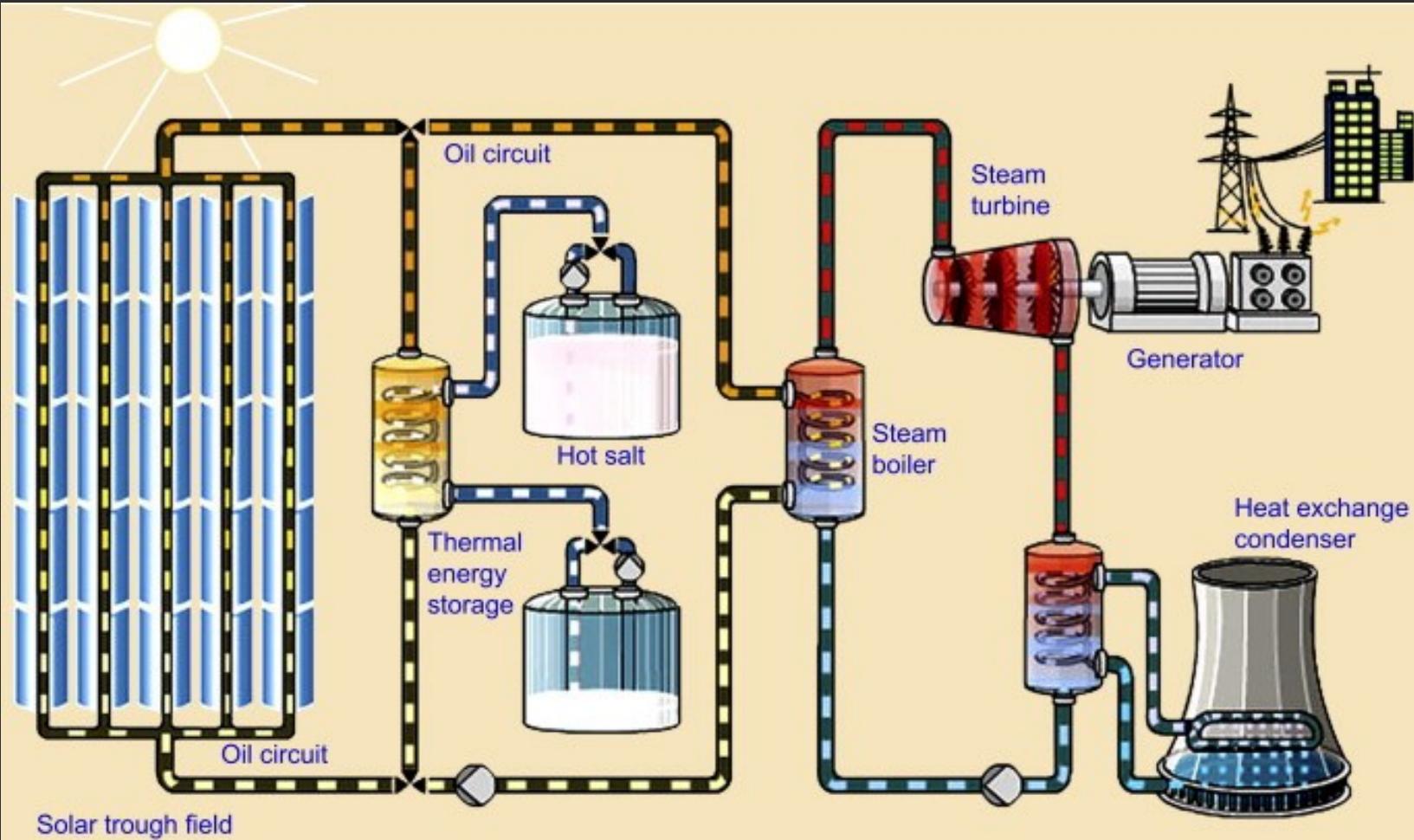
- ❖ Line Focused
 - ❖ Parabolic Trough Collectors
 - ❖ Linear Fresnel Reflectors
- ❖ Point Focused
 - ❖ Central Receiver System/Power Tower
 - ❖ Dish Sterling



Parabolic Trough Collectors (PTC)



Schematic of a parabolic trough concentrator





A parabolic trough concentrator. (By Z22 - Own work, CC BY-SA 3.0, <https://commons.wikimedia.org/w/index.php?curid=27881587>)

354 MW Luz Solar Electric Generating Systems (SEGS)
Nine Plants built 1984 - 1991



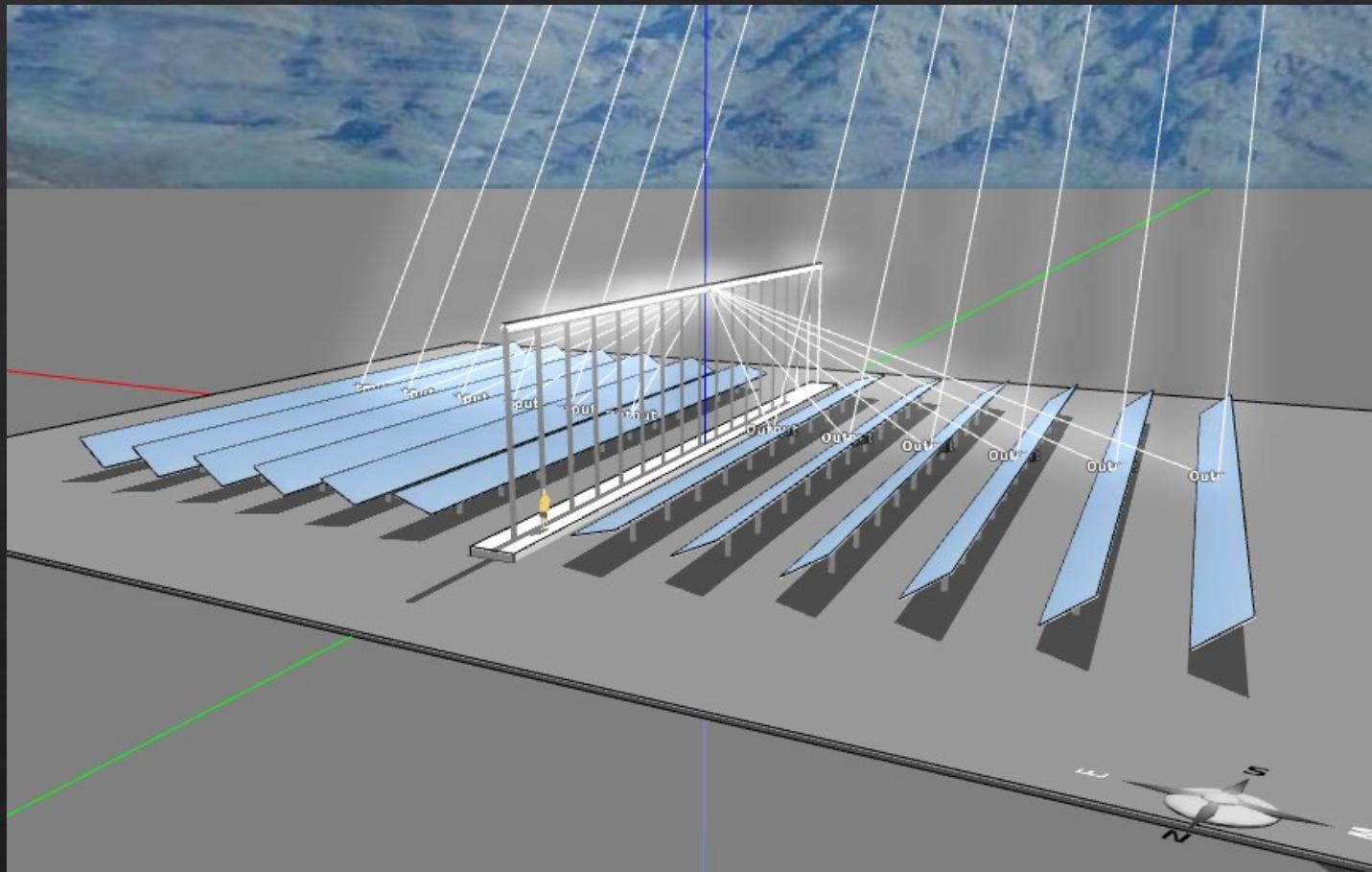
50 MW AndaSol One and Two
Parabolic Trough Plant w/ 7-hr Storage, Andalucía



Abengoa 50MW Trough Plants Seville, Spain

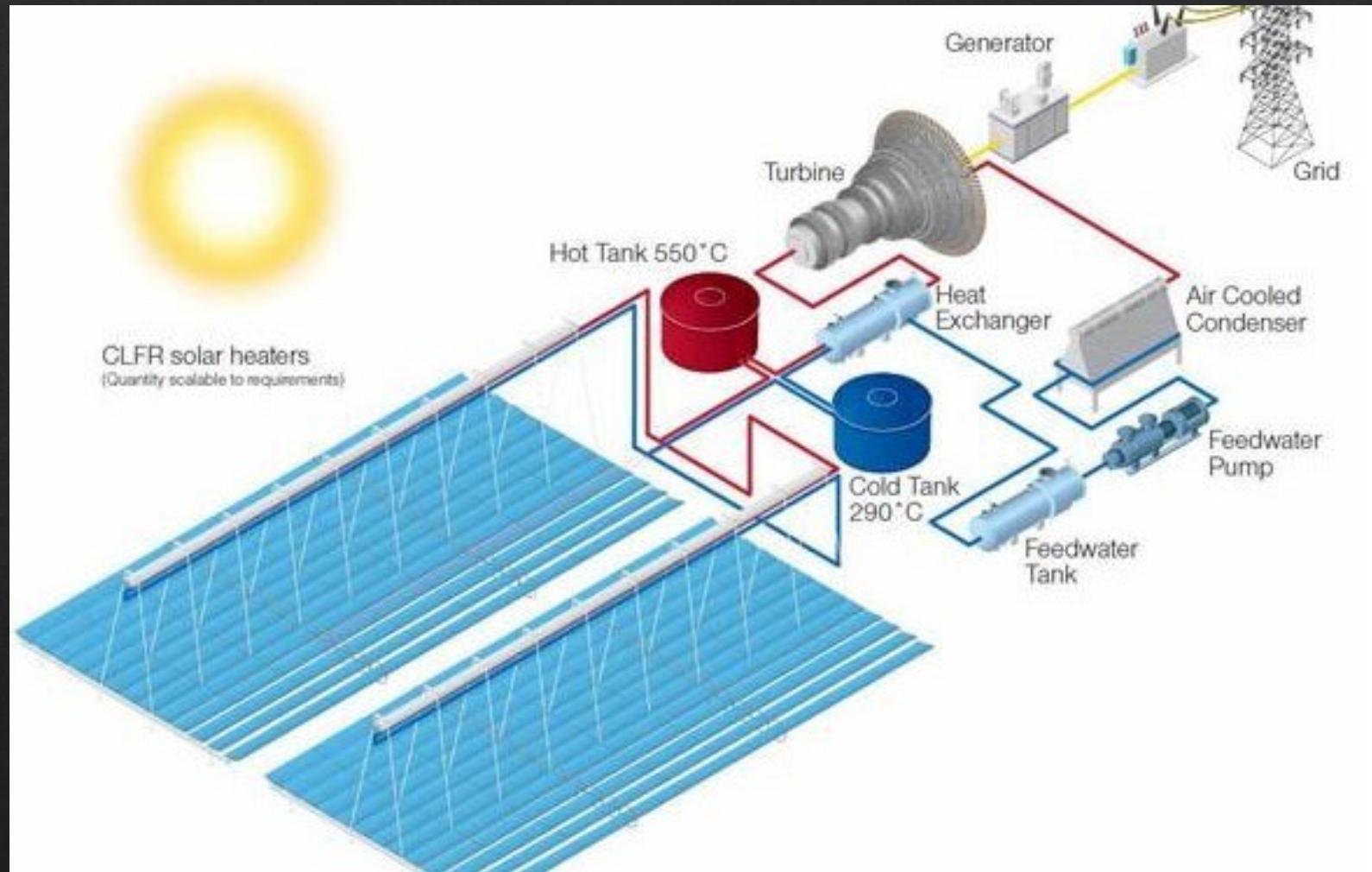


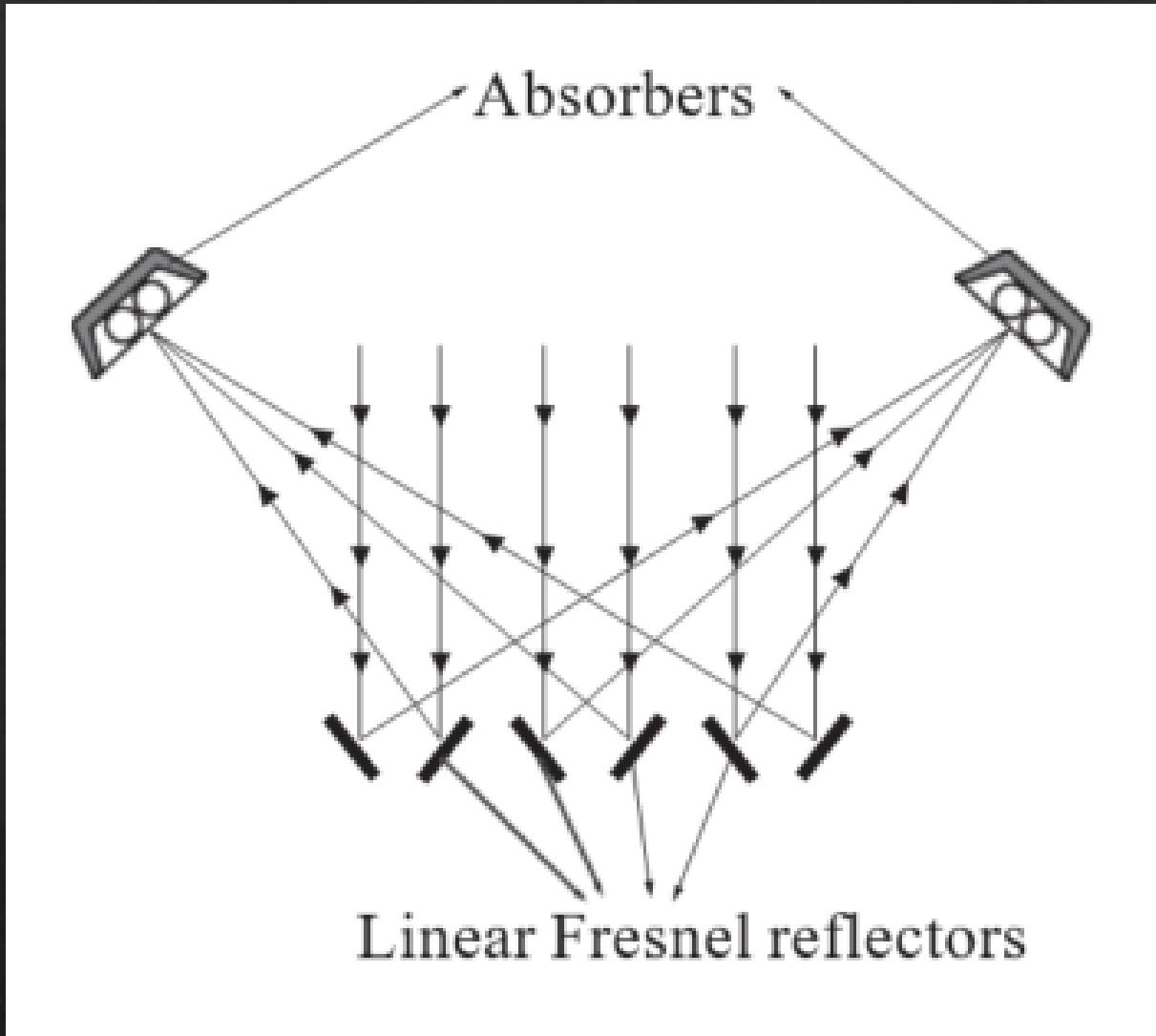
Linear Fresnel Reflectors (LFR)



Linear Fresnel Reflectors (LFR)







Schematic of a line-focus compact linear Fresnel reflector-collector-concentrator

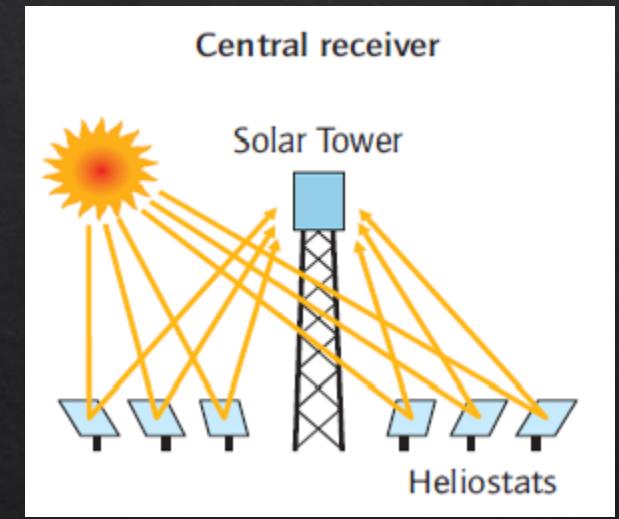
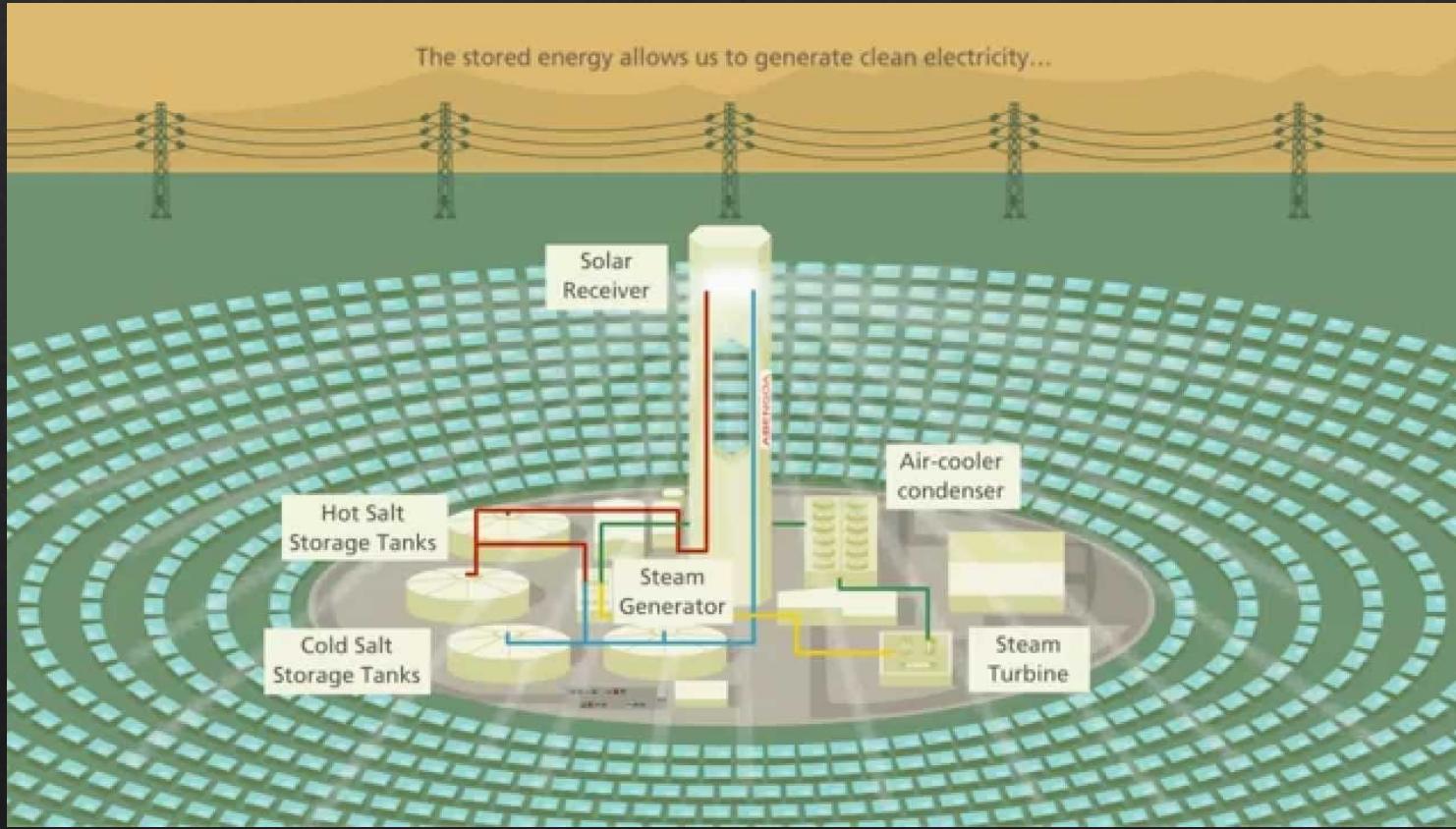


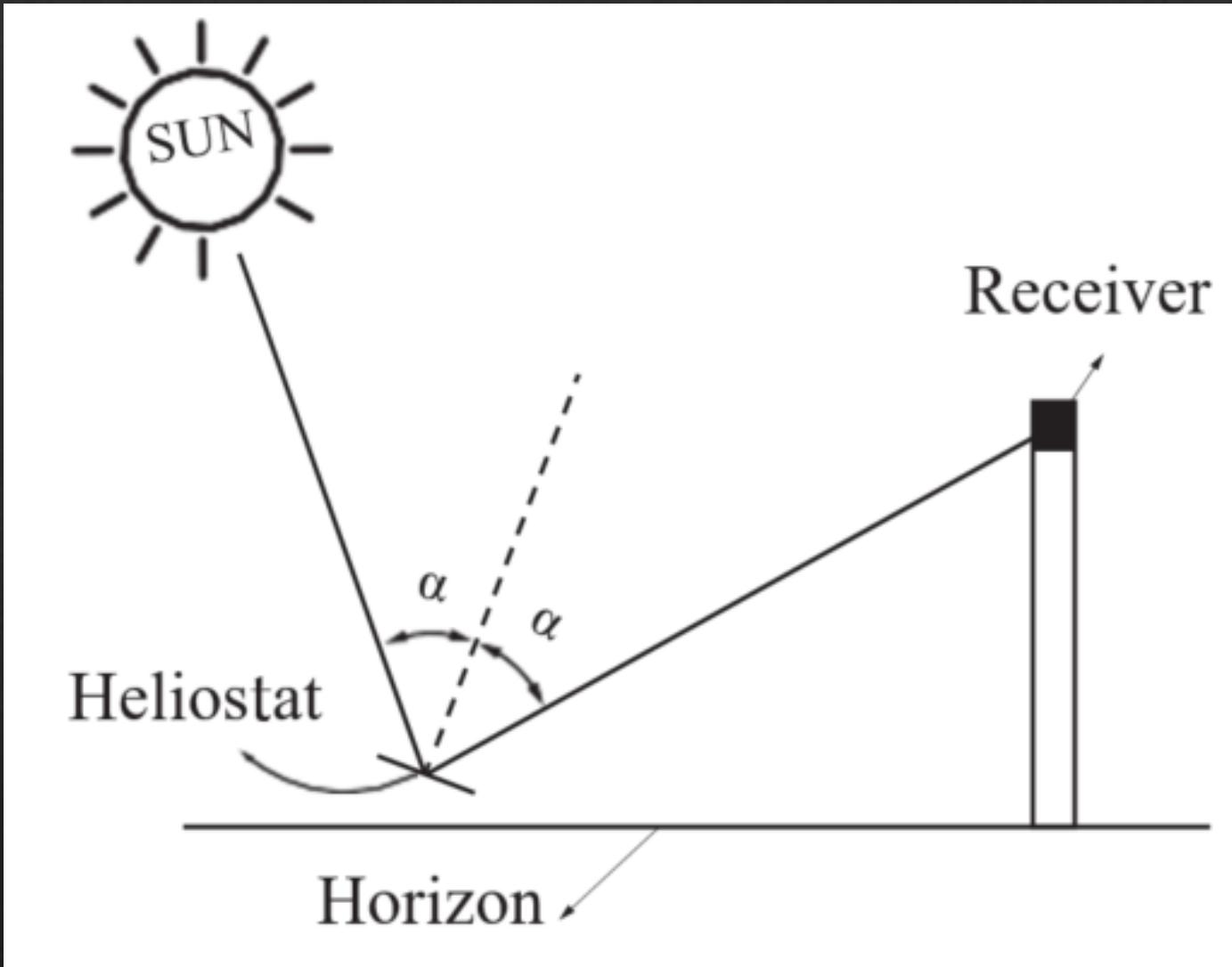
World's First Utility-Scale (50 MW) Molten Salt Fresnel Concentrated
Solar Power Plant Connects to China's Grid - June 19, 2020 -
<https://helioscsp.com/worlds-first-utility-scale-molten-salt-fresnel-concentrated-solar-power-plant-connects-to-chinas-grid/>

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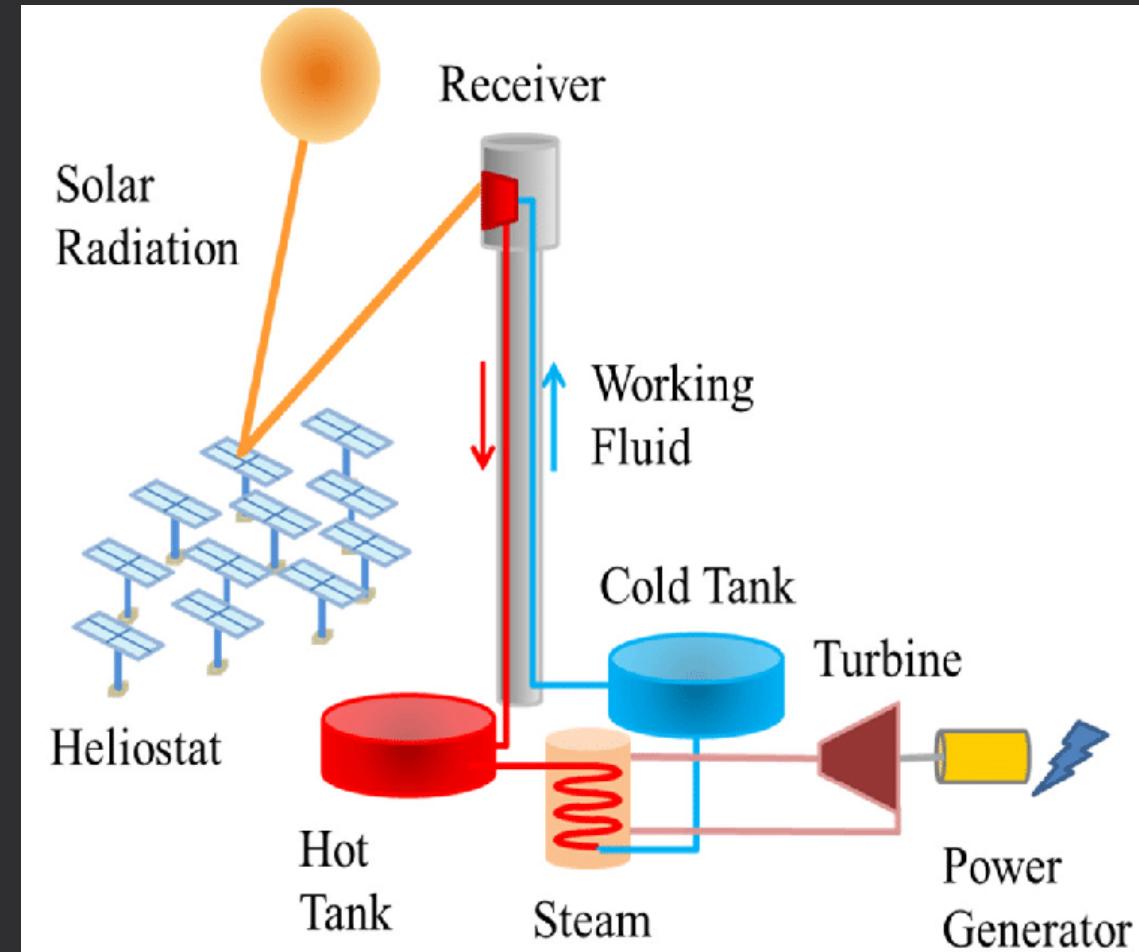
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Central Receiver System (CRS) / Solar Power Tower (SPT)





Schematic of reflection of solar radiation on a heliostat

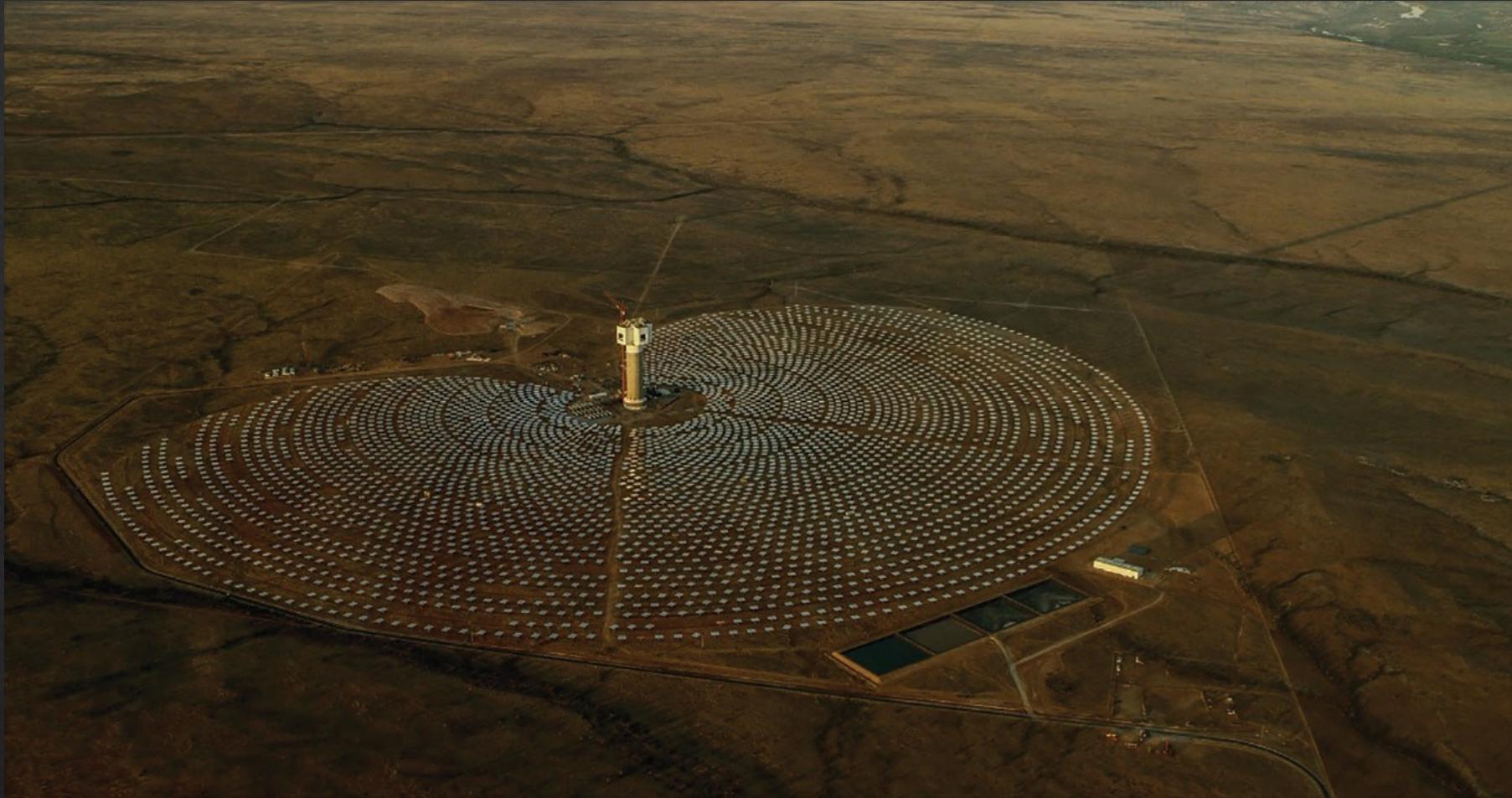




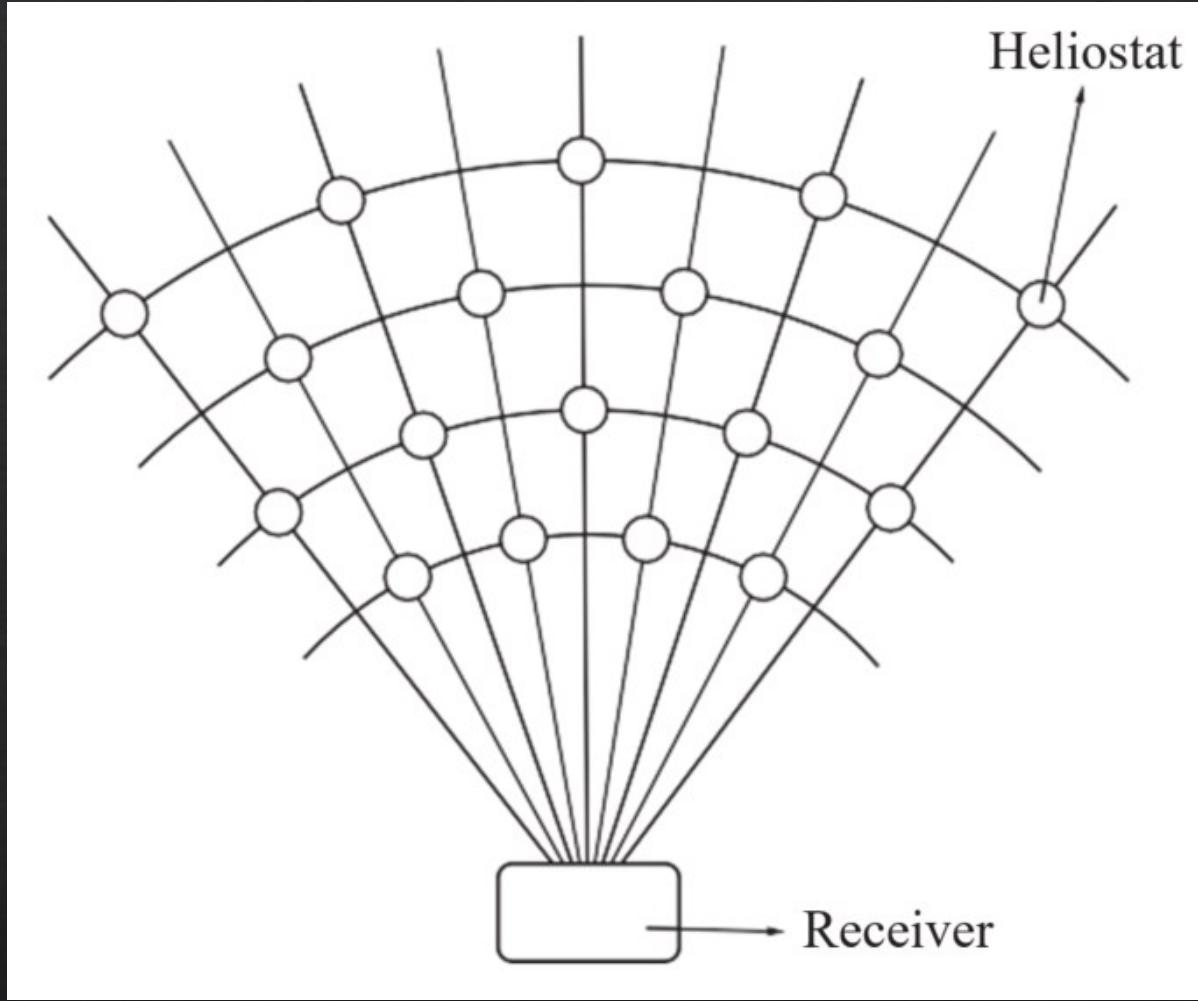
A heliostat field and central tower. (Image by Samuel Faber from Pixabay, <https://pixabay.com/photos/sun-solar-energy-solar-power-plant-4020112/>)



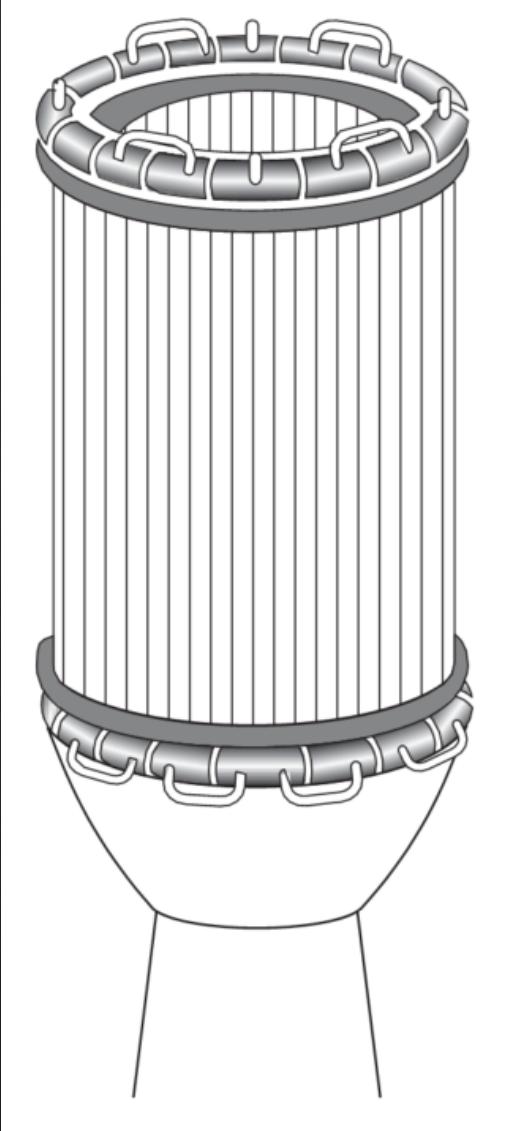
Arrangement of heliostats in the heliostat field for the PS20 power plants with 1255 heliostats. (By Koza1983 – Own work by the original uploader, CC BY 3.0, <https://commons.wikimedia.org/w/index.php?curid=7008971>)



Arrangement of heliostats in a heliostat field. (Image by Christo Ras from Pixabay, <https://pixabay.com/photos/solar-farm-solar-photovoltaic-4683339/>)



Schematic of heliostats in a staggered pattern

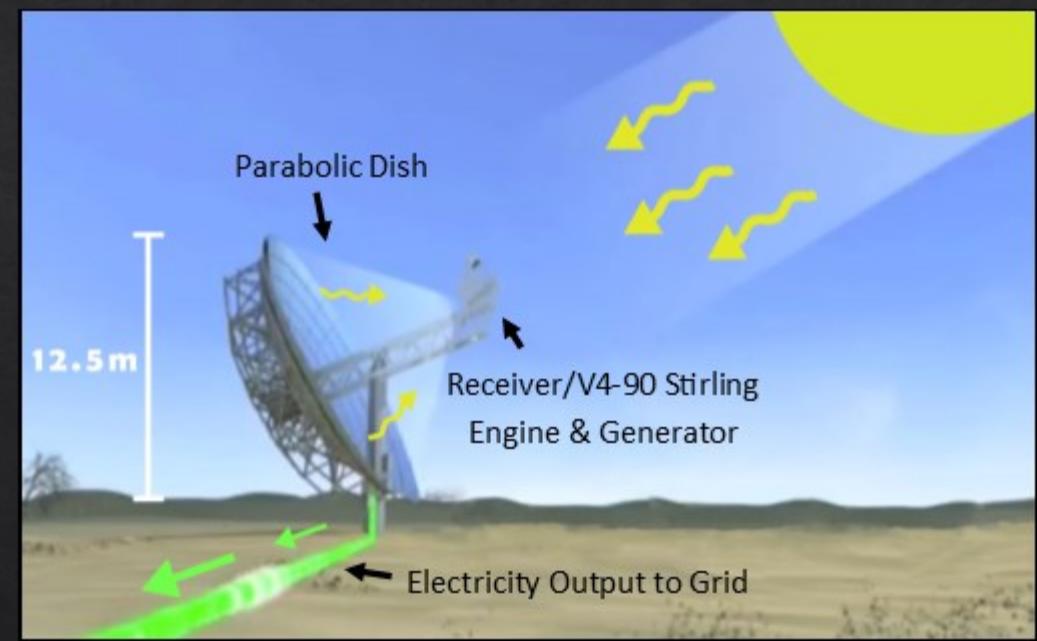


Schematic of a cylindrical external central receiver



External central receivers. (Image by Michael4Wien from Pixabay, <https://pixabay.com/photos/sun-electricity-production-renewable-4535891/>)

Dish Sterling



1MW Dish Demonstration – Phoenix, AZ



Technology Comparison

	Trough	Power Tower	Dish / Engine	PV
Typical Operating Temp	390C	565C	800C	n/a
Utility scale (>50 MW)	x	x	x	x
Distributed (<10MW)			x	x
Energy Storage	x	x		
Water use for cleaning	x	x	x	x
Water use for cooling	preferred	preferred		
Land Use (acre/MW)*	5-9	3-9	8-9	5-9
Land Slope	<3%	<5%	<5%	<5%
Technical maturity	medium	low	low	low to high

Advantages of CSP

- ❖ Stores solar energy in the form of heat not electricity
- ❖ Thermal storage is more efficient than battery storage (PV) at large scale
- ❖ Dispatchable – Flexibility to grids for handling fluctuations
- ❖ Thermal inertia
- ❖ More similar to conventional coal or gas-powered plants than it is to PV plants
 - ❖ Heat from sun instead of fuel



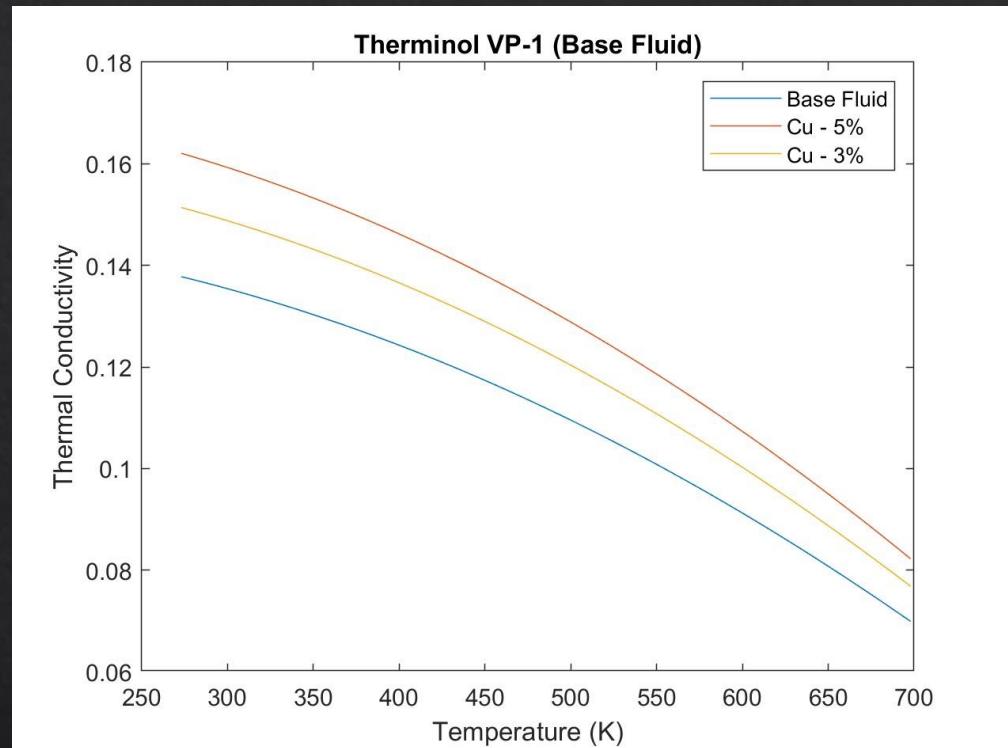
Heat Transfer Fluids (HTF)

A liquid or a gas that transfers heat from one component to another is called heat transfer fluid (HTF)

Heat Transfer Fluid	Classification	Min Temp °C	Max Temp °C
Hitec Solar Salt	Salt (Nitrate)	238	593
Hitec	Salt (Nitrate)	142	538
Hitec XL	Salt (Nitrate)	120	500
Caloria HT 43	Hydrocarbon Mineral	-12	315
Therminol VP-1	Mixture of Biphenyl and Diphenyl Oxide (Synthetic Oil)	12	400
Therminol 59	Synthetic Oil	-45	315
Therminol 66	Synthetic Oil	0	345
Dowtherm Q	Synthetic Oil	-35	330

Nanofluids

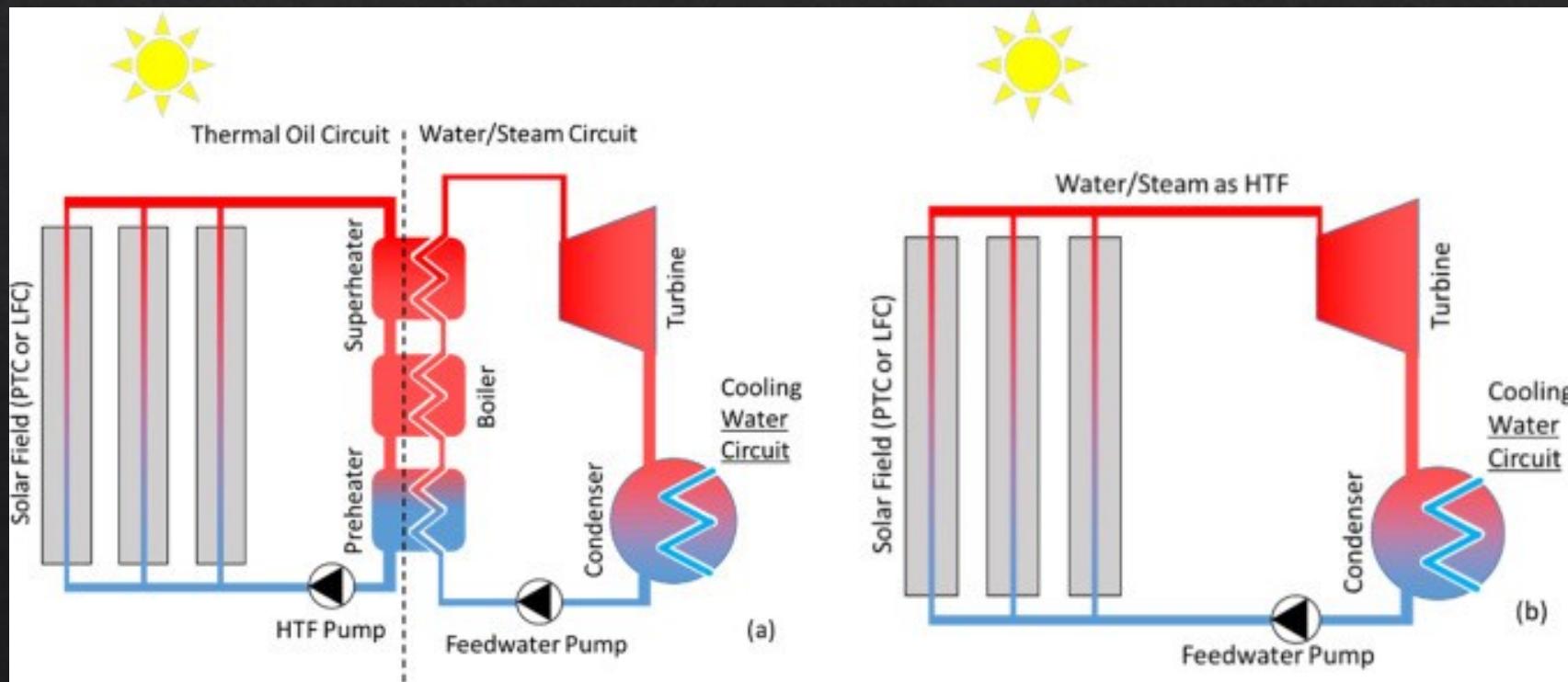
- ❖ Nanoparticles + Base Fluids
- ❖ Nanoparticles improve thermophysical properties of Heat Transfer Fluid (HTF)
 - Example:
 - Base Fluid: Therminol VP-1
 - Nanoparticle: Copper
 - Fraction: 3% and 5%
 - Result: Thermal conductivity is increased significantly – enhanced heat transfer.

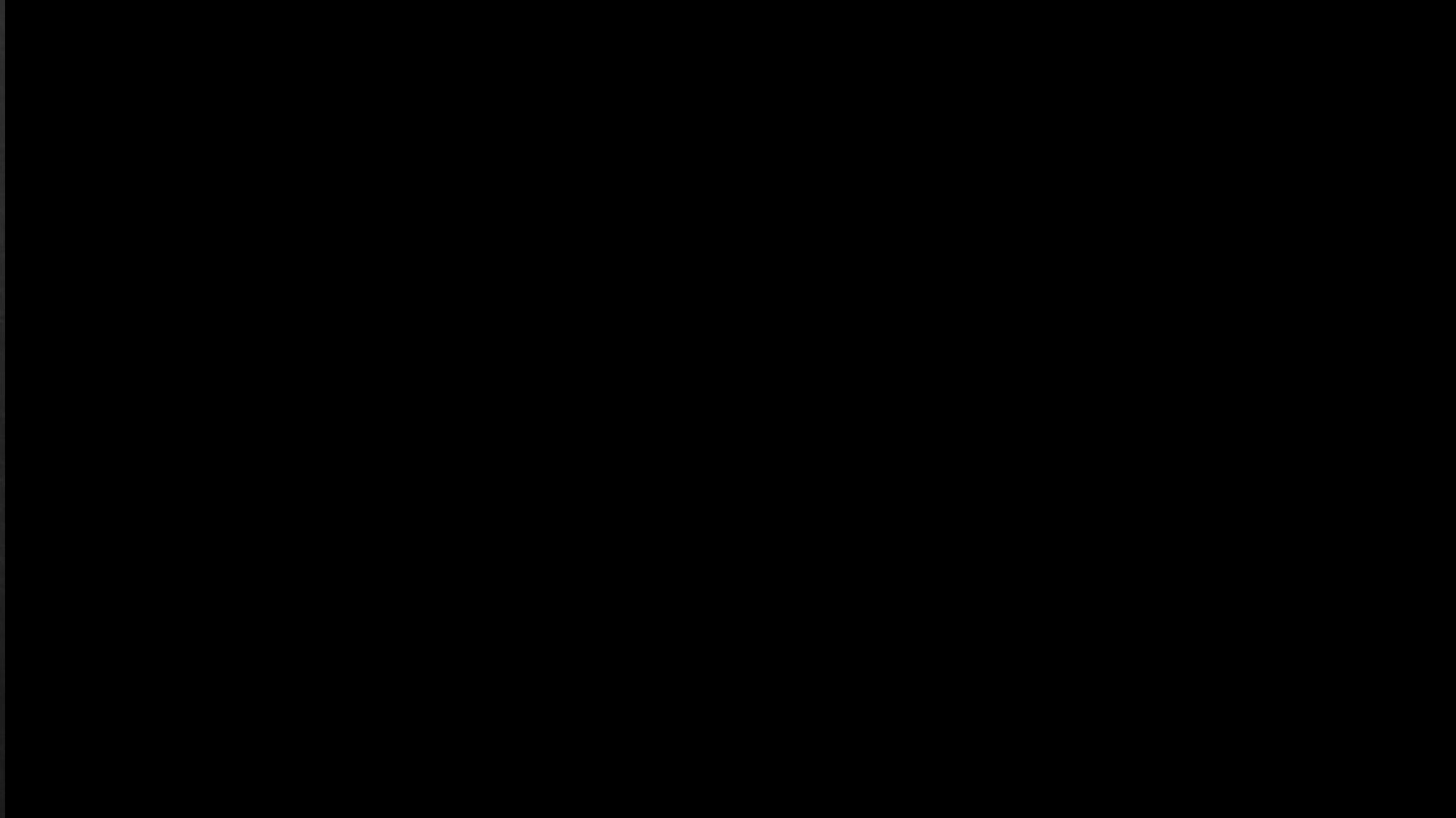


Thermal conductivity of Therminol VP-1 vs Temperature with different fractions of Cu-particles

Direct Steam Generation (DSG)

- ◊ In the DSG configuration, **water enters the solar receiver** at low temperature and supercritical pressure and is heated to temperatures above 550°C. No additional heat exchanger or steam generator is required unless the plant includes an indirect-type TES.





<https://www.youtube.com/watch?v=QNU1JMhzxA>

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What's New & CSP Resources

- ❖ CSP Gen3
- ❖ **Resources**
 - ❖ National Renewable Energy Laboratory (NREL)
 - ❖ SolarPACES
 - ❖ HelioCSP
- ❖ **Tools/Software**
 - ❖ System Advisor Model (SAM)
 - ❖ SolarPILOT
 - ❖ HALOS
 - ❖ TRYNSYS

End of Lecture!