EEE407 - Renewable Energy
Week 6: Solar Thermal Electricity

ADANA ALPARSLAN TÜRKEŞ
SCIENCE AND TECHNOLOGY UNIVERSITY

Dr Kasım Zor

Department of Electrical and Electronic Engineering

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Outline

Solar Thermal Electricity (STE)

- So called Concentrated Solar Power (CSP)
- A technology that produces heat by using mirrors or lenses to concentrate sunlight into a heat receiver, which brings the solar energy to a heat transfer fluid. This heat can be used to generate electricity with a steam turbine or as process heat for industrial application [1].

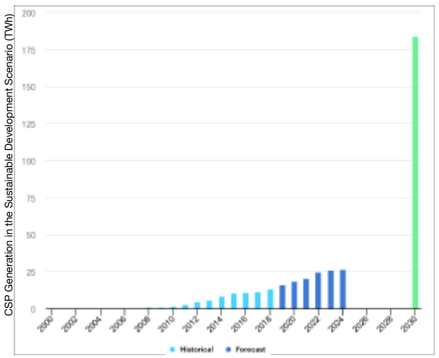
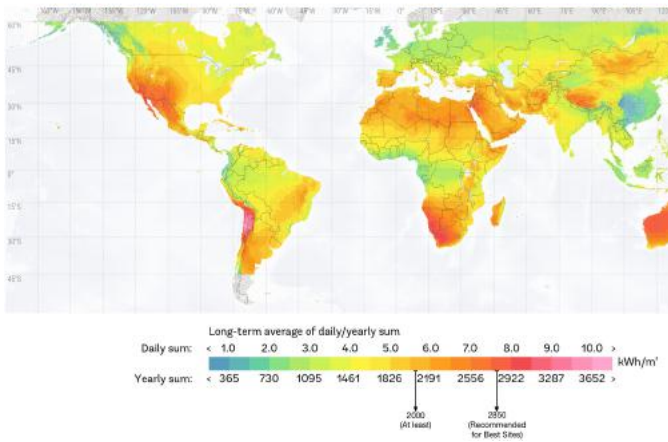


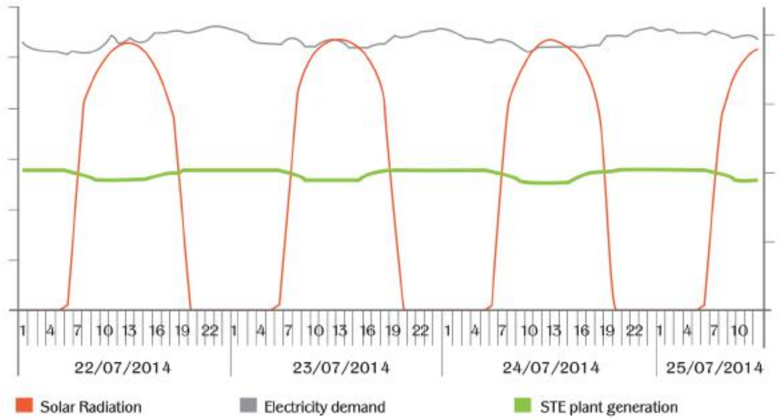
Figure 1: Current Situation [2]

Introductory Video - CSP [3]

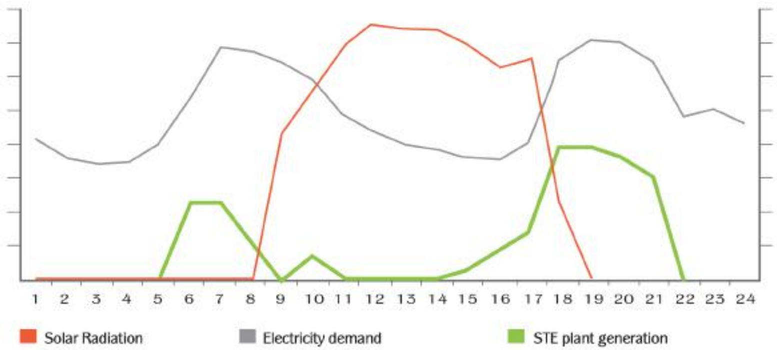
Direct Normal Irradiation (DNI) [4]



Base-Load Designed Power Plant Scenario [5]



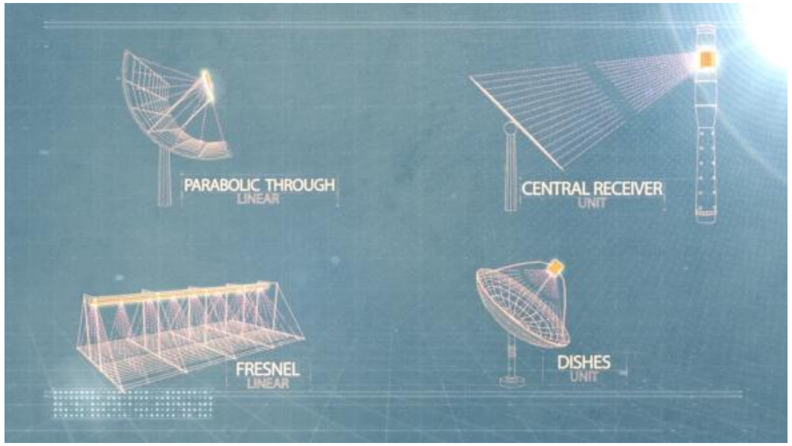
Peak-Load Designed Power Plant Scenario [5]



Video - Introduction to CSP Plants [6]

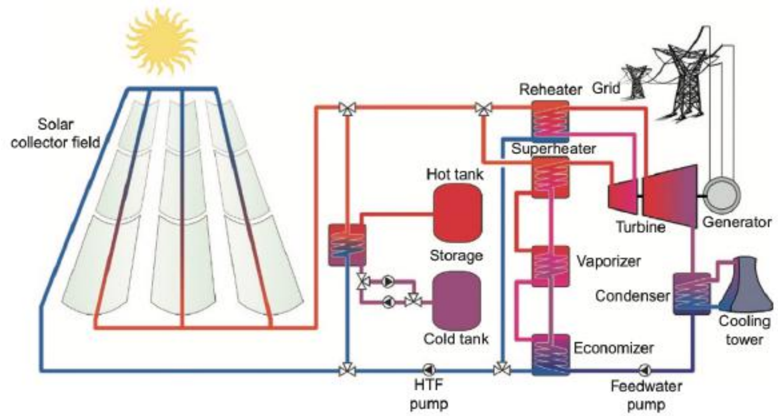
Outline

Four Main CSP Technologies [6]



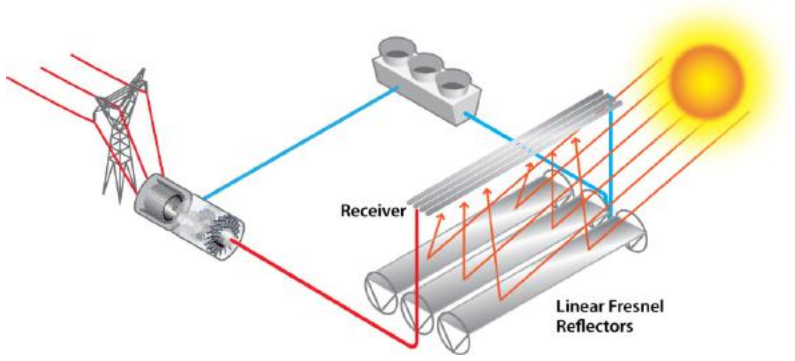
Video - Parabolic Trough Collector [7]

Parabolic Trough Collector [8]



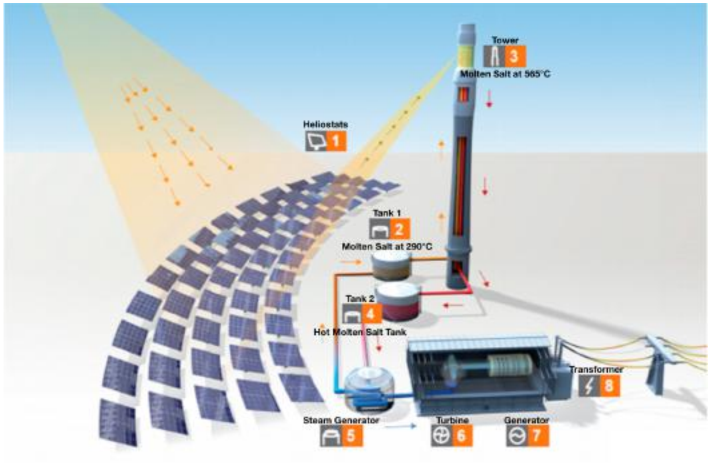
Video - Linear Fresnel Reflector [9]

Linear Fresnel Reflector [10]



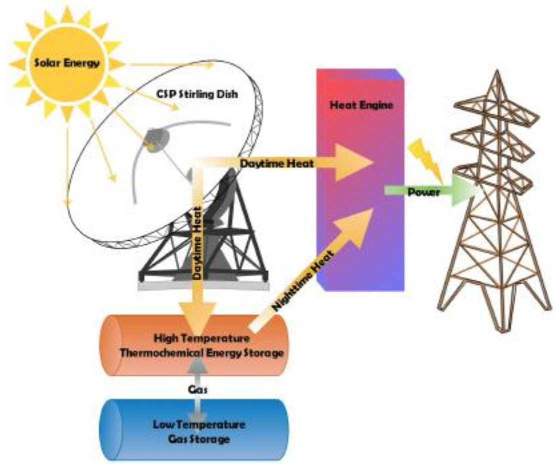
Video - Central Receiver (Solar Tower) [11]

Central Receiver (Solar Tower) [12]



Video - Parabolic Dish Systems [13]

Parabolic Dish Systems [14]



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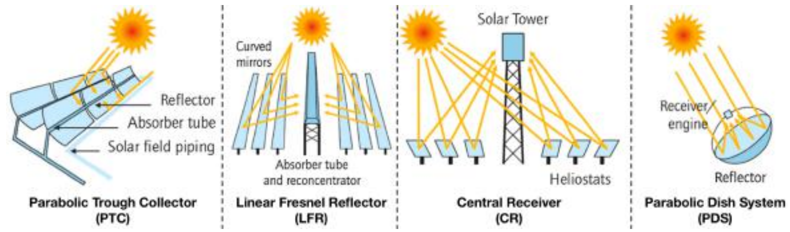
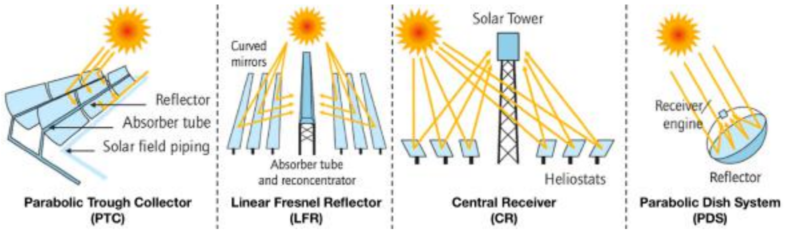
Comparison of CSP Technologies - Part 1 [15, 16]



	PTC	LFR	CR	PDS
Capacity (MW_e)	10–200	10–200	10–150	0.01–0.4
Solar η_{max} (%)	20 (E)	21 (D)	20 (D), 35 (E)	29 (D)
Solar-to-Electricity η_{annual} (%)	15	8–10	20–35	20–35
Collector Concentration (sun)	70–80	>60	>1,000	>1,300
Area Requirement (m^2/MWh)	4–6	6–8	8–12	30–40

*E: Expected, D: Demonstration

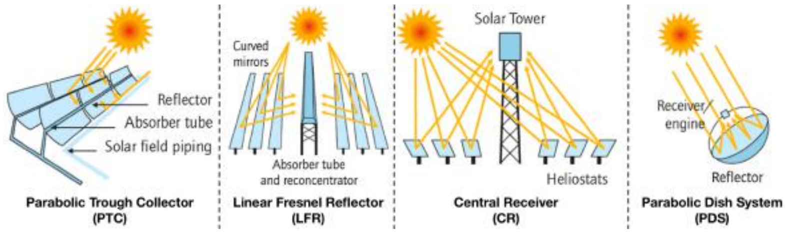
Comparison of CSP Technologies - Part 2 [15, 16]



	PTC	LFR	CR	PDS
Land Requirement	Large	Medium	Medium	Small
Typical Shape	Rect.	Rect.	Circ. or Rect.	Rect.
Water Cooling (L/MWh)	3,000 or Dry	3,000 or Dry	1,000 or Dry	-
Air Cooling	Low to Good	Low	Good	Best
Storage with Molten Salt	CA	P	CA	P

*CA: Commercially Available, P: Possible, but not proven

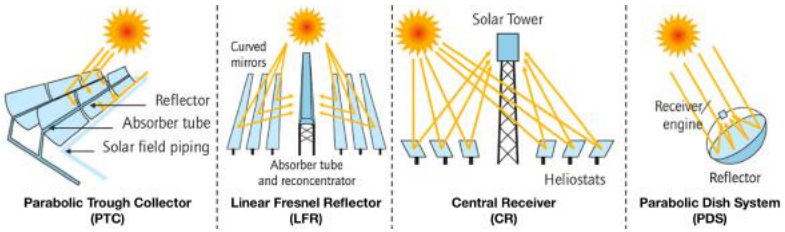
Comparison of CSP Technologies - Part 3 [15, 16]



	PTC	LFR	CR	PDS
T_O ($^\circ C$)	290–550	250–560	250–650	800
Annual C_F (%)	25–28 (No TES) 29–43 (7h TES)	22–24	55 (10h TES)	25–28
Grid Stability	Medium to High	Medium	High	Low
Steam Conditions ($^\circ C$/bar)	380–540/100	260/50	540/100–160	-

*TES: Thermal Energy Storage

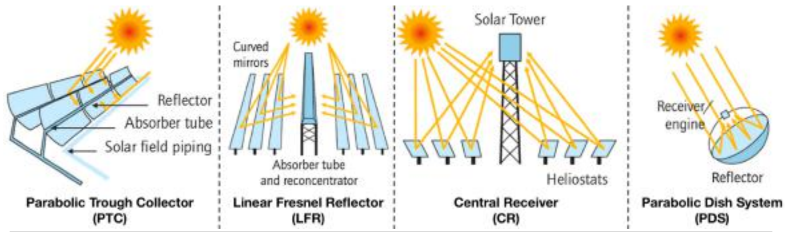
Comparison of CSP Technologies - Part 4 [15, 16]



	PTC	LFR	CR	PDS
Development Status	Most Proven	D	Mature	D
Distribution (%)	>82	~ 4	~ 13	<1
Technology Risk	Low	Medium	Medium	Medium
Future Potential	Limited	Sign.	Very Sign.	High Pot.

*D: Demonstration

Comparison of CSP Technologies - Part 5 [15, 16]



	PTC	LFR	CR	PDS
LCOE (USD/kWh)	0.26–0.37 (No TES) 0.22–0.34 (with TES)	0.17–0.37 (6h TES)	0.20–0.29 (6–7.5h TES) 0.17–0.24 (12–15h TES)	-
Plant Cost (USD/W)	3.22	-	3.62	2.65
O&M Cost (USD/kWh)	0.012–0.020	Low	0.034	0.210

*TES:Thermal Energy Storage, O&M: Operation and Maintenance

Outline

CSP Projects by Country [17]

CSP Projects by Country [18]

CAP (MW)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
World	1 266	1 705	2 567	3 842	4 499	4 750	4 860	4 959	5 674	6 275
Africa	45	65	65	65	165	325	425	525	976	1 076
Algeria	25 o	25 o	25 o	25 o	25 o	25 o	25 o	25 e	25 e	25 e
Egypt		20	20	20	20	20	20	20 o	21 u	21 e
Morocco	20	20	20	20	20	180	180	180 o	530	530 e
South Africa					100 o	100 o	200 o	300 o	400 o	500 u
Asia		3	10	70	245	245	255	255	455	655
China			1	11	11	11	21	21	221	421
India		3 e	4 e	54 e	229 e	229 e	229 e	229 e	229 o	229 o
Korea Rep		0 e	0 e	0 e	0 e	0 e	0 e	0 e		
Thailand			5	5	5	5	5	5	5 e	5 e
Eurasia				1	1	1	1	1	1	1
Turkey				1 o	1 o	1 o	1 o	1 o	1 o	1 e
Europe	739	1156	2 007	2 311	2 312	2 312	2 312	2 312	2 312	2 321
France										9 o
Germany	2	2	2	2	2	2	2	2 e	2 o	2 e
Italy	5 o	5 o	5 o	5 o	6 o	6 o	6 o	6 o	6 e	6 e
Romania								0	0	0 e
Spain	732	1149	2 000	2 304	2 304	2 304	2 304	2 304	2 304	2 304 o
European Union (28)	739	1156	2 007	2 311	2 312	2 312	2 312	2 312	2 312	2 321
Middle East	6	6	6	106	106	106	106	106	156	448
Israel	6 e	6 e	6 o	6 e	6 e	6 o	6 e	6 e	6 e	248 u
Kuwait										50 e
Saudi Arabia									50 u	50 e
United Arab Em				100 o	100 o	100 u	100 e	100 u	100 e	100 e
N America	473	472	476	1 286	1 667	1 758	1 758	1 758	1 772	1 772
Mexico									14 o	14 o
USA	473	472	476	1 286	1 667	1 758	1 758	1 758 o	1 758 o	1 758 o
Oceania	3	3	3	3	3	3	3	2	2	2
Australia	3	3	3	3	3	3	3	2	2	2 o

Greenway CSP Mersin Tower Plant [17]

- March 2013, Mersin, Turkey
- Solar Tower (50 m)
- 510 Heliostats (30 daa)
- $T_{Boiler} = 550$ °C at 55 bar
- Fluid: Water
- Output Type: Steam Rankine
- $P_{Net} = 1.0$ MW
- Thermal Storage: Molten Salt

Figure 2: Mersin CSP Plant [19]

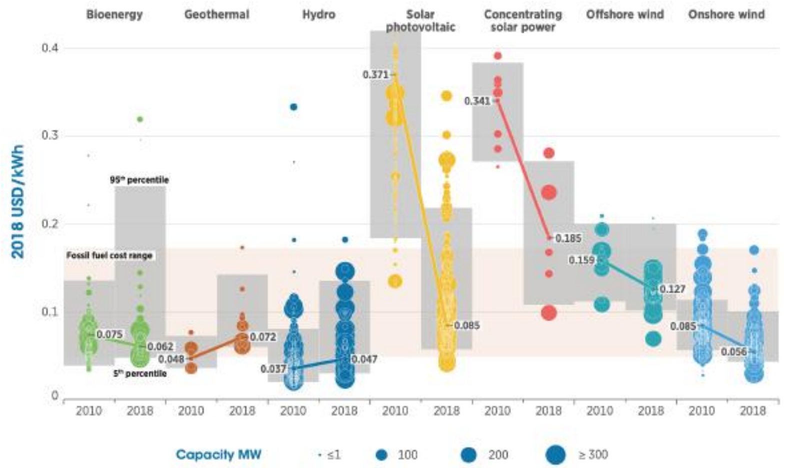
Video - Greenway CSP Mersin Tower Plant [20]

Outline

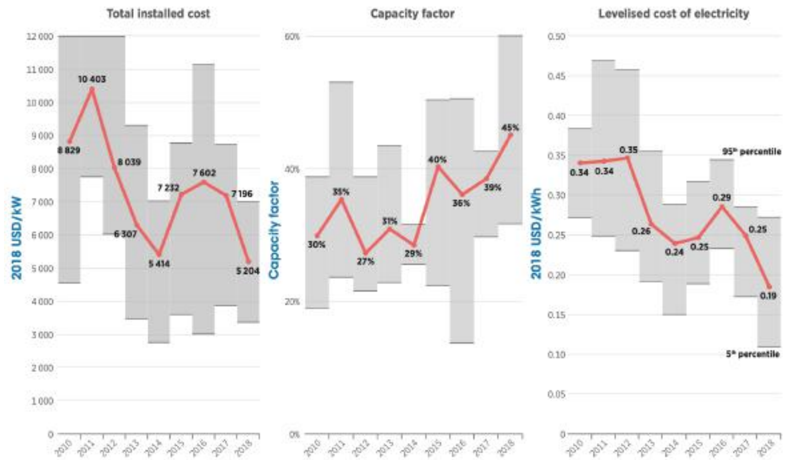
Turkish Support Schemes for CSP [21]

Renewable Energy Type	Support (UScents/kWh)
Hydraulic	7.3
Wind	7.3
Geothermal	10.5
Biomass (including Landfill)	13.3
Solar	13.3
Bonuses for Domestically Manufactured CSP Components	
Vacuum Tubes	+2.4
Reflective Surface Panels	+0.6
Solar Tracking System	+0.6
Heat Energy Storage Systems	+1.3
Tower and Steam Production System	+2.4
Stirling Engine	+1.3
Integration of Solar Panels and Mechanical Systems	+0.6
Total CSP Support	up to 22.5

Economics of Renewable Energy Systems [22]



Economics of CSP [22]



Outline

Question 1 [23]

What are the main advantages of a CSP plant with solar tower? Please note that more than one correct answer is possible.

- ☑ Easy storage of energy
- ☑ High temperature fluid that yields higher efficiencies
- ☐ Compact and modular
- ☐ Low investment costs

Question 2 [23]

The world electricity consumption is approximately 20,300 TWh per year. It is considered that the total electricity demand of the world is covered by installing a CSP plant in the Sahara desert, where the average solar insolation per day is 6.3 kWh/m^2. Assuming that the overall efficiency of the CSP plant is 20%, how much area in km^2 will be needed to cover the world electricity demand?

Solution:

$$A = \frac{20300 \ \ TWh}{0.2 \times 6.3 \ \ kWh/m^2 day \times 365 \ \ days} = 44140 \ \ km^2$$

Question 3 [24]

Calculate electrical energy generation unit cost of a 10 MW CSP plant with a unit equipment cost of 2,500 USD/kW, a power plant lifetime (ℓ) of 10 years, an efficiency of 30%, a land price of 10 USD/m^2, and a valuation ratio (ξ) of 6% per year by taking into account the followings:

- In layout planning of the plant,
  - 10 m^2 area is needed for deploying 1 m^2 heliostat,
  - Heliostats will be placed by leaving a margin of 10%,
  - For other equipment, an additional area will be reserved which corresponds to the half of the area occupied by the heliostats.
- Net power capacity of each heliostat is 0.285 kW/m^2.
- Average solar insolation per year is 2,200 kWh/m^2.

Hint: C_{year} and $C_{Investment}$ stand for the costs of annual electrical energy generation and investment respectively.

$$C_{year} = C_{Investment} \times [\frac{\xi \times (1+\xi)^{\ell}}{(1+\xi)^{\ell} - 1}]$$

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