

Solar Thermal Energy

PHYS 4400, Principles and Varieties of Solar Energy

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February 10, 2015



What is solar thermal energy?

Solar thermal energy refers to optimizing the efficiency with which the Sun's radiant energy is converted to thermal energy.

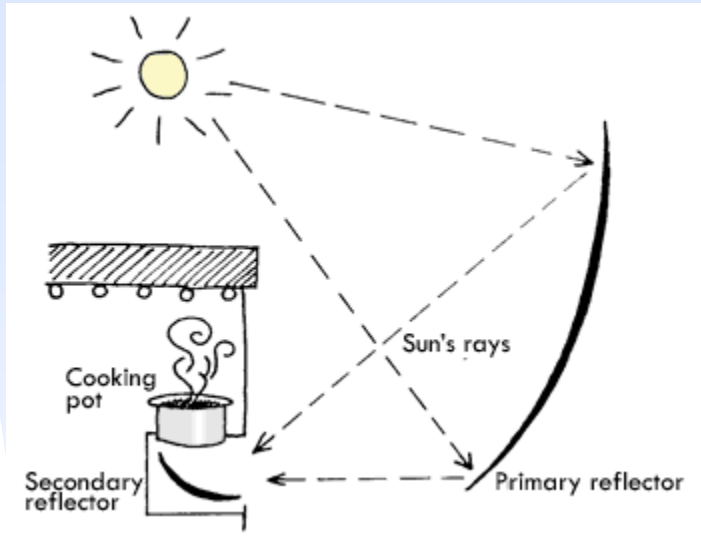
Within this definition, the efficiency relies critically on the efficiency of light absorption, and avoiding any re-emission.

As simple as the warmth evident when standing in the bright sun while wearing a dark colored shirt.

Solar thermal energy can be used immediately, or stored.



Solar cooker



Focusing the Sun's rays onto a small surface area concentrates the intensity. These cookers can routinely reach ~300 °F.

What feature does a typical solar cooker lack?



Solar furnace – heliostats!



The solar furnace at Odeillo in the Pyrénées-Orientales in France can reach temperatures up to 3,500 °C (6,330 °F).

Energy is used in numerous ways, including the generation of electricity via a steam turbine, making hydrogen fuel, testing re-entry materials for space vehicles, or performing high-temperature metallurgic experiments.



Tracking the Sun

Active tracker

Active trackers use motors and gear trains to direct the tracker as commanded by a controller responding to the solar direction. Light-sensing trackers typically have two photosensors, such as photodiodes, configured differentially so that they output a null when receiving the same light flux.

Passive tracker

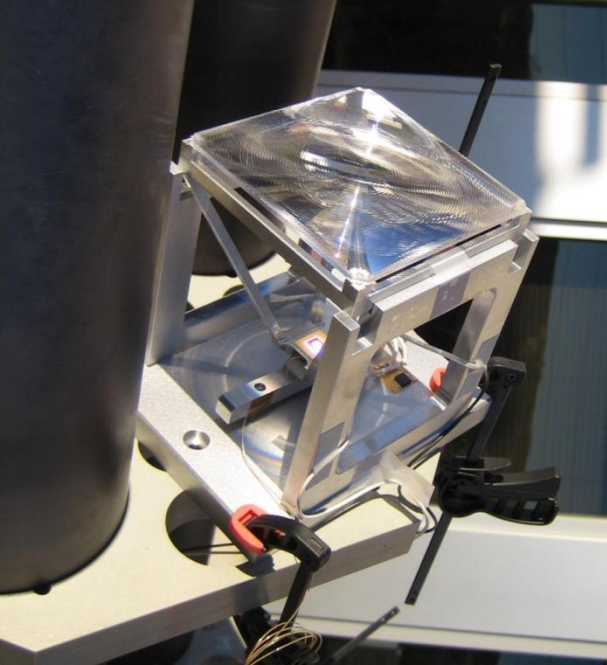
Common Passive trackers use a low boiling point compressed gas fluid that is driven to one side or the other (by solar heat creating gas pressure) to cause the tracker to move in response to an imbalance (works fine for common PV types).

Chronological tracker

A chronological tracker counteracts the Earth's rotation by turning at an equal rate as the earth, but in the opposite direction. Actually the rates aren't quite equal, because as the earth goes around the sun, the position of the sun changes with respect to the earth by 360° every year or 365.24 days. A chronological tracker is a very simple yet potentially a very accurate solar tracker specifically for use with a polar mount.



Tracking the Sun



Three categories of solar thermal collectors

Low-temperature collectors

Significant category, used frequently to heat swimming pools, for ventilation through convection, or via other air or water heating

Medium-temperature collectors

Solar water heating (residential water or hydronic space heating); solar drying; cooking.

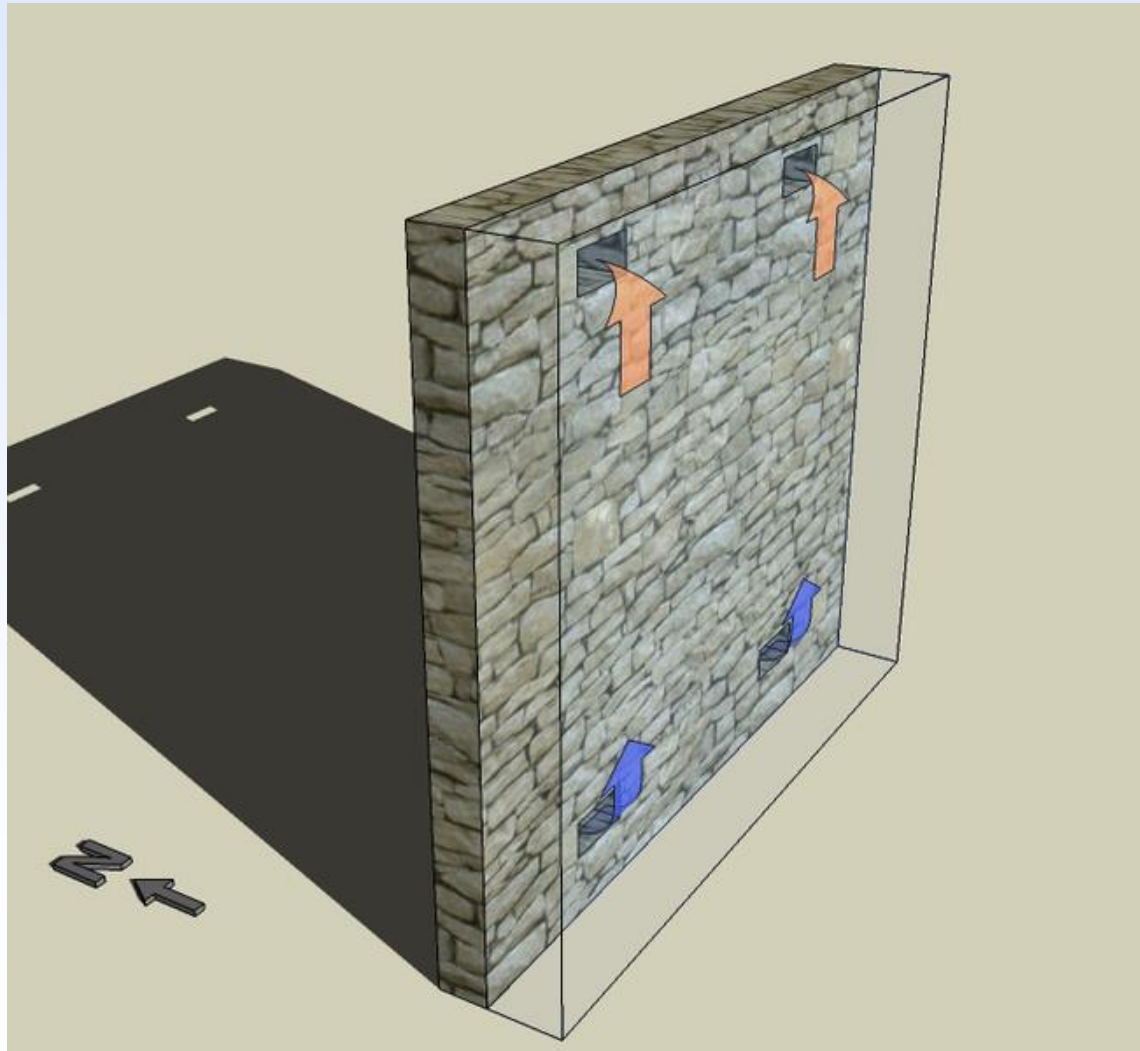
High-temperature collectors

Required to reach temperatures necessary to efficiently convert thermal energy to electricity. Up to 600 °C, steam turbines, standard technology, have an efficiency up to 41%.



Trombe wall

Trombe wall: a passive solar heating and ventilation system consisting of an air channel sandwiched between a window and a sun-facing thermal mass.

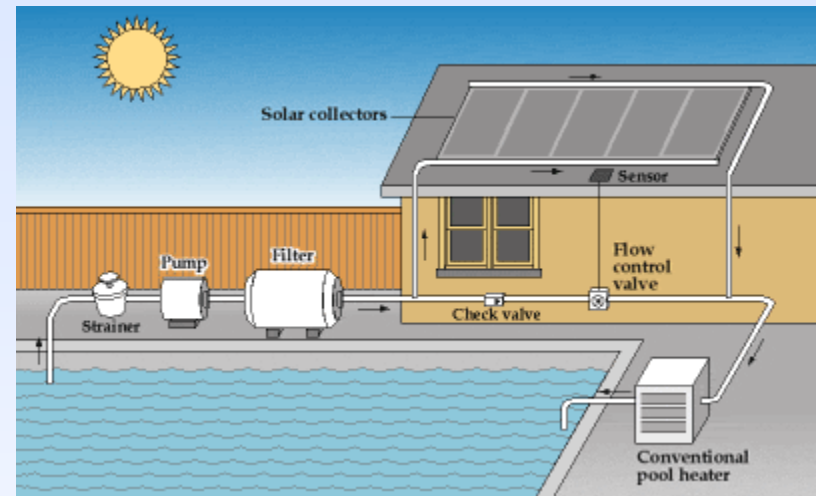


Solar kiln

“Be careful that whenever the kiln is left empty that you do not leave the doors completely closed since the temperature of an empty kiln can exceed 200°F, which can damage the plastic fan blades.” http://pubs.ext.vt.edu/420/420-030/420-030_pdf.pdf



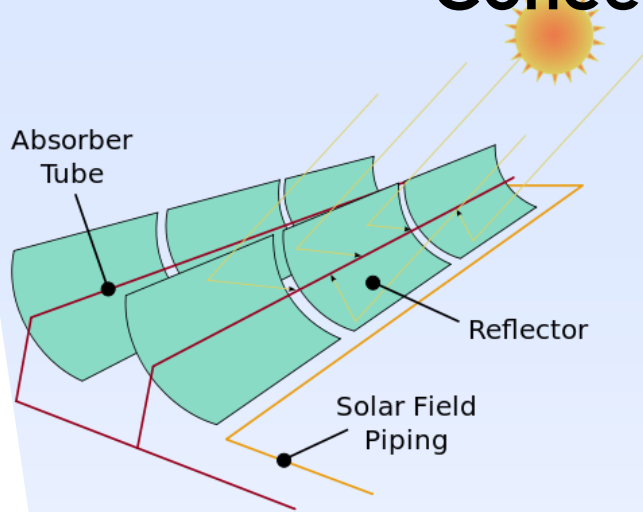
Solar pool heating



- A solar collector -- the device through which pool water is circulated to be heated by the sun.
- A filter -- removes debris before water is pumped through the collector.
- A pump -- circulates water through the filter and collector and back to the pool.
- A flow control valve -- automatic or manual device that diverts pool water through the solar collector.



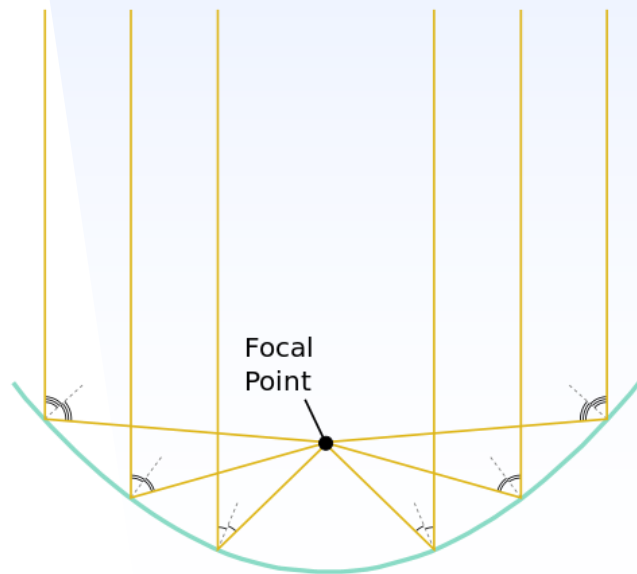
Concentrated Solar Power (CSP)



Types of solar collectors: parabolic trough

Parabolic trough, straight in one dimension, curved parabolically in the other, and lined with metallic mirror surface ($R = 94\%$).

Current commercial plants utilizing parabolic troughs are hybrids; fossil fuels are used during night hours, but the amount of fossil fuel used is limited to a maximum 27% of electricity production, allowing the plant to qualify as a renewable energy source.



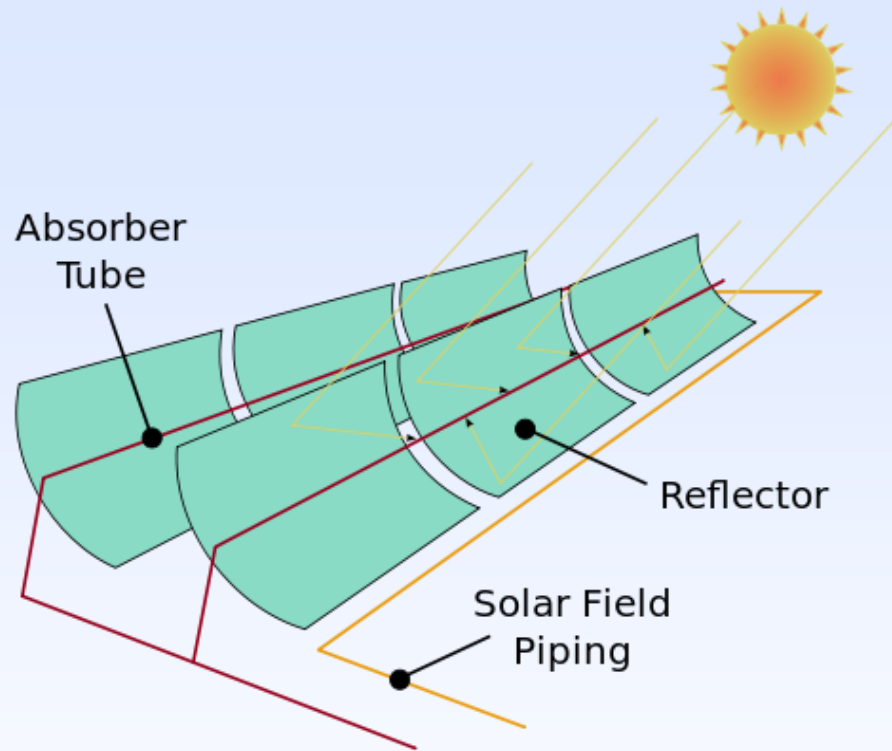
Solar Energy Generating Systems (SEGS)



Nine solar power plants totaling 354 MW – the largest solar thermal plant in the world. At night, the turbines burn natural gas. The facilities have a total of 936,384 mirrors; lined up, the parabolic mirrors would extend over 229 miles (369 km). An automated washing mechanism is used to periodically clean the parabolic reflective panels.



Solar Energy Generating Systems (SEGS)- cont.



Absorber tubes contain a synthetic oil, and heat to $> 400\text{ }^{\circ}\text{C}$ by sunlight focused to $\sim 75\times$ standard sunlight. The heated oil then transfers heat to boil water, generate steam, and power the Rankine cycle steam turbine to generate electricity. Note that the troughs do not require 2-D tracking.



Solar Energy Generating Systems (SEGS)- cont.

Kramer Junction averages 340 days of sun/year, and receives an average direct normal radiation of 7.4 kWh/m²/day (310 W/m²), one of the best in the U.S.

Accidents and incidents

In February 1999, a 900,000 gallon Therminol storage tank exploded at the SEGS II (Daggett) solar power plant, sending flames and smoke into the sky.



Rankine steam engine: ~42% efficiency

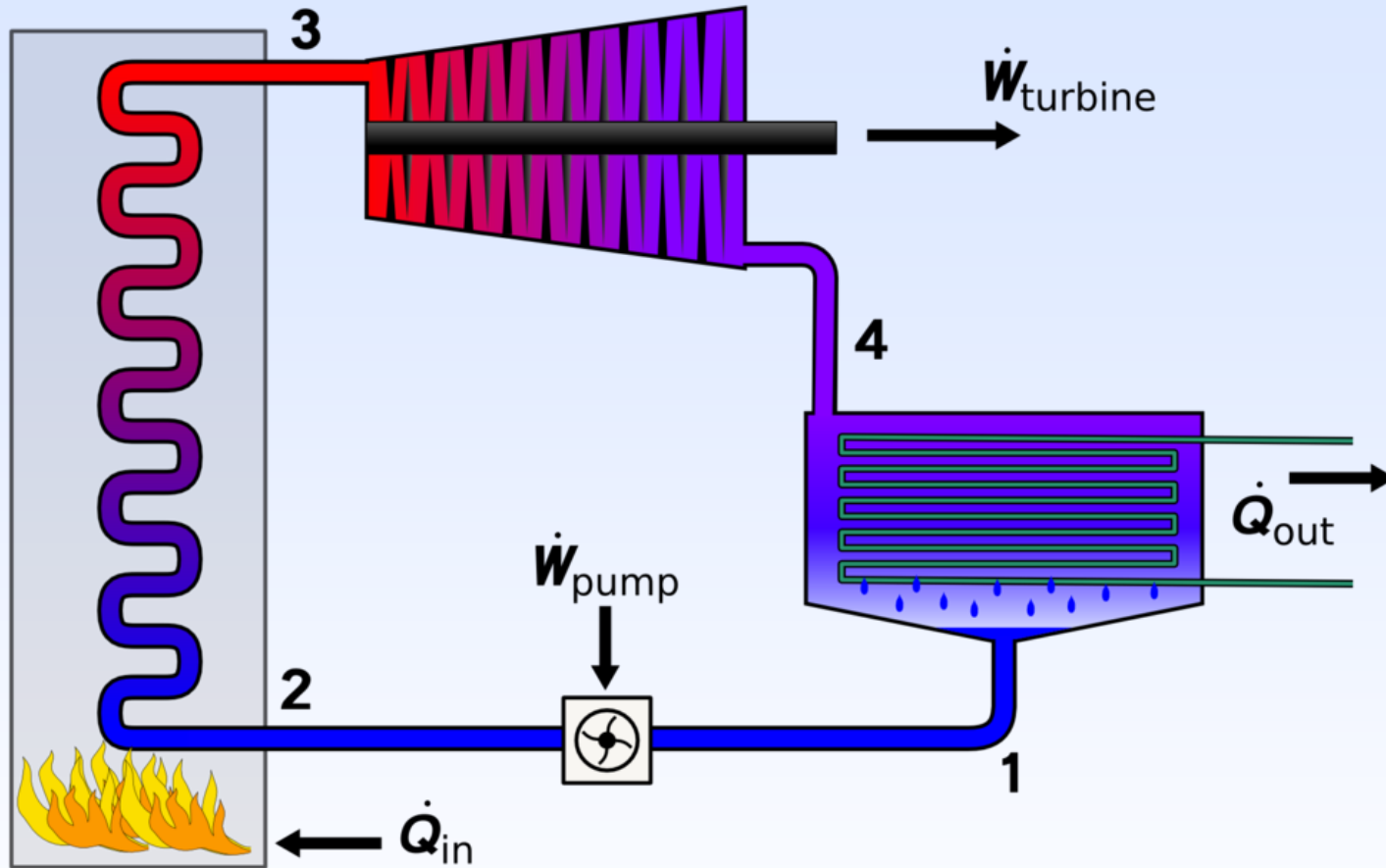
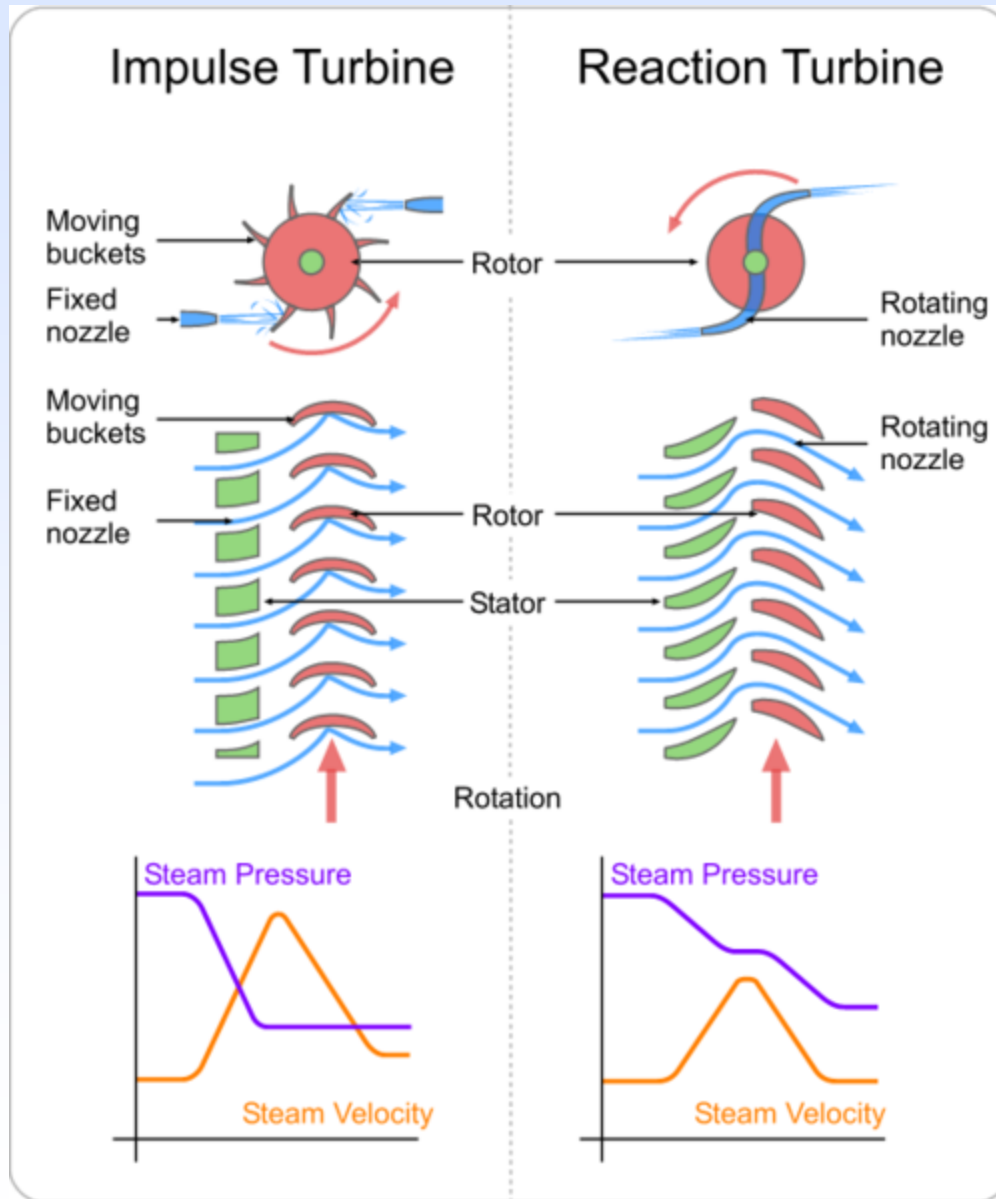


Diagram showing the basic layout of a Rankine cycle; Fluid is pumped to high pressure going from state 1 to 2. Heat is added in the boiler by the burning of fuel (although heat can be added by any method) boiling the fluid to state 3. The vapour expands through the turbine dropping significantly in pressure and temperature to state 4. Finally the vapour is condensed back to a liquid and fed back in the pump.

Turbine designs: impulse vs. reaction



Power tower design for CSP



“Within the receiver the concentrated sunlight heats molten salt to over 1,000 °F (538 °C). The heated molten salt then flows into a thermal storage tank where it is stored, maintaining 98% thermal efficiency, and eventually pumped to a steam generator.”

“eSolar's proprietary sun-tracking software coordinates the movement of 24,000 1 meter-square mirrors per 1 tower using optical sensors to adjust and calibrate the mirrors in real time. This allows for a high density of reflective material which enables the development of modular concentrating solar thermal (CSP) power plants in 46 megawatt (MW) units on approximately π square mile parcels of land, resulting in a land-to-power ratio of 4 acres (16,000 m²) per 1 megawatt.”

