RENEWABLE ENERGY TECHNOLOGY

Prepared By:

Dr. Md. Rifat Hazari

Assistant Professor

Modified By:

S M Imrat Rahman

Senior Lecturer

Summer 2019-20

American International University-Bangladesh

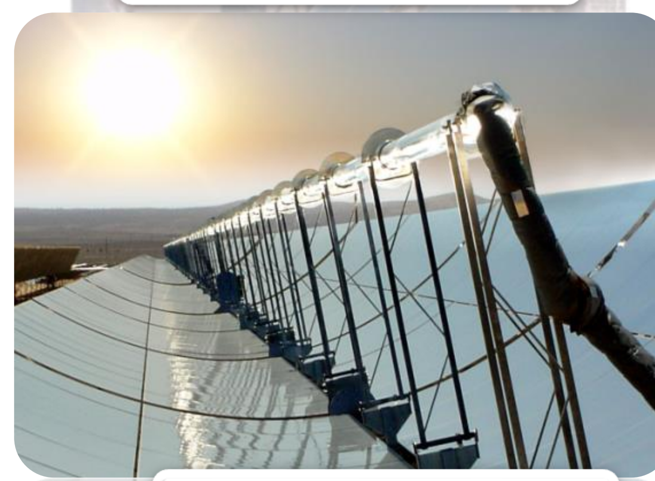
Solar Thermal Power Technologies
Solar Thermal Electricity

Concentration Technologies

Currently four key solar thermal power technologies

Modular (< $50kW_e$)

Parabolic Dish



Parabolic Trough

Large Scale (> $10MW_e$)

Solar Tower

Linear Fresnel

Key Solar Technologies

- Each solar collector technology has its own specific range of practically achievable concentration ratios
- As such, each technology is adapted to one or more types of temperature range and thus power generation cycles

	Concentration	Tracking	Focal Spot	Temperatures
Linear Fresnel	15 – 60	One-Axis	Line	< 500°C
Parabolic Trough	30 - 100	One-Axis	Line	< 600°C
Heliostat Field	500 - 1’000	Two-Axis	Point	< 1200°C
Parabolic Dish	1’000 - 10’000	Two-Axis	Point	< 750°C

Data Source: C. Philibert, 2005

- Other technologies do exist, but are significantly less developed

Early Attempts at Solar Power

- First power producing solar thermal power plant was built in Egypt in 1913, using parabolic trough technology

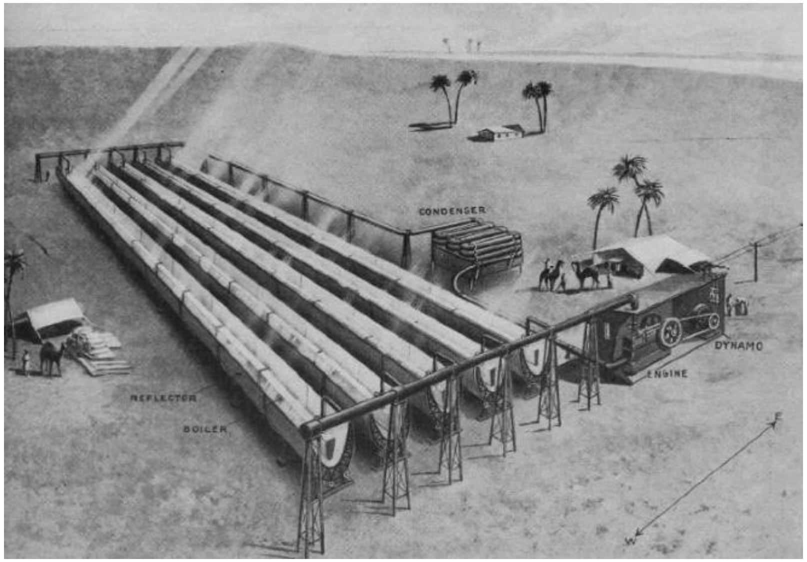


Image Source: Wikipedia, 2012

- First patent deposited in 1907
- Steam production to drive a 40 kW reciprocating steam engine
- Payback time of 2 years against coal from England at 13 $/ton

SEGS Power Plants

- First modern solar thermal power plants, the Solar Energy Generating Systems (or SEGS) were built in California in the 1980s
- Initial built to hedge against high oil/gas prices after the oil crises of the 1970s

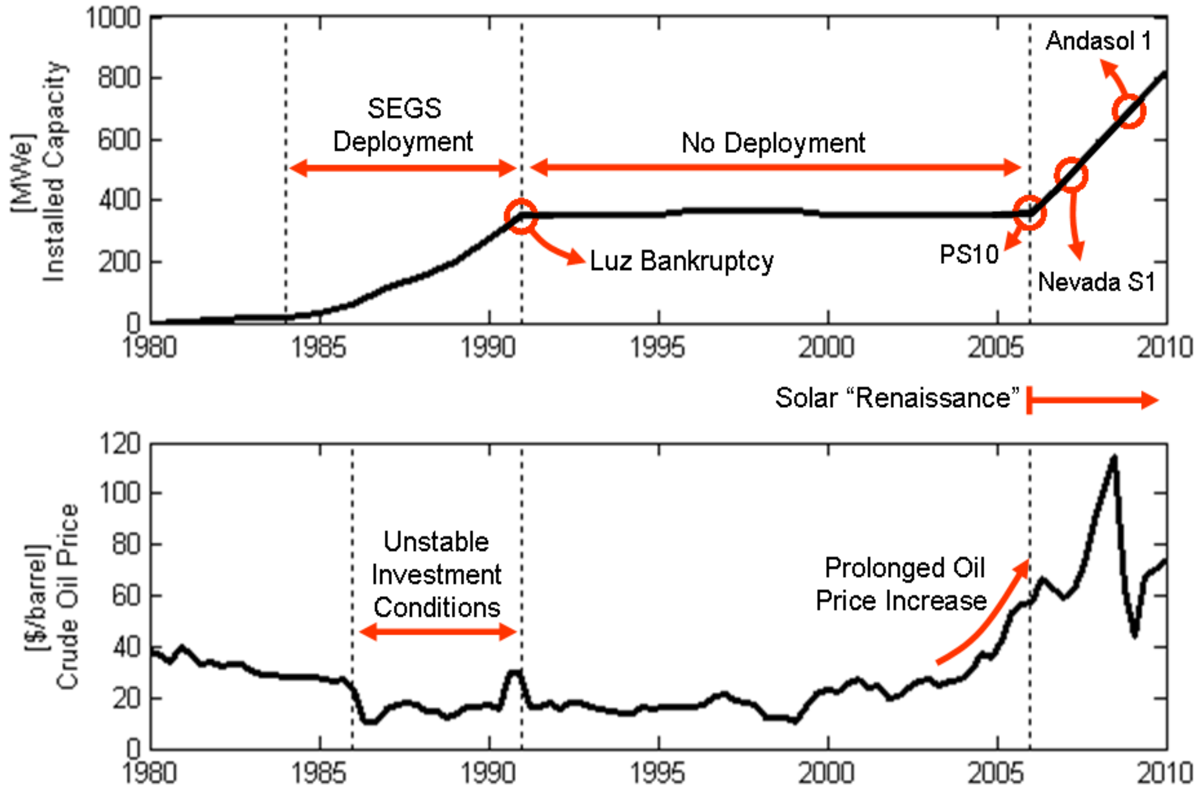

SEGS 3-7, Kramer Jct.


Parabolic Troughs


Mirror Washing

Recent CSP Deployment

- Solar thermal power development began in the 1980s with the SEGS. A new “solar renaissance” started in 2006 with new power plants



Spanish Solar Renaissance

- In 2004 a royal decree equalized conditions for CSP and PV plants
- Feed-in tariffs for solar energy were guaranteed, removing some economic barriers to the deployment of solar thermal technology

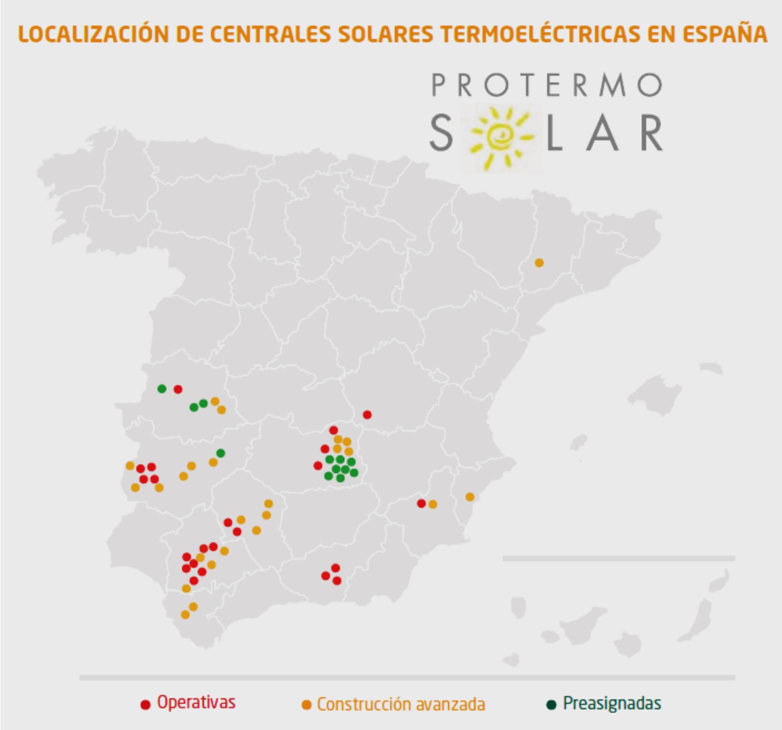


Image Source: Protermosolar, 2011

- By early 2012, over 1000 MW of solar thermal power had been deployed
- Another 1200 MW are currently under construction
- Over 90% of all CSP plants built are of the parabolic trough type

Commercial Solar Plants

- Commercial solar thermal power plants in Spain:

Andasol 1, 2 & 3

PS 10 & 20

Solnova 1, 2 & 4

Puerto Errado II

Solar Thermal Electricity
Parabolic Trough Power Plants

Parabolic Trough Plants

- Over 90% of all installed solar thermal power plants are based around the use of parabolic troughs with Rankine-cycles
- The technology was well-proven, making it easier to obtain funding when the second wave of CSP construction started
- Continuous operation of the SEGS plants since 1984
- However, limited innovation in commercial plants…

Types of Trough Plants

Two main types of parabolic trough plant have emerged:

- 'SEGS-type': daytime-peaking, no storage
- 'Andasol-type´: day load and evening peak, with storage

Power-plants based around standard steam-cycle technology

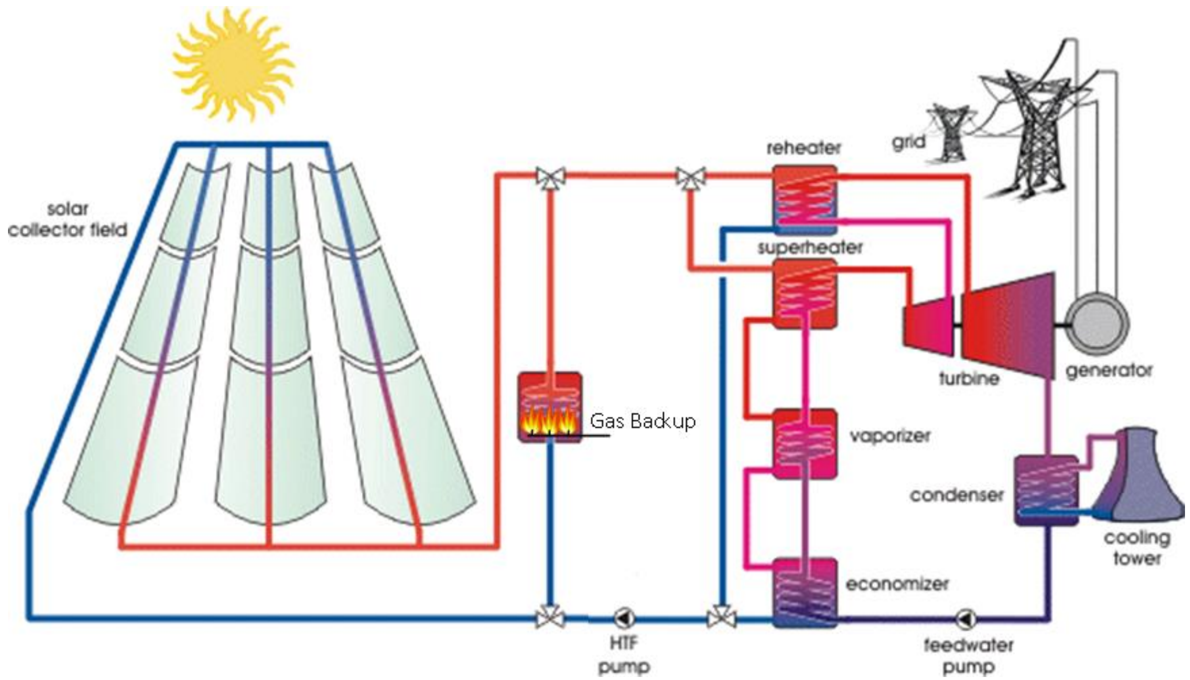
- Compatible temperature levels between solar collector and power block
- Lower risk: well understood technology

Plant design strongly affect by local regulation and incentive measures:

- USA: Loan guarantees and tax credits
- Spain:
  - ✓ Limited to 50MW power block
  - ✓ Limited to 13% fossil co-firing

SEGS – Type Power Plant

- Designed primarily to meet midday peak electricity demands
- Reheat steam cycle used to allow higher cycle efficiency at the low steam temperatures
- Operating temperatures limited by heat transfer fluid



<u>Thermal Oil HTF (heat Transfer fluid)-System</u>

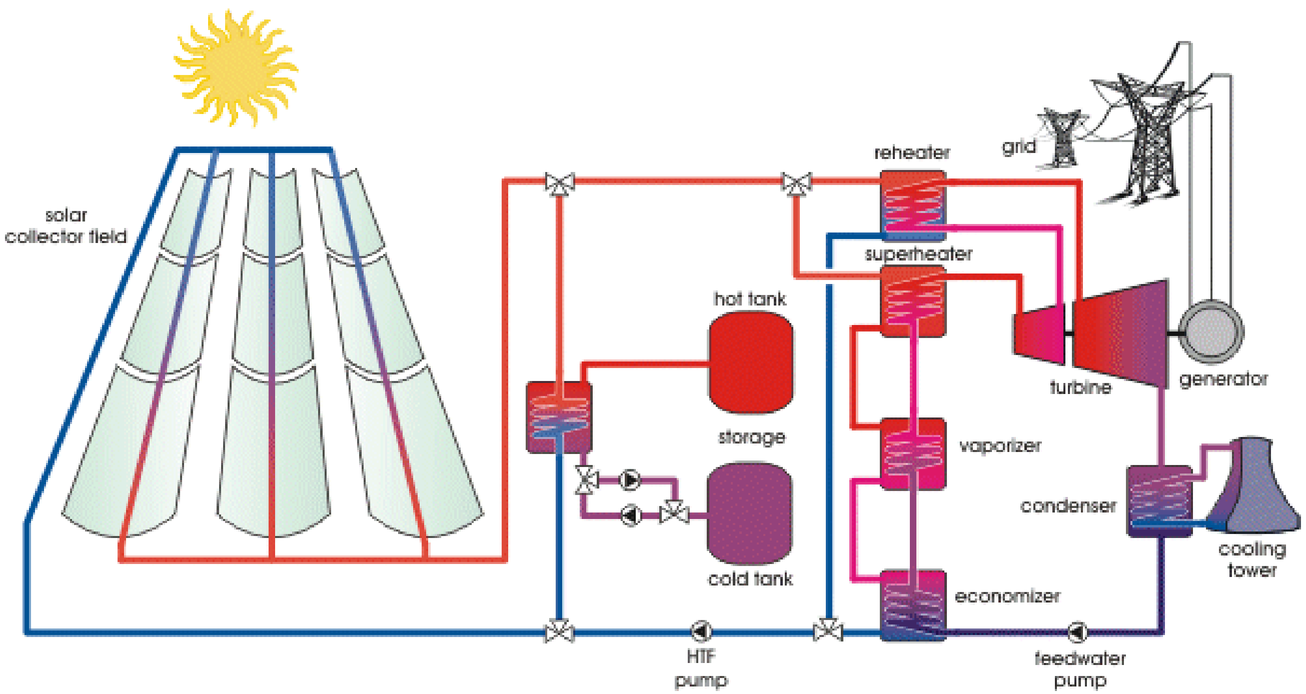
- Medium: Therminol-72
- Thermal Stability: 400°C

<u>Power Block</u>

- Reheat Rankine-cycle
- Steam Temperature: 390°C
- Steam Pressure: 100 bar

Andasol – Type Power Plant

- Designed to meet two daily peaks, midday and early evening
- Thermal energy storage tanks used to harness extra energy during daily hours, allowing production to be extended in the evening
- Larger solar field required to charge storage tanks



<u>Molten-Salt Storage</u>

Medium: $NaNO_3$-KNO_3

Thermal Stability: 580°C

<u>Power Block</u>

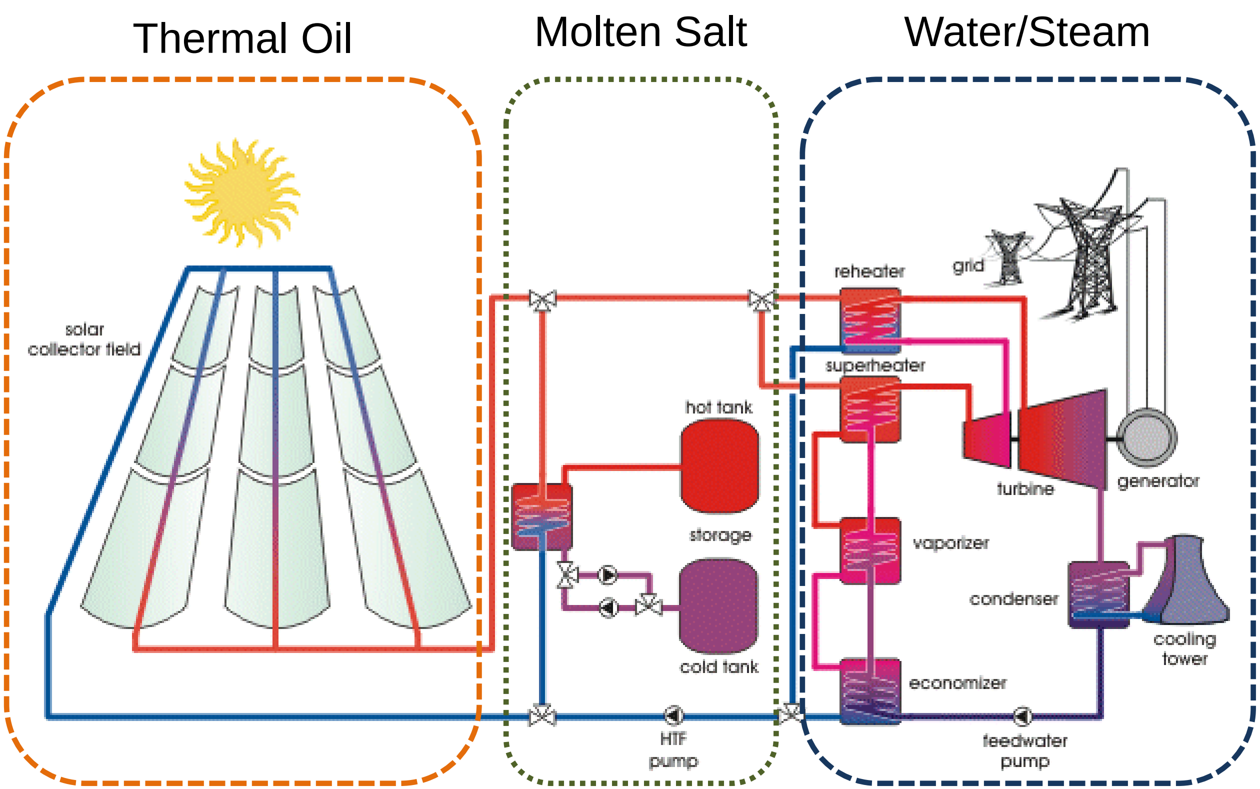
Reheat Rankine-cycle

Steam Temperature: 390°C

Steam Pressure: 100 bar

Molten – Salt Storage System

- Thermal energy storage based on molten salts adds complexity to the system, as three separate fluid loops are required



<u>Thermal Oil</u>

- Good heat transfer
- Low freezing point
- No phase-change

<u>Molten Salt</u>

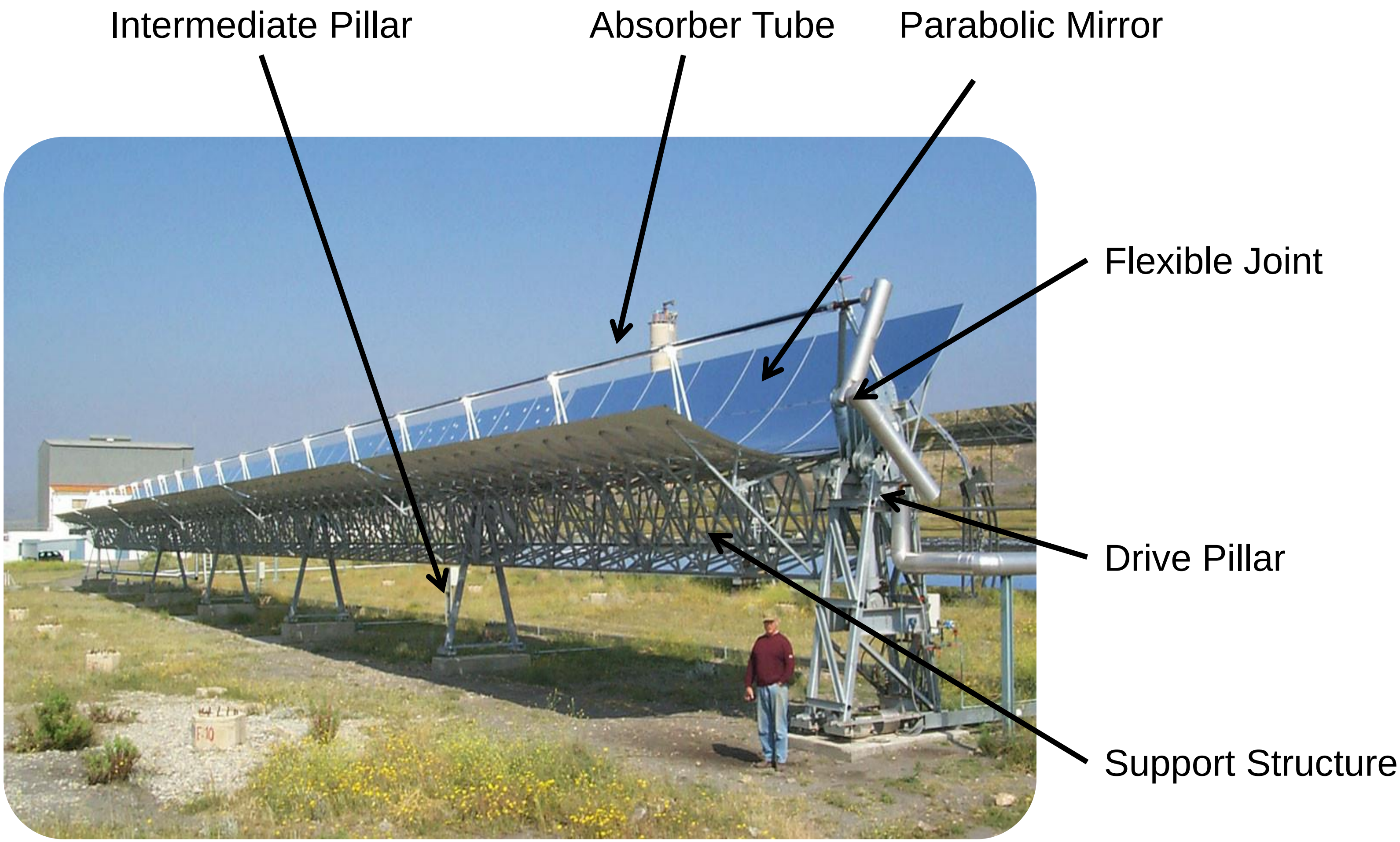
- High heat capacity
- Pre-available product
- Inexpensive
- Chemically inert

Parabolic Trough Plants

- Over 90% of all installed solar thermal power plants are based around the use of parabolic troughs with Rankine-cycles

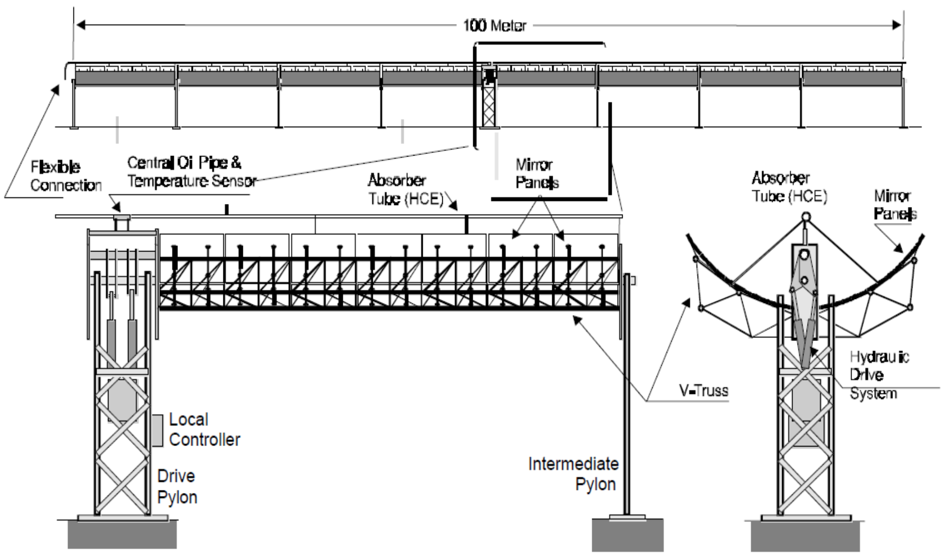
Parabolic Trough Collector

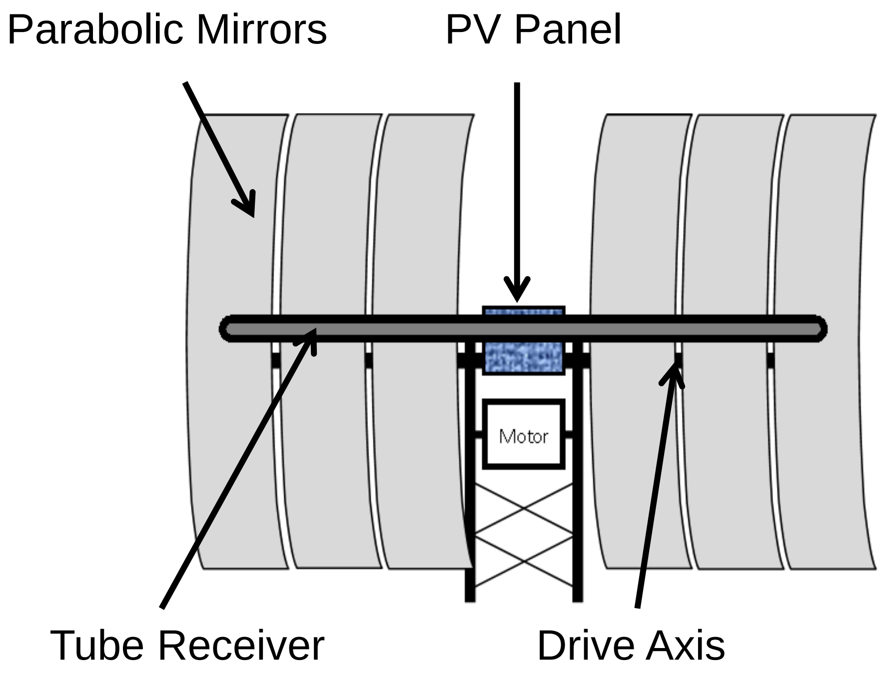
- A large number of different parabolic collector designs have been proposed but all share a similar structure



Parabolic Trough Collector

- A large number of different parabolic collector designs have been proposed but all share a similar structure
- The central drive pillar provides tracking power and control for the entire solar collector assembly





Output of a Trough Collector

The net energy supplied by a given parabolic trough collector is a function of a number of factors, and can be defined by:

$$\dot{Q}_{tr}^{+} = A_{tr} I_{o} \cdot \varepsilon_{surf} \varepsilon_{\cos} \cdot \mathrm{IAM} \cdot (1 - f_{shd})(1 - f_{end})$$

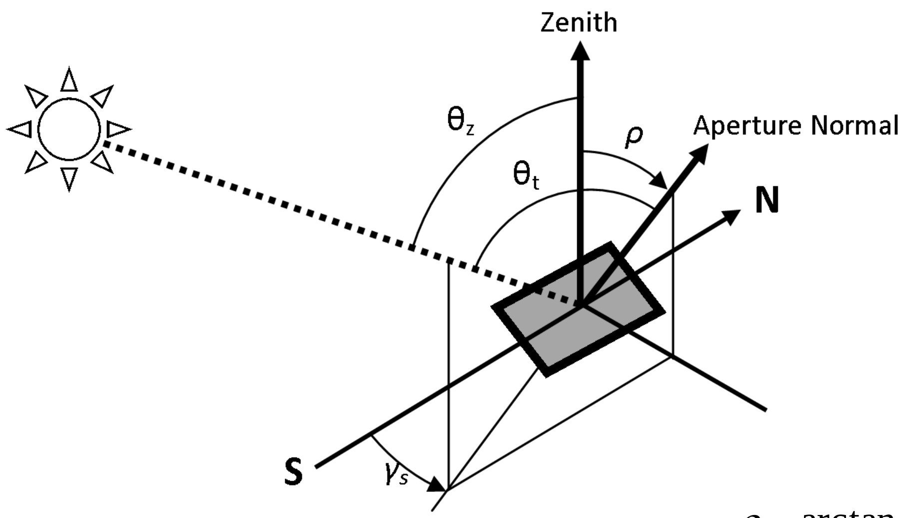
Q_{tr}:	thermal power [W]	ε_{cos}:	cosine effectiveness [-]
A_{tr}:	trough aperture area [m^2]	f_{shd}:	shadowing factor [-]
I_o:	incident beam radiation [W/m^2]	IAM:	incidence angle modifier [-]
ε_{surf}:	surface effectiveness [-]	f_{end}:	end-loss factor [-]

Cosine Effectiveness

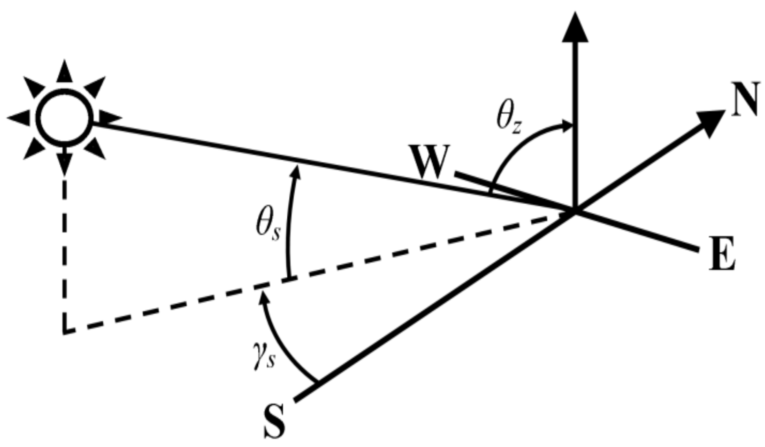
- Commercial parabolic troughs employ NS-single-axis tracking, resulting in non-zero incidence angles

$$\varepsilon_{\cos} = \cos\theta_t \qquad \text{with} \qquad \cos\theta_t = \sqrt{1-\cos^2\theta_s \cos^2\gamma_s}$$

- North-south aligned parabolic troughs give flat efficiency in summer



$$\rho = \arctan\frac{\sin\gamma_s}{\tan\theta_s}$$



Θ_t : Trough Incidence Angle

Image Source: J. Spelling, 2011

Incidence Angle Modifier

- In addition to the basic cosine-effect, other optical losses occur when the incidence angle is non-zero
- The incidence angle modifier (IAM) considers the optical path-length

$$\mathrm{IAM} = 1 - a_1 \frac{\theta_t}{\cos\theta_t} + a_2 \frac{\theta_t^2}{\cos\theta_t}$$

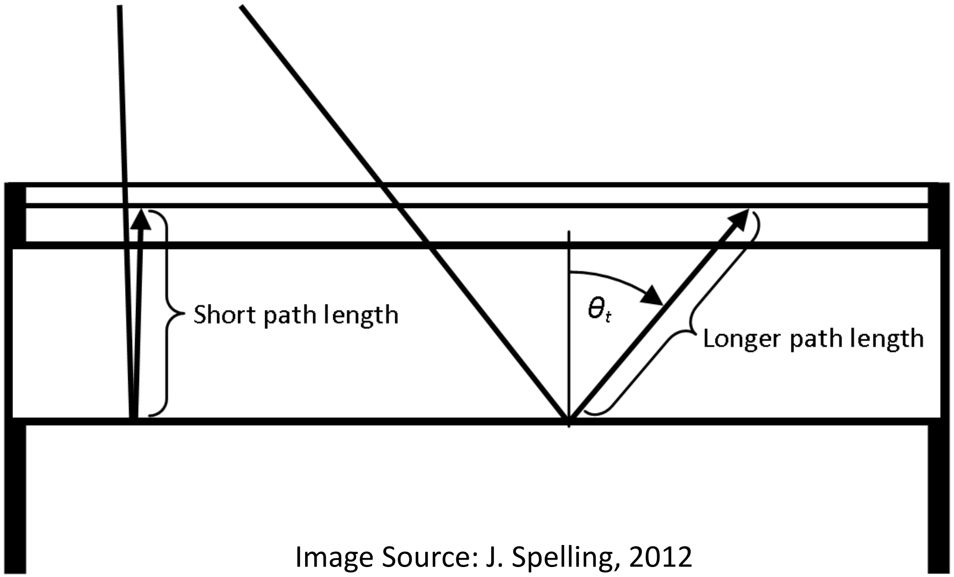
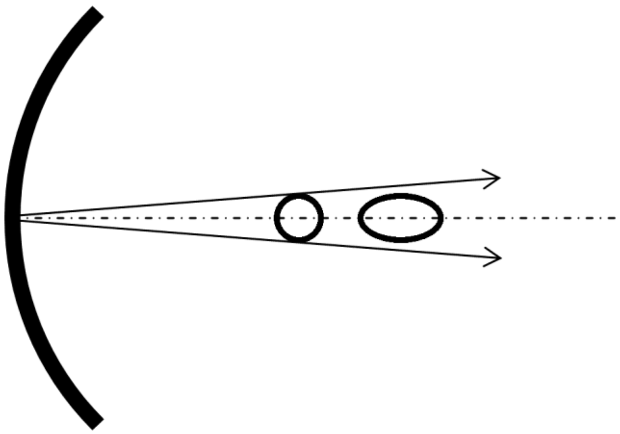


Image Source: J. Spelling, 2012



Incidence Angle Modifier

- In addition to the basic cosine-effect, other optical losses occur when the incidence angle is non-zero
- The incidence angle modifier (IAM) considers the optical path-length

$$\mathrm{IAM} = 1 - a_1 \frac{\theta_t}{\cos\theta_t} + a_2 \frac{\theta_t^2}{\cos\theta_t}$$

LS-2 Collector	Value
a_1	0.0159
a_2	0.1405

Data Source: Dudley *et al.*, 1994

Unique for each collector design!

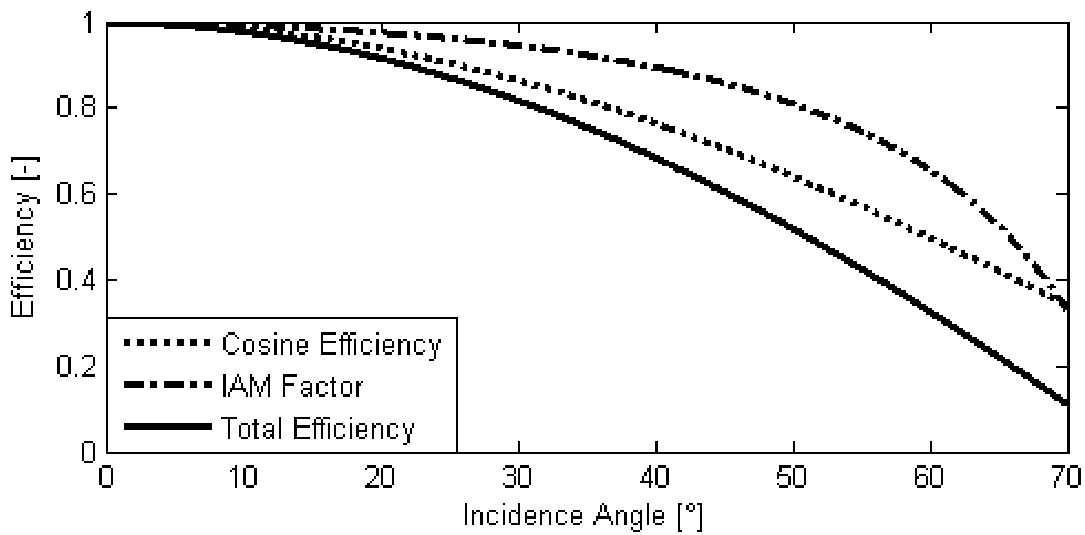


Image Source: J. Spelling, 2012

Tube – End Losses

- Tube-end losses take into account the fact that the collector has a finite length, leading to a certain inactive length of the collector

$$f_{end} = \frac{l_{focus} \tan \theta_t}{l_{trough}}$$

l_{focus}: Trough Focal Length

l_{trough}: Entire SCA length

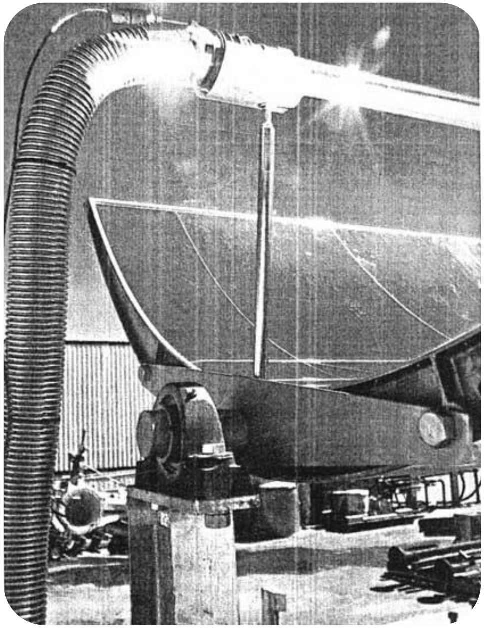


Image Source: Stine, 1987

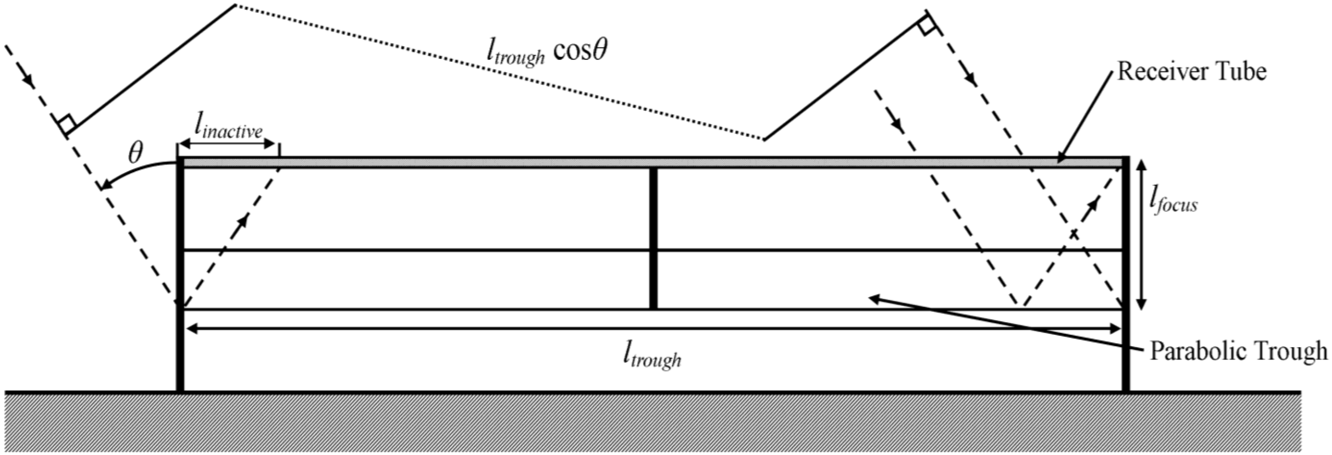


Image Source: J. Spelling, 2011

Shadowing Losses

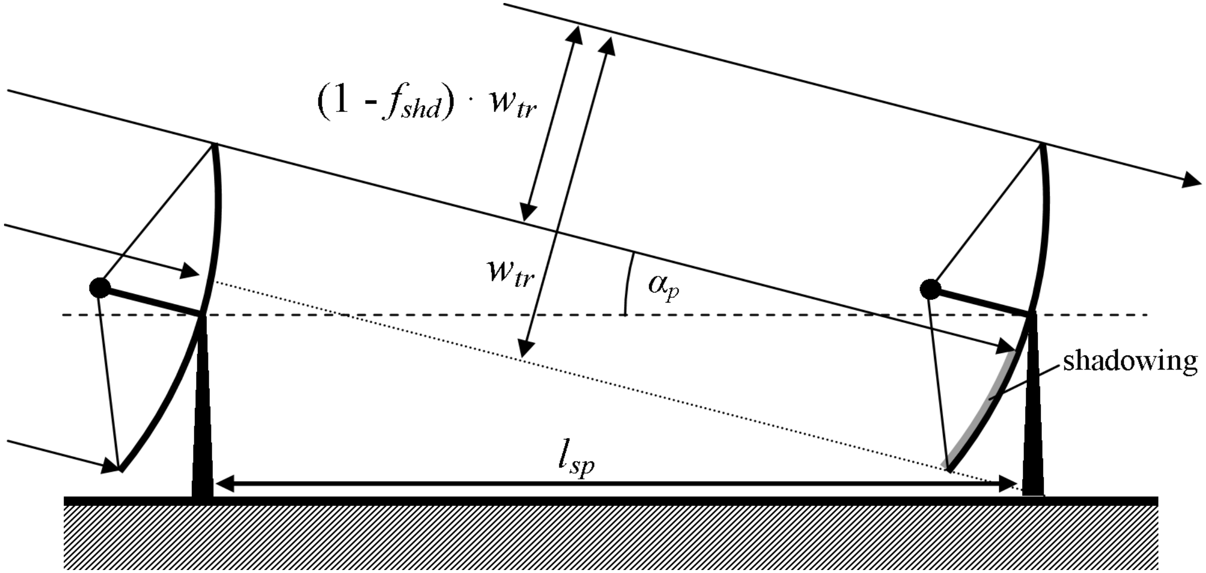
- As the collectors are not operated in isolation, the effect of shadowing between rows needs to be taken into consideration:

$$f_{shd} = 1 - \frac{l_{sp}}{w_{tr}} \frac{\cos\theta_z}{\cos\theta_t}$$

l_{sp}: Spacing between trough rows

w_{tr}: Parabolic Trough Width

θ_z: Solar Zenith Angle



MATHMETICAL PROBLEMS

1. A solar collector system consists of a receiver with surface area of 0.08 m^2. The aperture area of the collector is 9 m^2. The solar radiation from the aperture is 700 W/m^2 and the radiation received by the receiver is 1500 W/m^2. (Emissivity, ε=0.5 and Absorptivity, α=0.7) Calculate-

    1. Geometric and optical concentration ratio of the system.
    2. Maximum temperature that can be achieved on the receiver surface.
    3. If the surface temperature is 150^0C, calculate the useful energy extracted from the receiver.

2. A parabolic through solar thermal power plant (located at 23^0S, 18^0W) has the following dimensions

    Parabolic Trough Width= 1.25m

    Through Focal length= 1.5m

    Entire length of the collector aperture= 50m

    Total aperture area= 128 m^2

    Separation between two rows= 5m

    Surface effectiveness=0 .08

Calculate the thermal power supplied by the parabolic through collector at solar noon on 11th February if the incident beam radiation is 500 W/m^2. A1=.0159, A2=.1405

Renewable Energy Technology

Reference:

- Kalogirou, Soteris A. “Solar energy engineering: processes and systems”, Academic Press, 2009.
- Boyle, Godfrey. *Renewable energy*. OXFORD University press, 2004.
- Jain, Sachin, and Vivek Agarwal. "A single-stage grid connected inverter topology for solar PV systems with maximum power point tracking." *Power Electronics, IEEE Transactions on* 22.5 (2007): 1928-1940.
- Reddy, P. Jayarama. *Science technology of photovoltaics*. BS publications, 2010.
- Energy Technology, B.B.Parulekar, S.Rao, Khanna Publishers, India.
- J. F. Manwell, Jon G. McGowan, Anthony L. Rogers, “Wind Energy Explained: Theory, Design and Application”, Wiley