Introduction to Solar Energy Technologies

Dr. Syed Noman Danish
Assistant Professor
sdanish@ksu.edu.sa

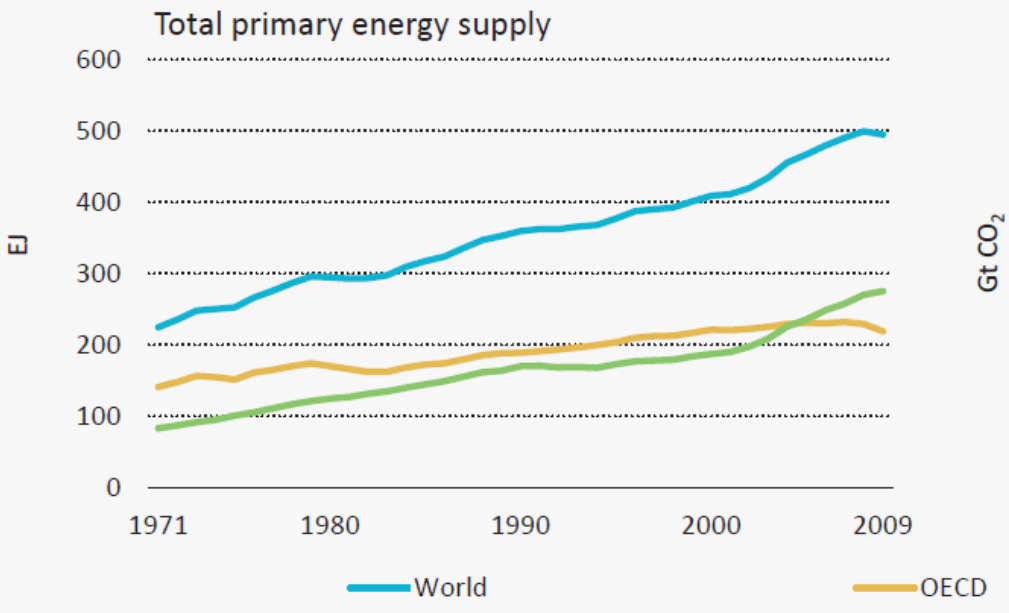
Outline

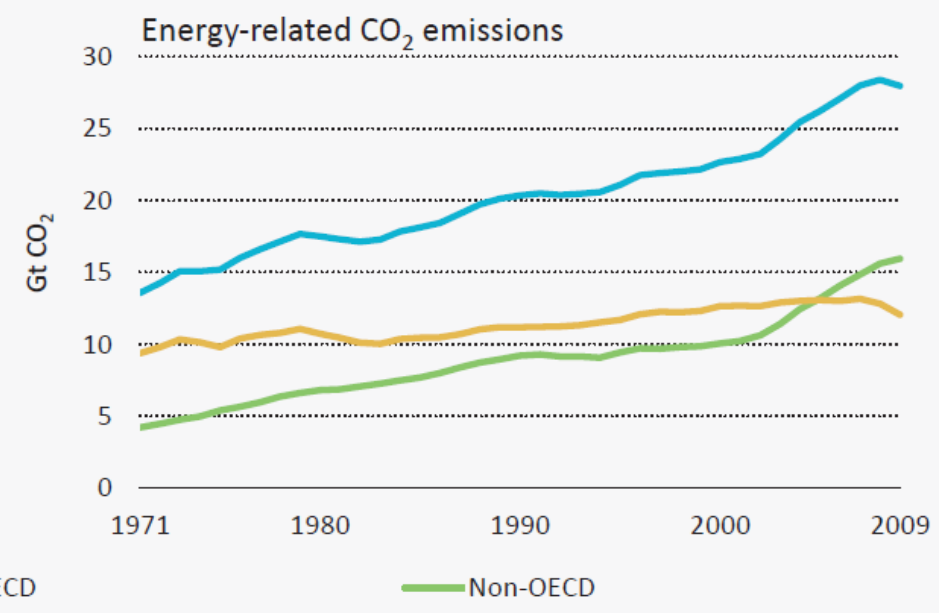
- Importance of Renewable Energy Technologies
- KSA Renewable Energy Plan 2012-2032
- Solar Energy
- Solar Energy Technologies
  - Concentrated Solar Power (CSP)
  - Solar PV
  - Solar Water Heating System

Importance of Renewable Energy Technologies

ENERGY TECHNOLOGY PERSPECTIVES 2012

Energy demand and emissions have doubled in the past 40 years

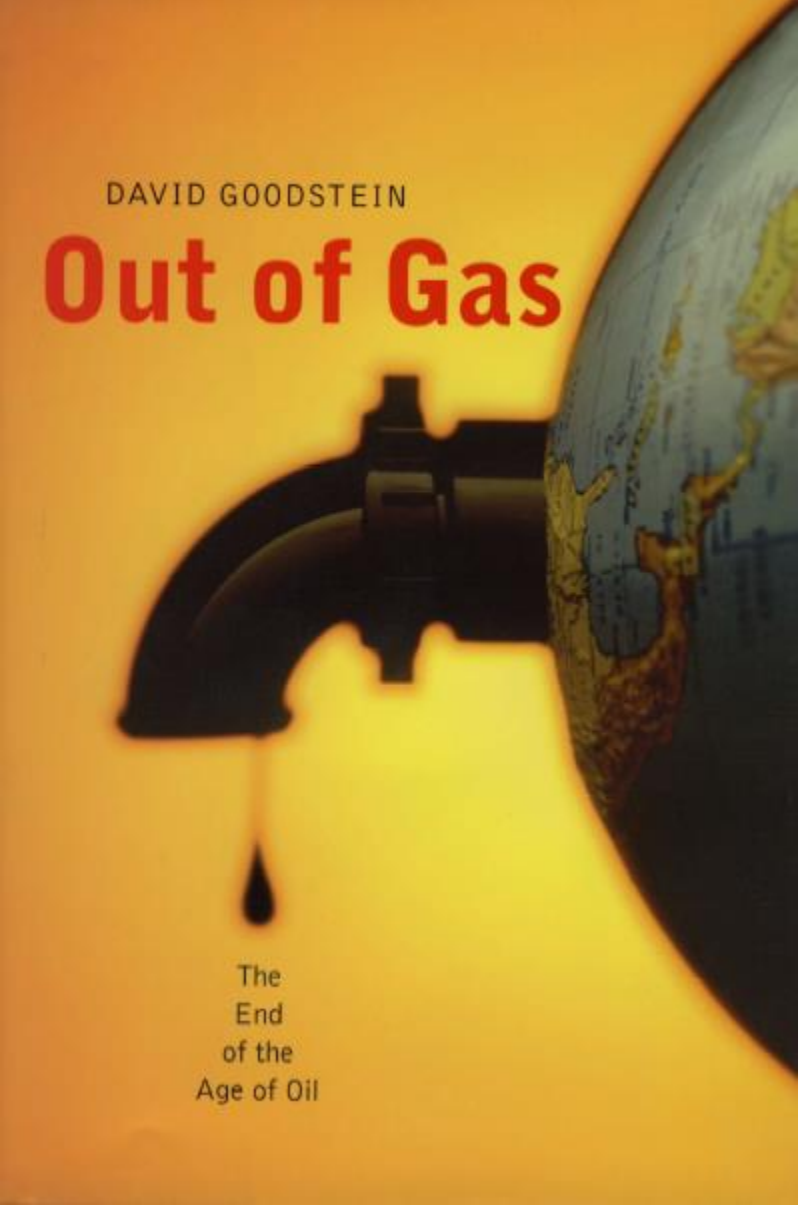




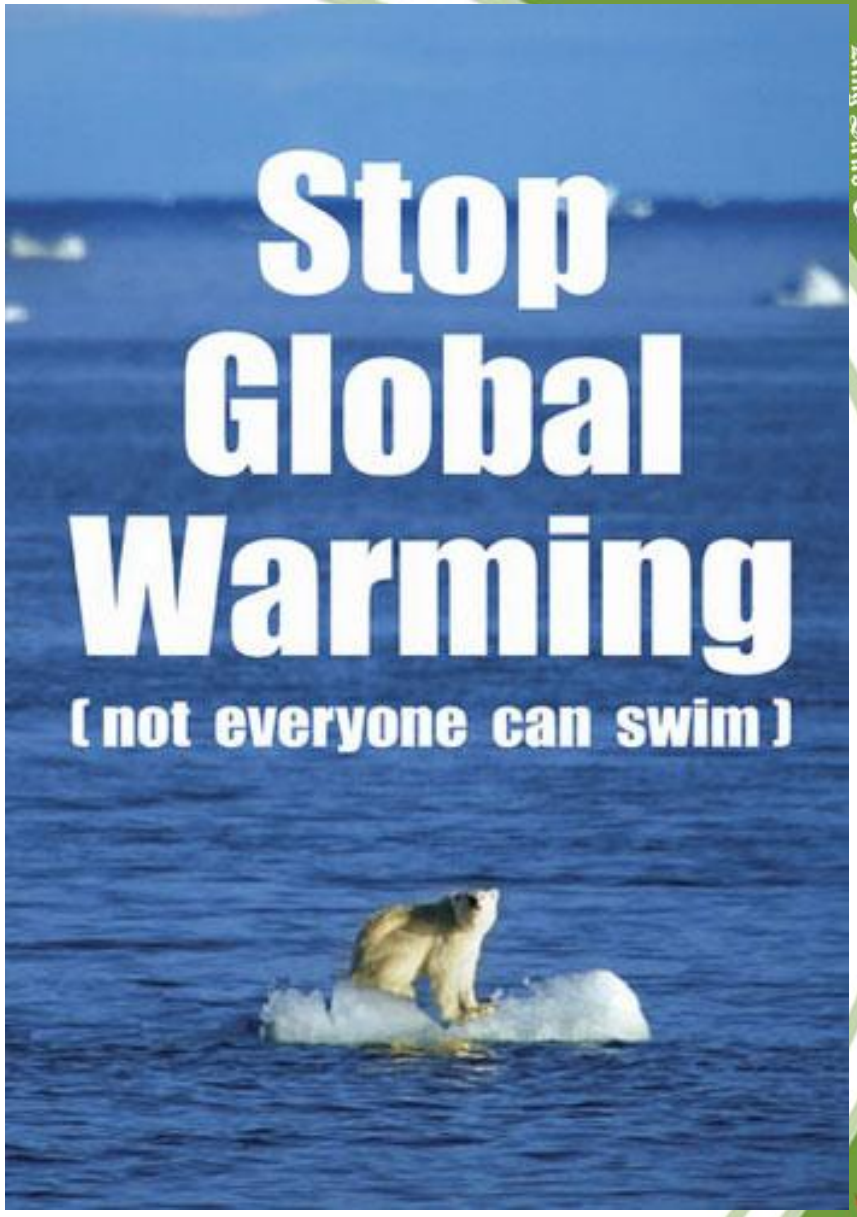
- **From 6,000 Mtoe to 12,000 Mtoe**
- **Rapid demand growth outside OECD**

- **CO2 emissions from 14Gt to 30Gt**
- **Since 2005, non-OECD countries emit more than OECD**

Source: IEA statistics



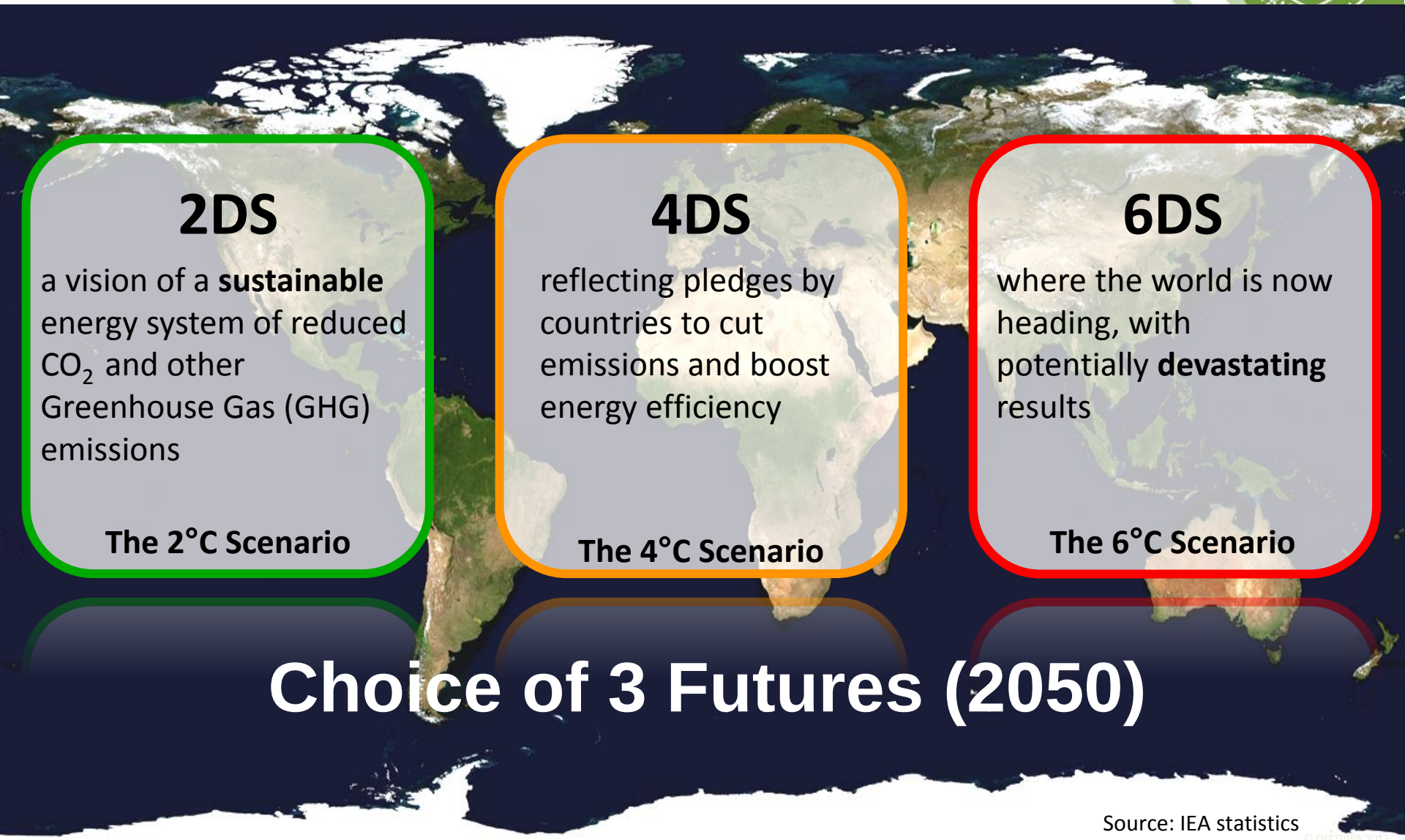
American Petroleum Institute estimates that we will consume all world oil within 40 years



International Panel on Climate Change (IPCC) estimates, “global average sea level will rise by 2 feet in next century”

Importance of Renewable Energy Technologies

ENERGY TECHNOLOGY PERSPECTIVES 2012



2DS

a vision of a **sustainable** energy system of reduced CO_2 and other Greenhouse Gas (GHG) emissions

The 2°C Scenario

4DS

reflecting pledges by countries to cut emissions and boost energy efficiency

The 4°C Scenario

6DS

where the world is now heading, with potentially **devastating** results

The 6°C Scenario

Choice of 3 Futures (2050)

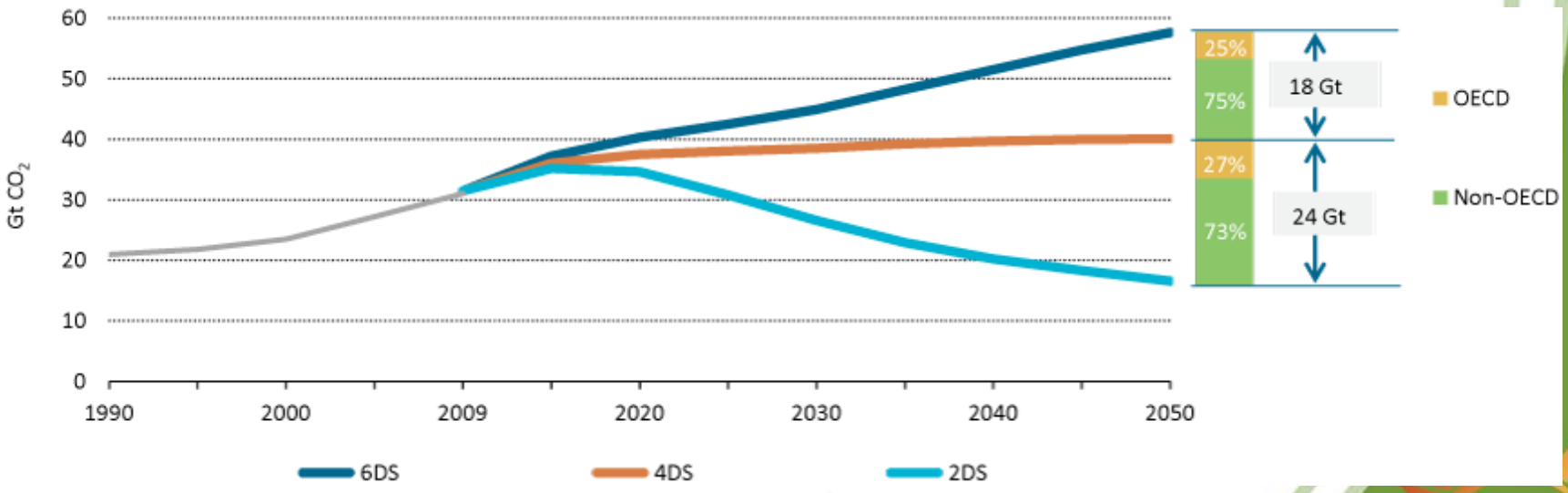
Source: IEA statistics

Importance of Renewable Energy Technologies

ENERGY TECHNOLOGY PERSPECTIVES 2012

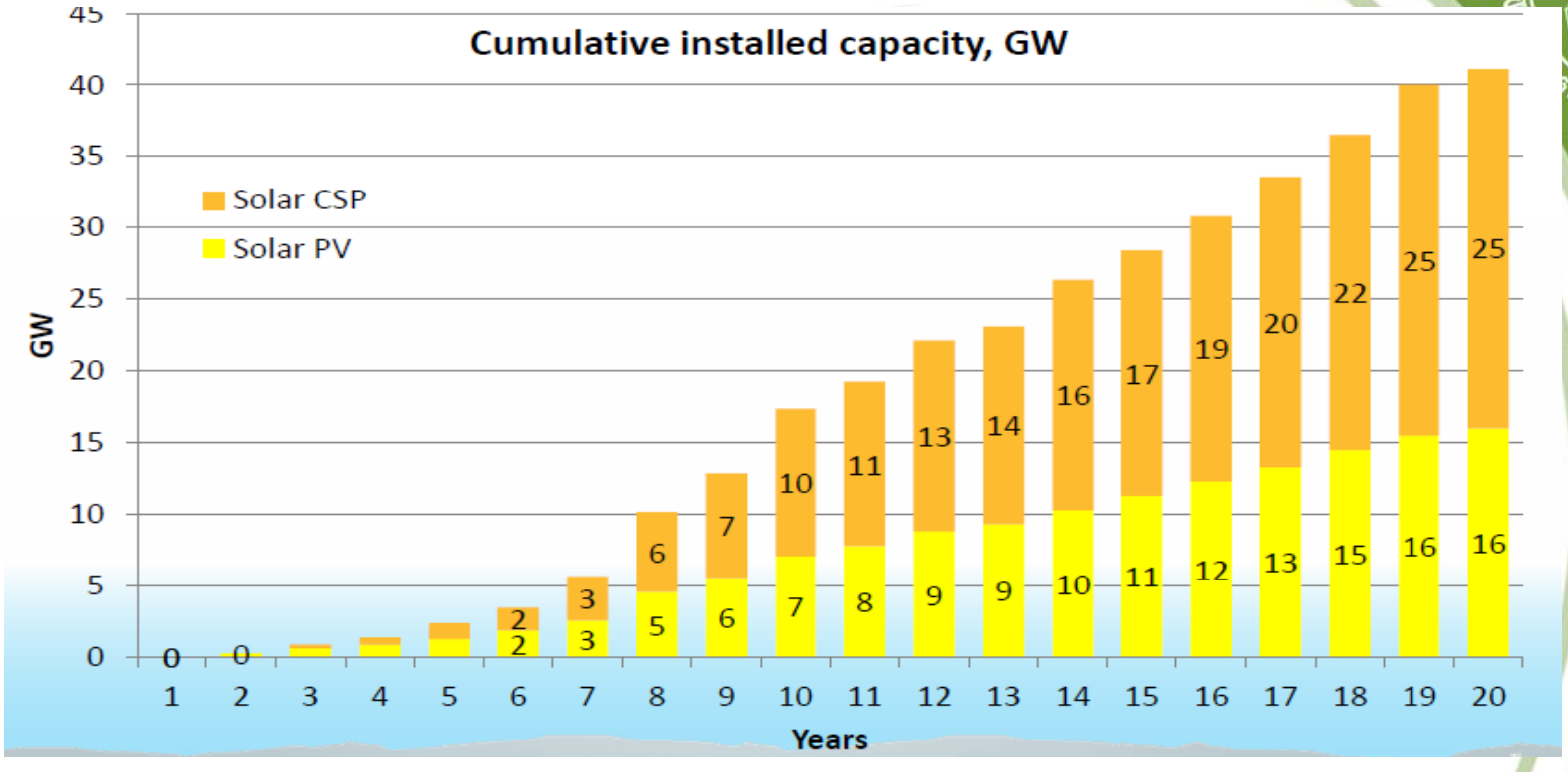
Need to Halve CO_2 by 2050

- To achieve ambitious climate goals, the world needs to cut energy-related CO_2 emissions by 50% from today's levels…
- …but as populations grow and energy consumption inevitably rises, the reduction challenge is even higher: **a gap of 24-42 Gt in 2050**



Source: IEA statistics

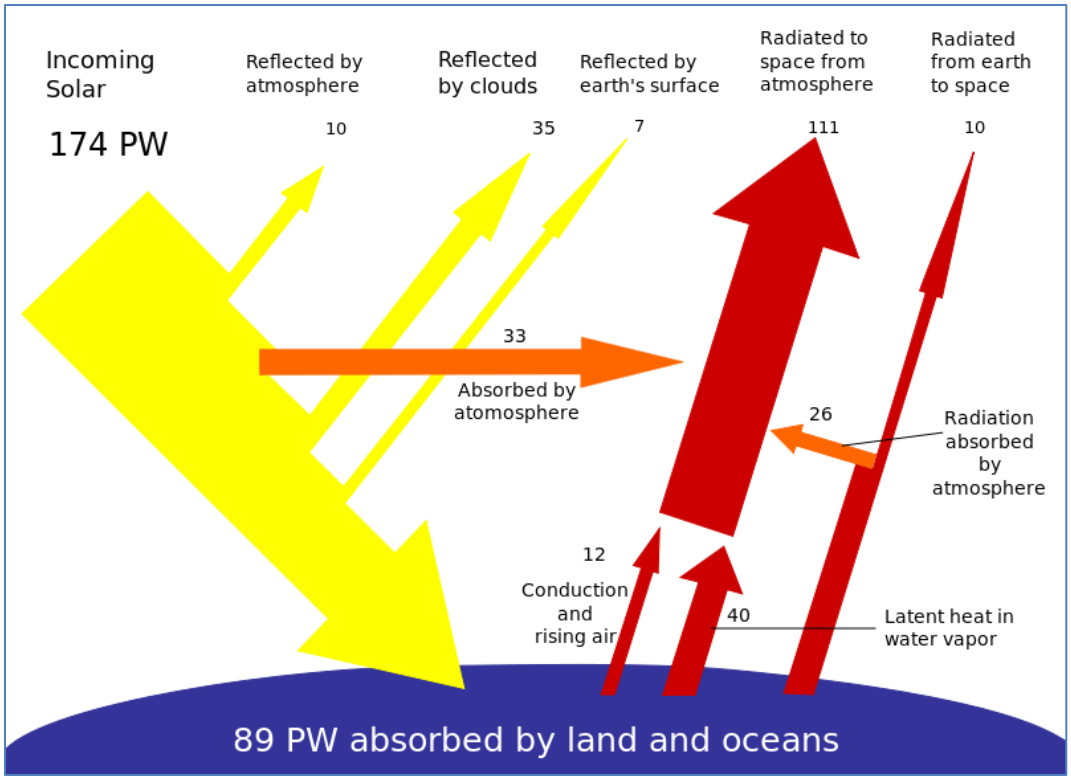
KSA Renewable Energy Plan 2012-2032



Source: SET Report 2013: Status of Renewable Energy in Saudi Arabia

- $109b for 41GW of solar capacity (30% of KSA's total electricity demand in 2032)
- Saving 523k barrels of oil per day by 2032
- Extra 21GW (Nuclear, Wind, and Geothermal)
- 1.1GW PV and 900MW CSP are planned to be completed in 2013

Solar Energy

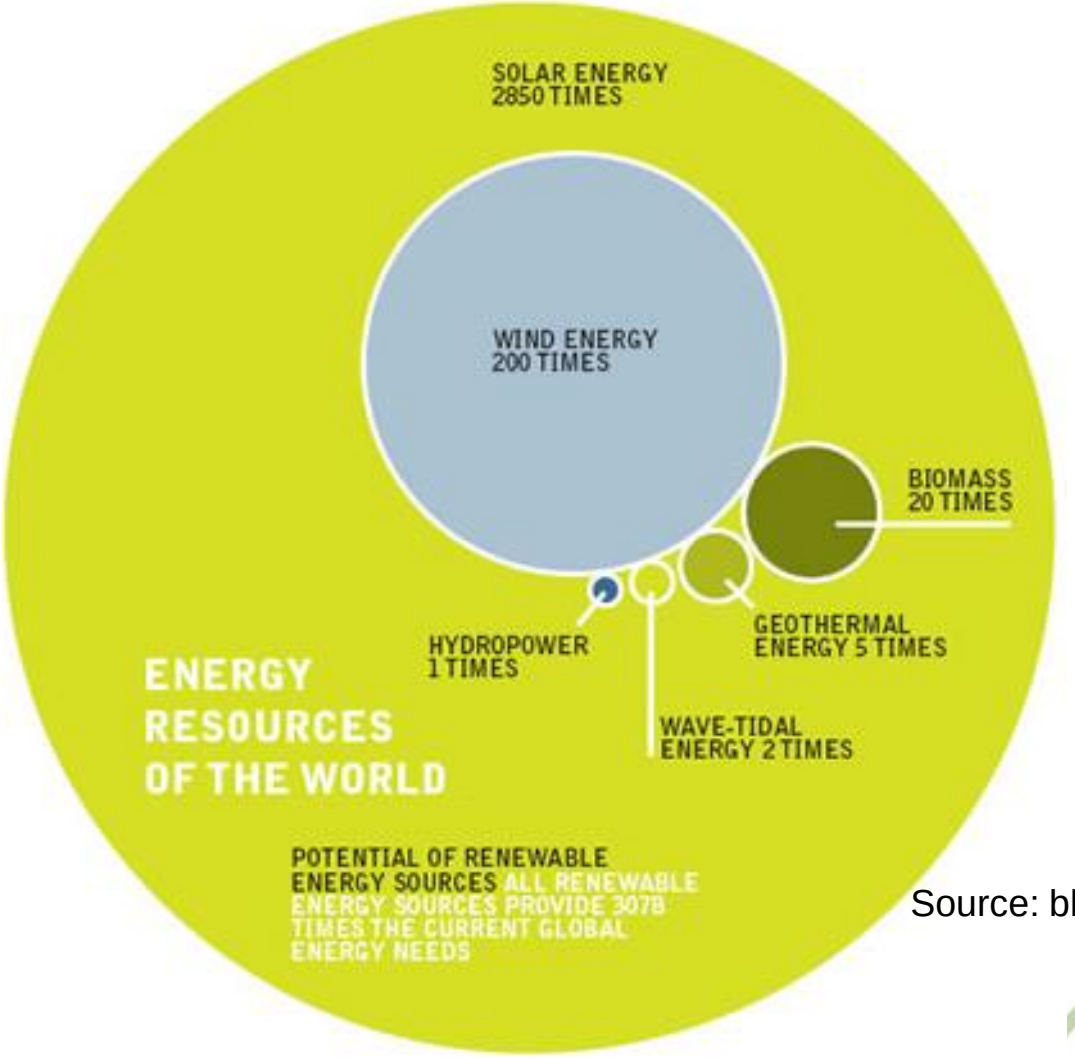


Yearly Solar fluxes & Human Energy Consumption in 2009 (EJ)	
Solar	3,850,000
Wind	2,250
Biomass potential	100–300
Pri. energy use	510
Electricity	62.5

- Earth receives 174 PW (only 1.5 trillionth of total solar energy)
- 30% is reflected back to space while the rest is absorbed by clouds, oceans and land masses.
- In one hour the earth receives more energy from the sun than the world consume in one year.
- If a 33 x 33 km parcel of land (1112 km^2 out of 2,217,949 km^2) was covered with solar collectors, the electricity needs of the entire KSA could be met!

Solar Energy

Potential



Source: blog.abengoa.com

Potential of the different renewable technologies

Solar Energy

Potential in KSA

Power production in Saudi Arabia (2010) = **219** TWh

Considering average yearly irradiance of **2.500** kWh/m^2 year

So for 1 km^2 of land, Total Available Energy = 2.500 GWh/year

To avoid shadowing, solar collectors can not cover all surface; assuming a land occupation factor of 50%

2500 GWh x 0,5 = 1.250 GWh

Avg. total efficiency in annual solar energy collection (parabolic troughs): 45% → 562,5 GWh

Rankine cycle efficiency: 35% → 197 GWh

219,000 / 197 = **1112** km^2 required → square of **33** km side length

Saudi Arabia land surface: 2,217,949 km^2

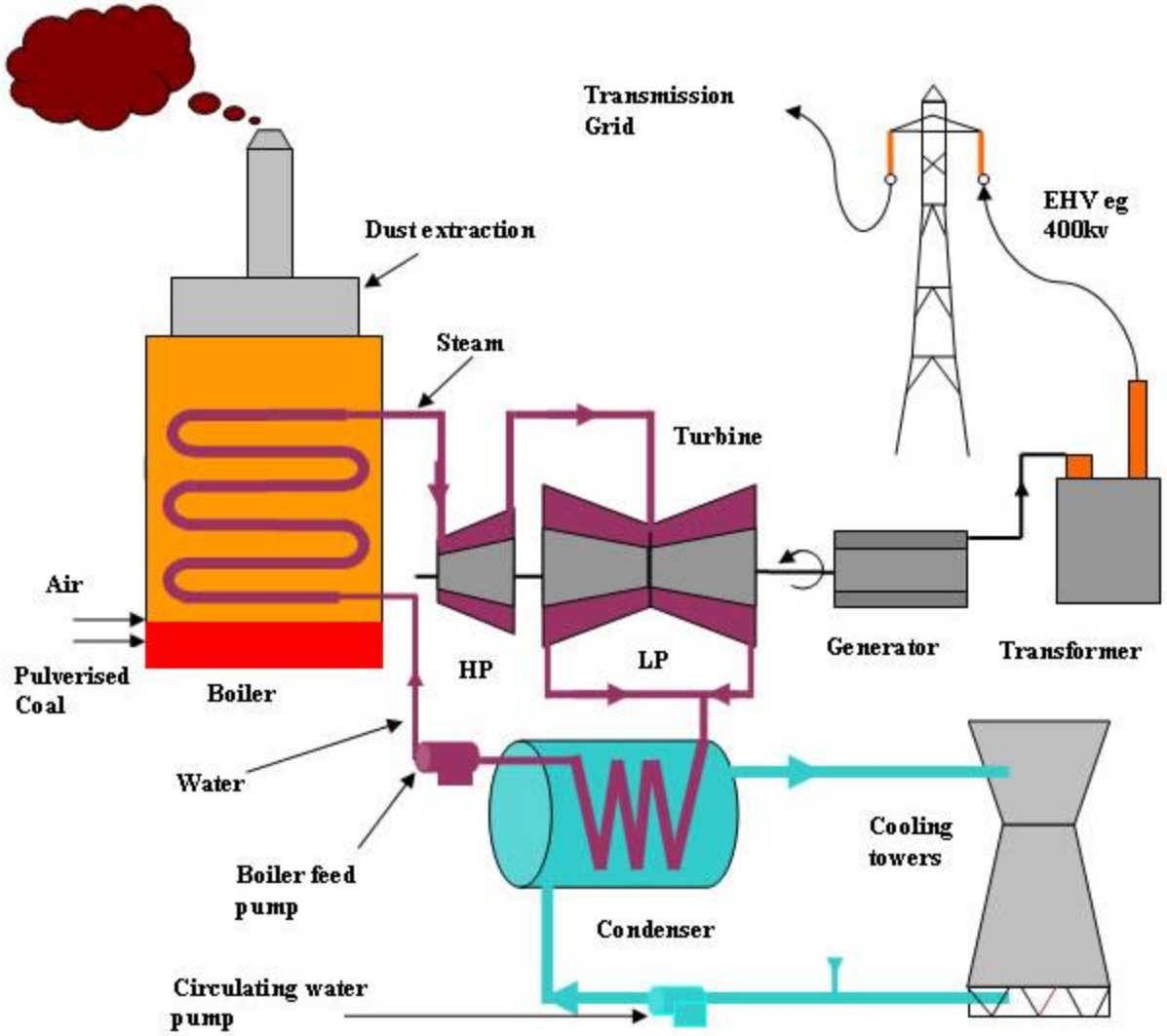
Solar Energy Technologies…

Concentrated Solar Power (CSP)

- Parabolic Trough Solar Thermal System
- Central Tower Solar Thermal System
- Linear Fresnel Solar Thermal System
- Parabolic Dish Solar Thermal System
- KSU Indigenous CSP Systems

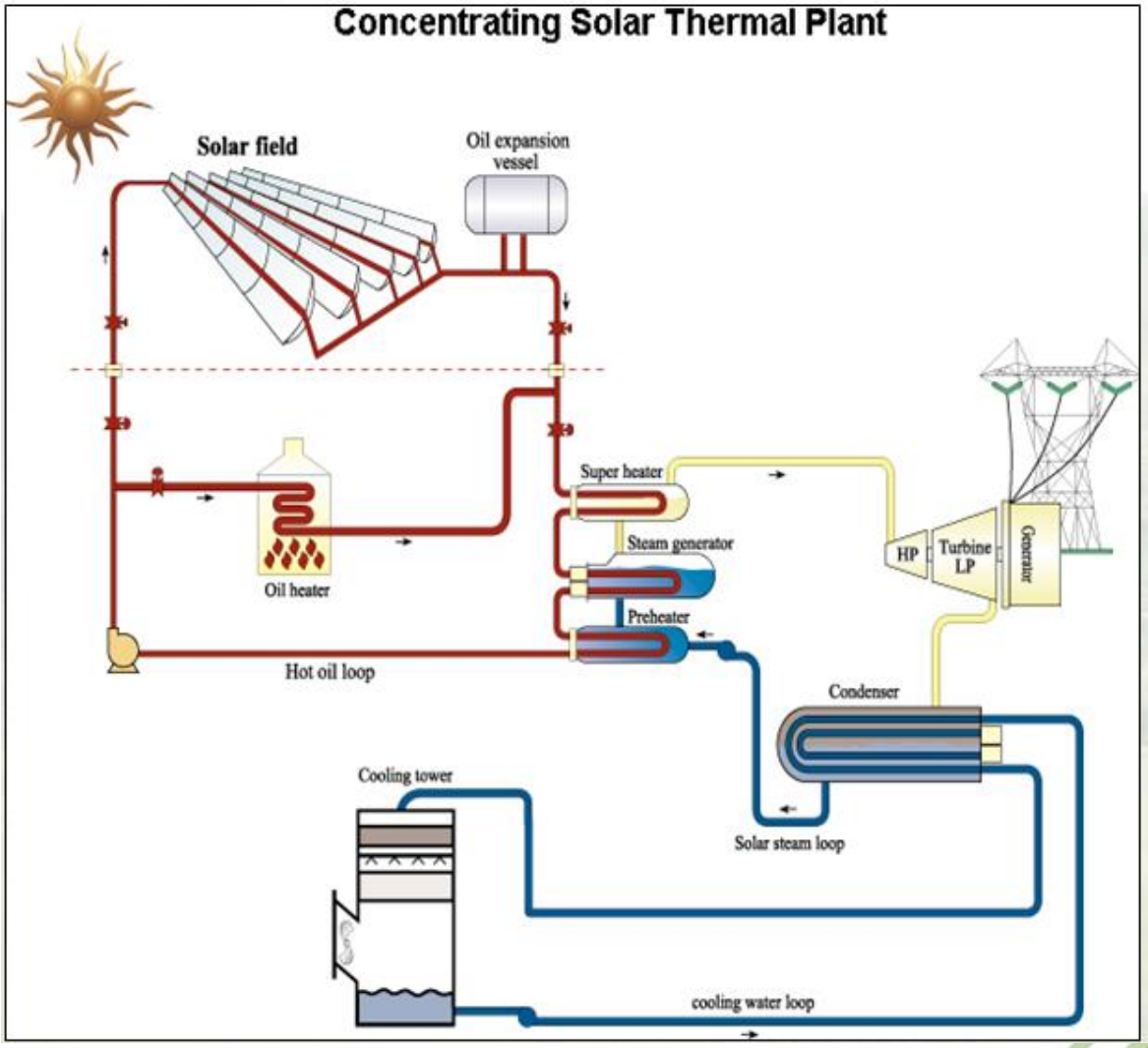
Concentrated Solar Power (CSP)

How does a coal or oil power generation system work?



Concentrated Solar Power (CSP)

How does a CSP power station work?



Schematic diagram of a solar-thermal energy conversion system.

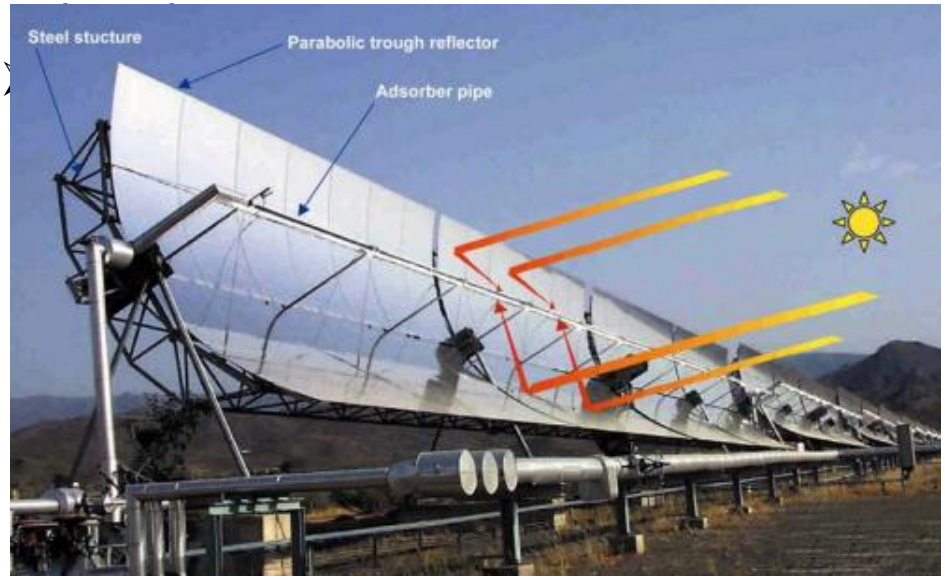
Concentrated Solar Power (CSP)

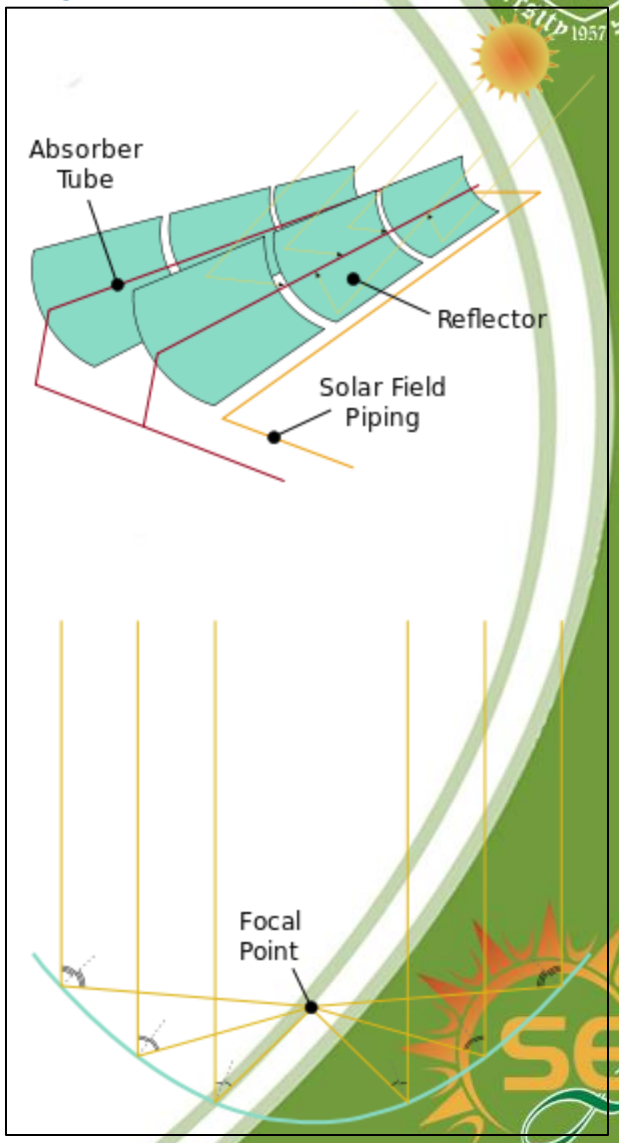
- Parabolic Trough Solar Thermal System
- Central Tower Solar Thermal System
- Linear Fresnel Solar Thermal System
- Parabolic Dish Solar Thermal System
- KSU Indigenous CSP Systems

Concentrated Solar Power (CSP)

1. Parabolic Trough Solar Thermal System

- The most mature existing CSP
- About 35 years of commercial experience
- The troughs concentrate sunlight onto a receiver tube that is positioned along the focal line of the trough.
- Sometimes a transparent glass tube envelops the receiver tube to reduce

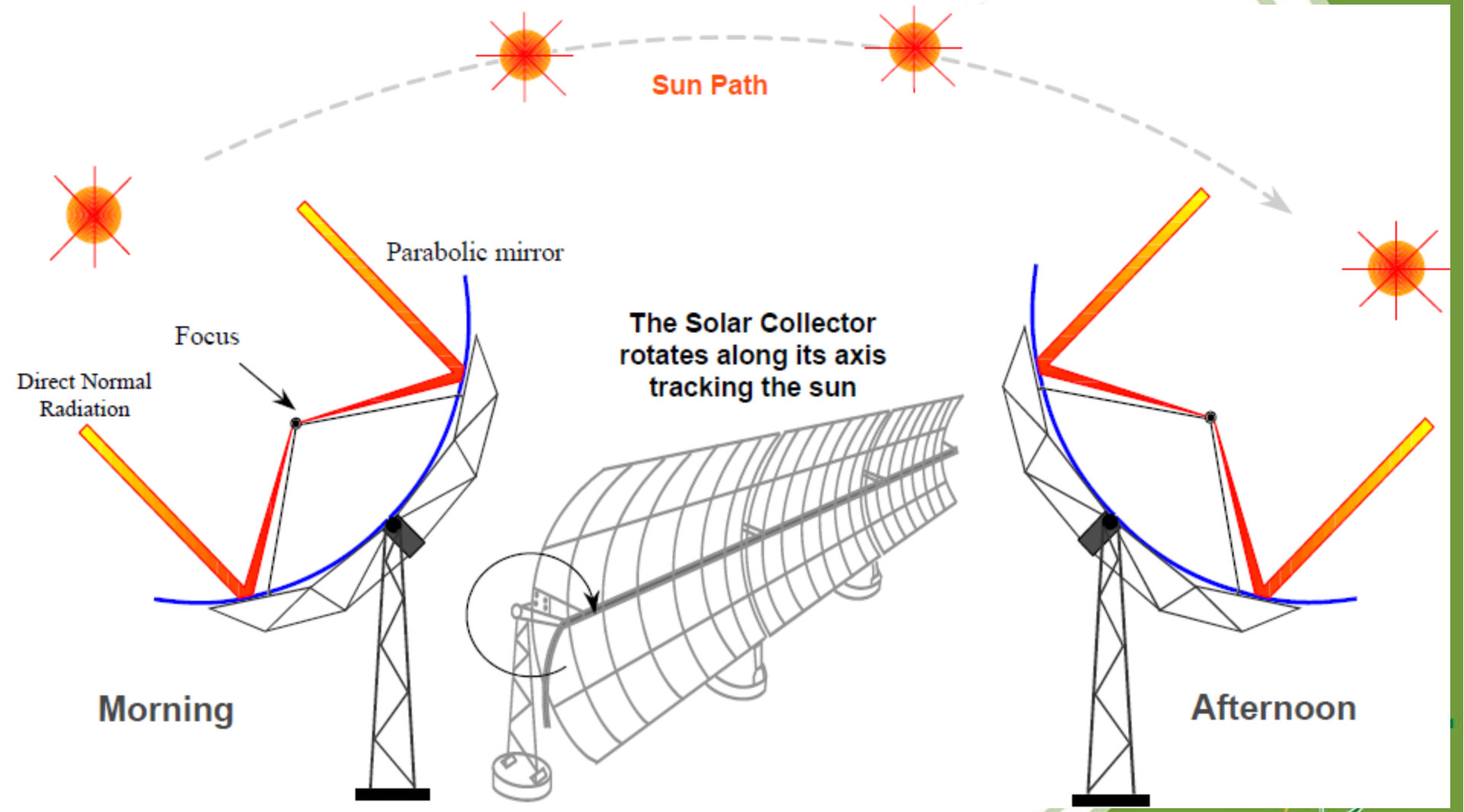




Concentrated Solar Power (CSP)

1. Parabolic Trough Solar Thermal System

ONE-AXIS PARABOLIC TROUGH COLLECTOR

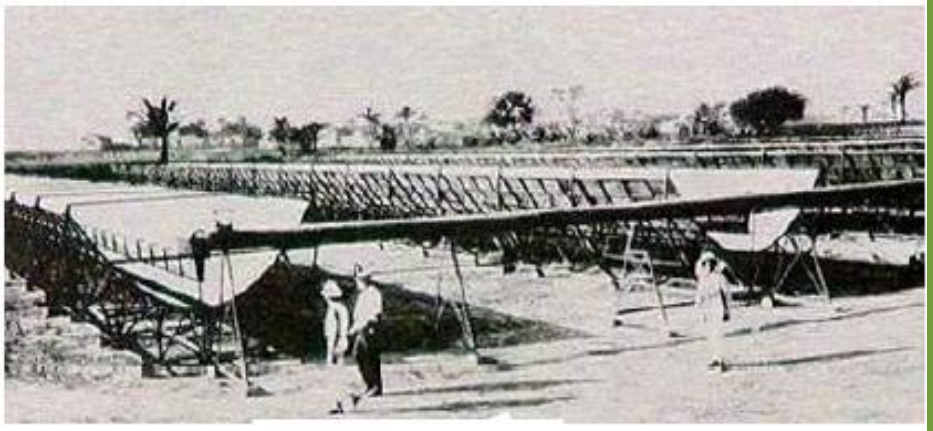


Concentrated Solar Power (CSP)

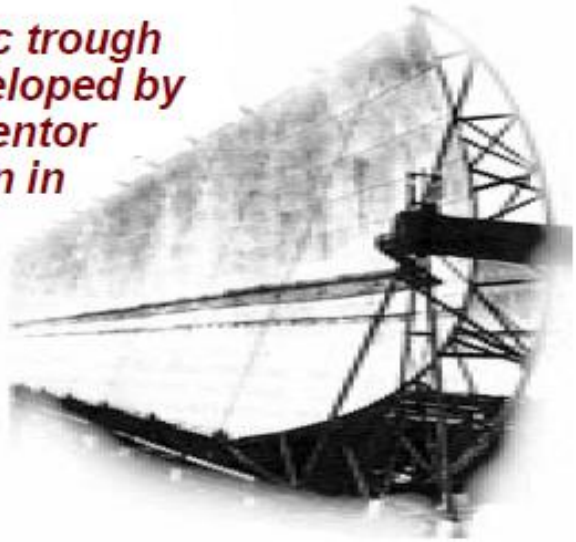
1. Parabolic Trough Solar Thermal System

FIRST APPLICATION OF MODERN ERA

Nearly 100 years ago, when coal was transported from England to Egypt, the first Parabolic Trough Collector to produce direct solar steam was constructed and installed in Meadi (near Cairo): 5 rows (62 m length x 4 m aperture) connected to a 120 HP steam turbine



First parabolic trough collector developed by American inventor Frank Shuman in Cairo (1912)



Concentrated Solar Power (CSP)

1. Parabolic Trough Solar Thermal System

SEGS IN CALIFORNIA

- 354 MW
- largest CSP facility in the world.
- 9 plants
- power 232,500 homes
- displace 3,800 tons of pollution per year
- 936,384 mirrors
- Land Use: 70 MW/km^2.
- 1,600 acres
- extend over 369 km
- LEC ~$0.13 kWh

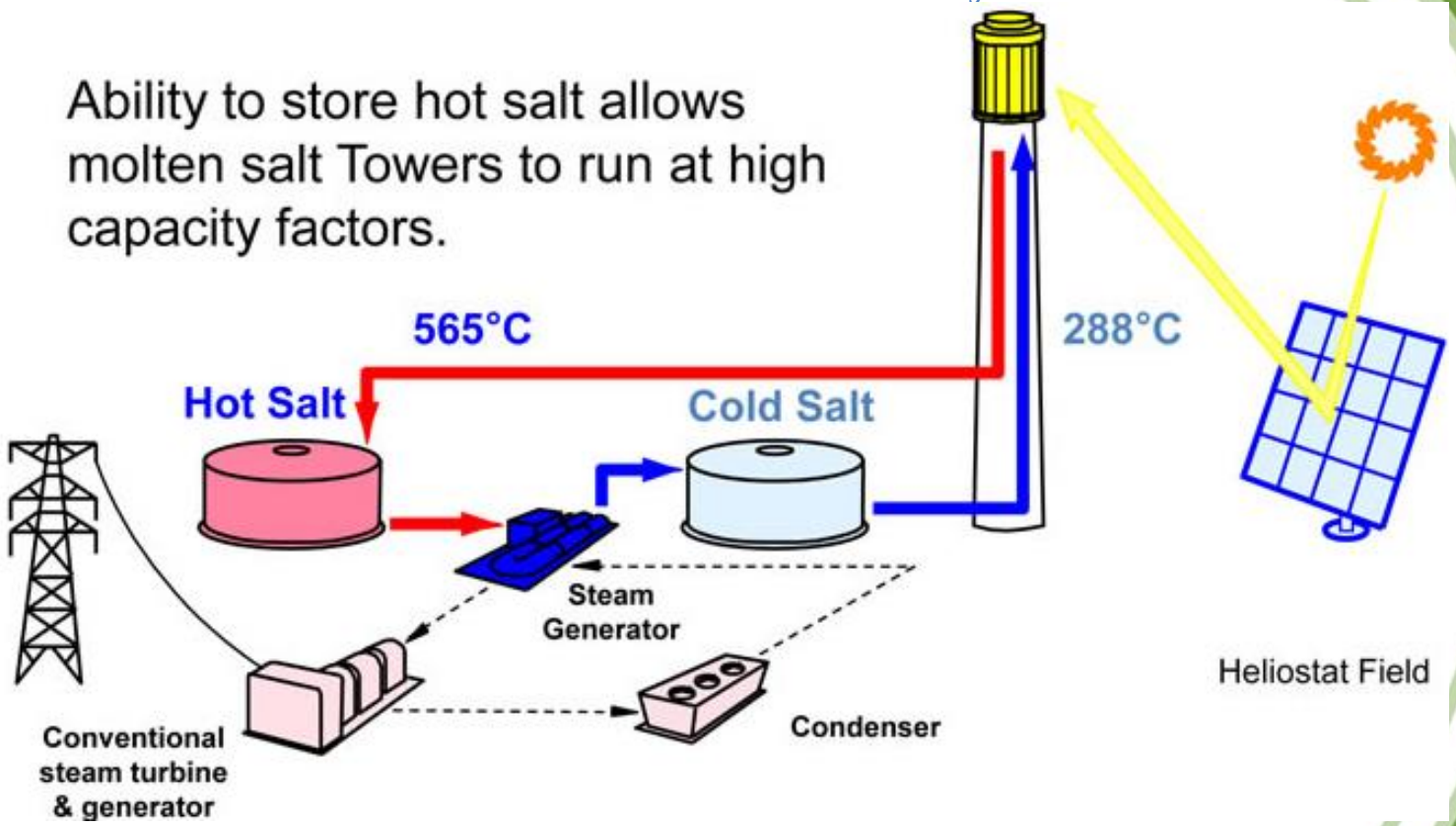
Aerial view showing portions of four of the nine SEGS III–VII plants

Concentrated Solar Power (CSP)

- Parabolic Trough Solar Thermal System
- Central Tower Solar Thermal System
- Linear Fresnel Solar Thermal System
- Parabolic Dish Solar Thermal System
- KSU Indigenous CSP Systems

Concentrated Solar Power (CSP)

2. Central Tower Solar Thermal System



- The central tower solar thermal system takes advantage of numerous heliostats to reflect sunlight onto the surface of the high-temperature heat absorber on the top of the center tower.
- The fluid medium (water, fused salt or air) is heated, thus directly or indirectly generate overheated steam or high-temperature air to propel the generating set.

Concentrated Solar Power (CSP)

2. Central Tower Solar Thermal System

IVANPAH 440 MW POWER FACILITY

Concentrated Solar Power (CSP)

2. Central Tower Solar Thermal System

Examples of Solar Power Towers

Power plants	Installed capacity (MW)	Yearly production (GWh)	Country	Developer/Owner	Completed
Ivanpah Solar Power Facility	*392 (U/C)*	420	United States	BrightSource Energy	2013
Crescent Dunes Solar Energy Project	*110 (U/C)*	500	United States	SolarReserve	2013
PS20 solar power tower	20[1]	44	Spain	Abengoa	2009
Gemasolar[2]	17	100	Spain	Sener	2011
PS10 solar power tower	11[3]	24	Spain	Abengoa	2006
Sierra SunTower	5[4]		United States	eSolar	2009
Jülich Solar Tower	1.5[5][6]		Germany		2008

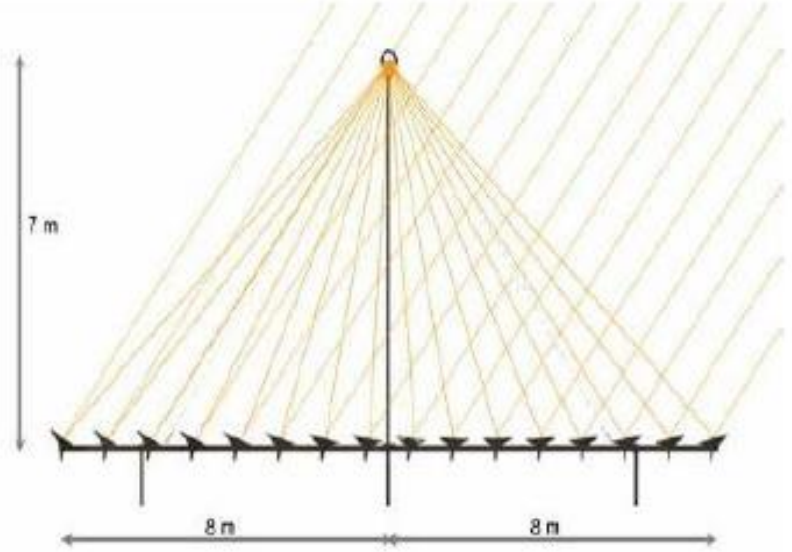
Concentrated Solar Power (CSP)

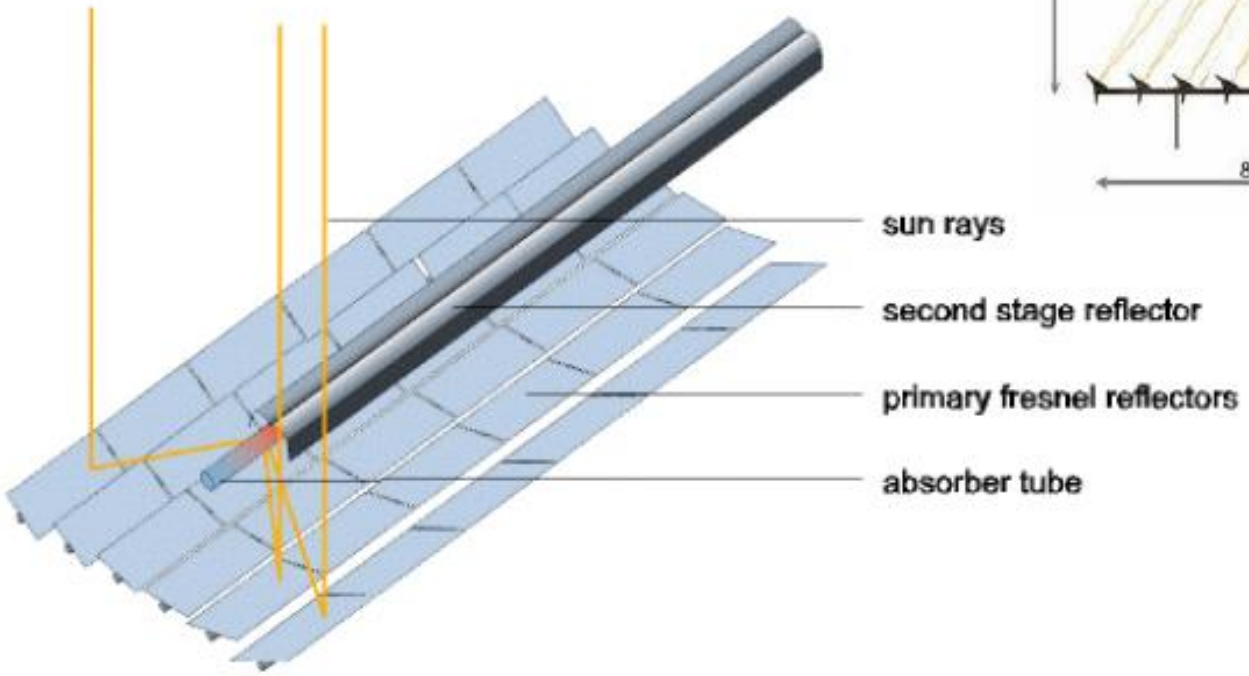
- Parabolic Trough Solar Thermal System
- Central Tower Solar Thermal System
- Linear Fresnel Solar Thermal System
- Parabolic Dish Solar Thermal System
- KSU Indigenous CSP Systems

Concentrated Solar Power (CSP)

3. Linear Fresnel Solar Thermal System

Fresnel collectors are one-axis solar tracking devices optically very similar to PTC, but with the parabola divided into many small, nearly flat, mirrors with independent movement and simultaneously focusing the linear absorber located in optical focus





Due to its potential advantages, LFCs are receiving significant attention. However, technological superiority over PTCs is not yet clear

Concentrated Solar Power (CSP)

3. Linear Fresnel Solar Thermal System

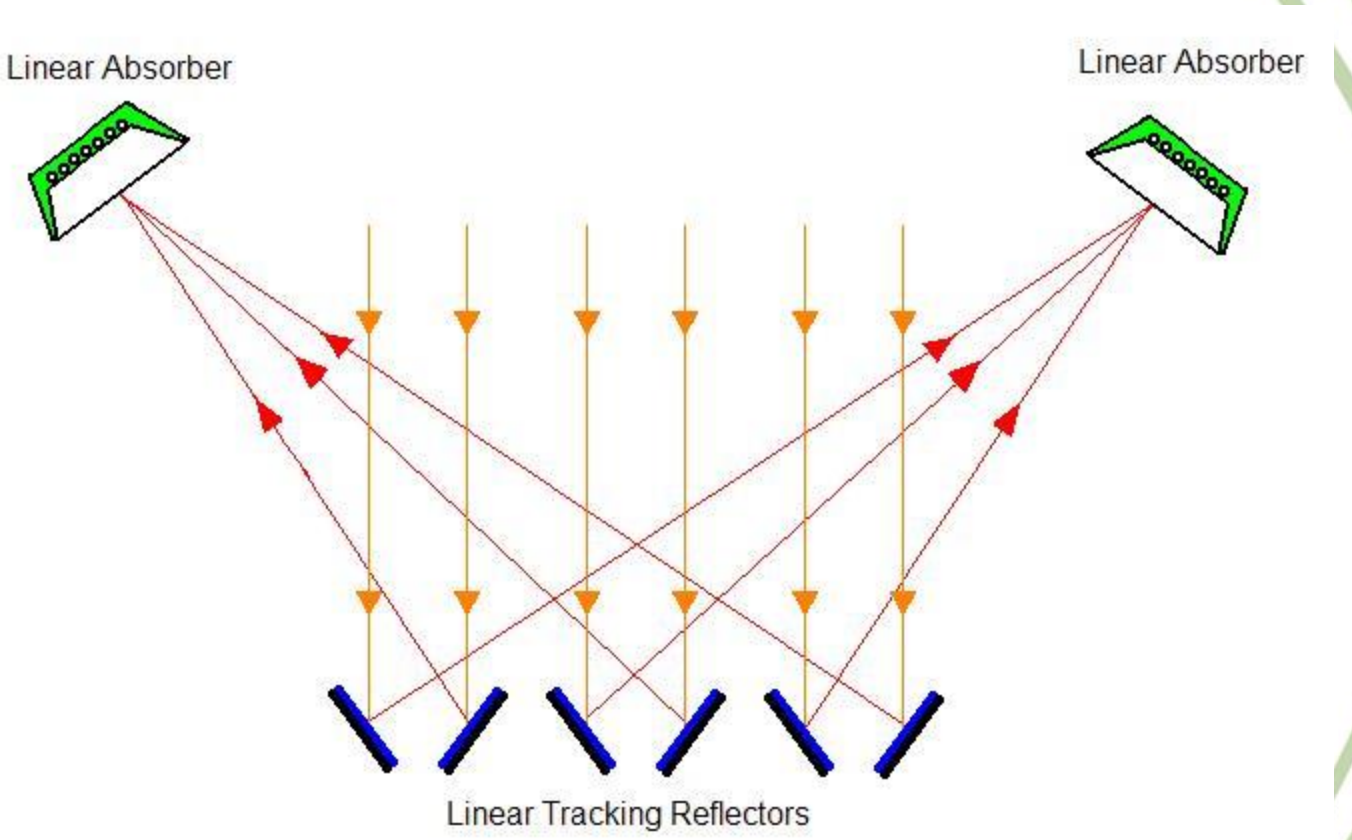
1.4 MW_e CSP plant (18,000 m^2 solar field) based on NOVA-1 technology (Novatec-Biosol Linear Fresnel Collector) located in Murcia, Spain (2009)

Land Use: 100 MW/km^2.

LEC \$0.08~\$0.10/kWh

Concentrated Solar Power (CSP)

3. Compact Linear Fresnel Solar Thermal System



CLFR solar systems alternate the inclination of their mirrors to focus solar energy on multiple absorbers, improving system efficiency and reducing overall cost. The concept also reduce the foot print by about 30% compared to LFR

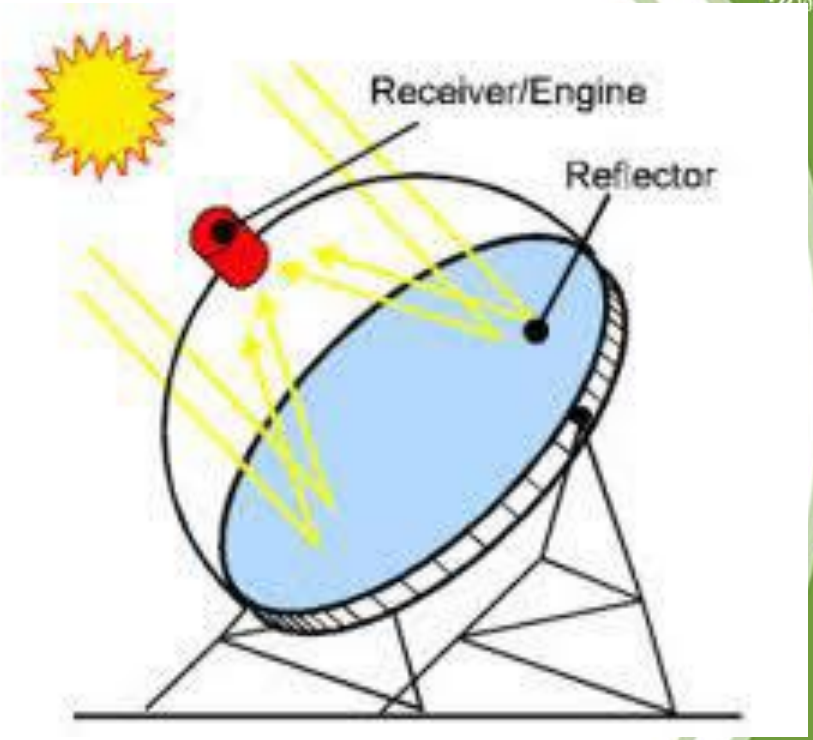
Concentrated Solar Power (CSP)

- Parabolic Trough Solar Thermal System
- Central Tower Solar Thermal System
- Linear Fresnel Solar Thermal System
- Parabolic Dish Solar Thermal System
- KSU Indigenous CSP Systems

Concentrated Solar Power (CSP)

4. Parabolic Dish Solar Thermal System

- Stirling Engine + parabolic solar dish = Solar Dish Stirling Engine
- Sunlight focused on engine with a cavity receiver on the focal point; working fluid is heated to run the Stirling cycle
- Working temperatures: 700 – 800 °C.
- World's Most Efficient Solar Electric Technology to date (yearly average higher than 20% and peak measured higher than 30%)



Concentrated Solar Power (CSP)

4. Parabolic Dish Solar Thermal System

Land Use: 100 MW/km^2.
LEC $0.30/kWh

1.5 MW MARICOPA SOLAR PROJECT

- Company developer: Tessera Solar.
- Installation of the project completed in just 4 months (Sept. 2009 / Jan. 2010).
- Utility: Salt River Project (SRP)
- 60 SunCatcher units (25 kW_e/unit) in 6 hectares land area

No water is needed for power generation or cooling process. Minimal water is used for site operations and washing mirrors

Concentrated Solar Power (CSP)

- Parabolic Trough Solar Thermal System
- Central Tower Solar Thermal System
- Linear Fresnel Solar Thermal System
- Parabolic Dish Solar Thermal System
- KSU Indigenous CSP Systems

Concentrated Solar Power (CSP)

5. KSU Indigenous CSP Systems

HIGH TEMPERATURE FALLING PARTICLE RECEIVER

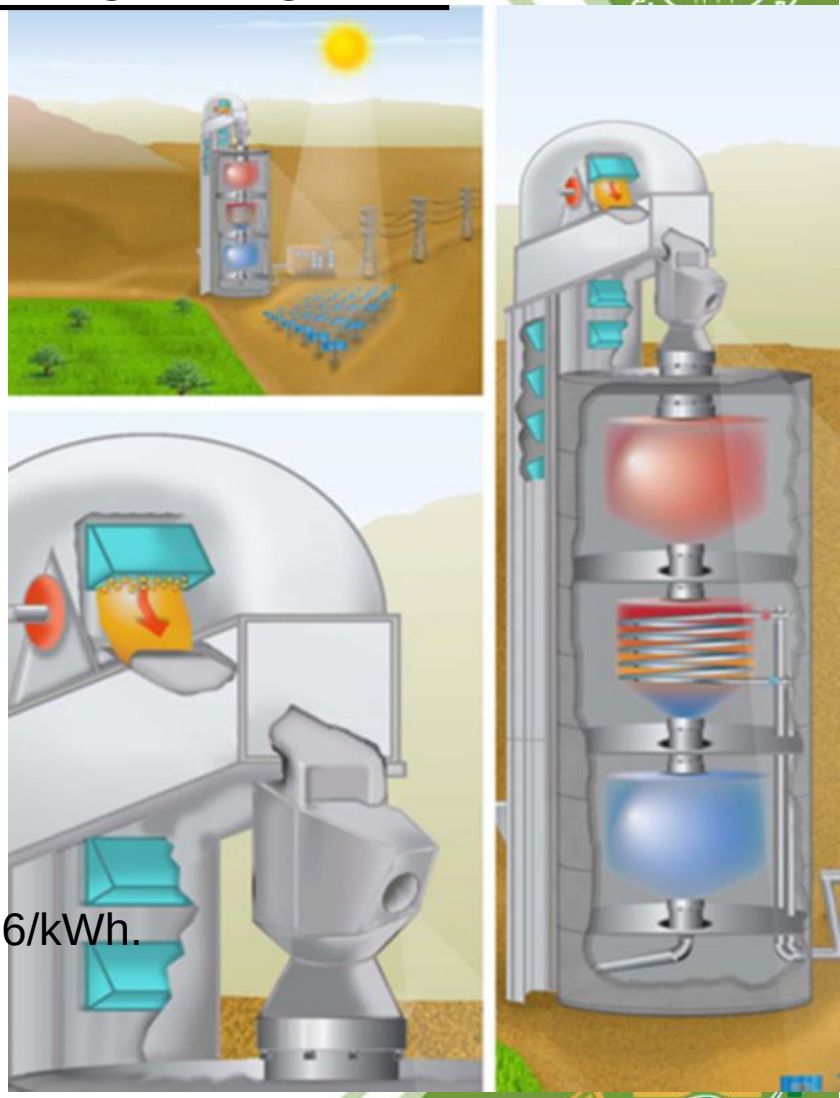
- **Key Institutions**

Sandia National Laboratories, DLR, King Saud University, U.S. Department of Energy, Bucknell University, Georgia Tech

- **Program Summary**

Period of performance: 36 months
Federal funds: $4,315,017
Cost-share: $1,081,814
Total budget: $5,396,831

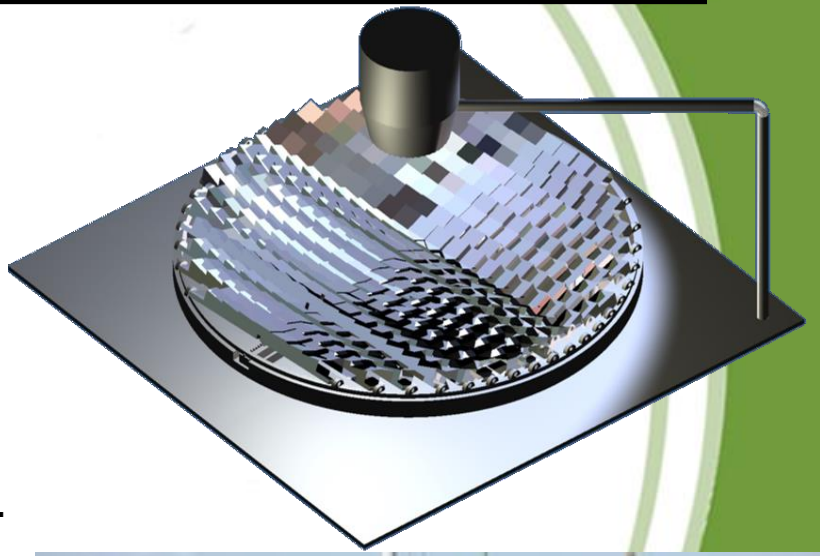
- **Technology Impact**
- Enable higher temperatures (up to ~1000°C)
- Increased power-cycle efficiencies (>50%)
- Allow cheaper thermal storage materials
- Lower the LEC towards the SunShot goal of $0.06/kWh.
- Concept is well suited for 10 – 100 MW_e plants.



Concentrated Solar Power (CSP)

5. KSU Indigenous CSP Systems

INNOVATIVE POINT FRESNEL COLLECTOR WITH POLAR SOLAR TRACKING SYSTEM FOR SOLAR POLY-GENERATION (ELECTRICITY AND WATER)



➢ Technology Summary

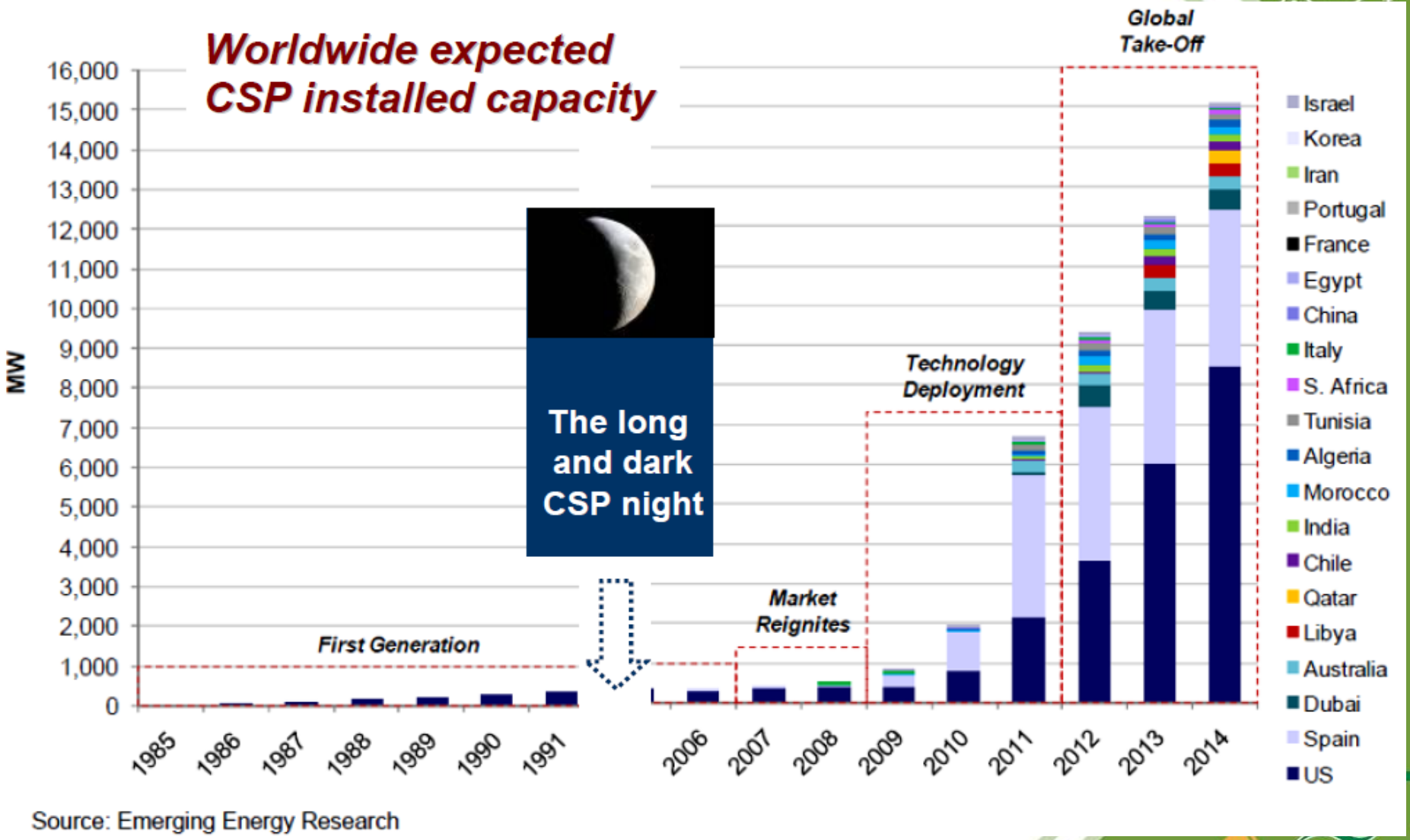
- Flat, square mirrors positioned on a rotating horizontal surface.
- Synchronized surface rotation and mirror tracking for point focusing.

➢ Advantages of Technology

- Highly efficient (70-75%) at 400^{o}C
- Cost-effective for a wide range of applications.
- Carbon free power generation.
- Power for water desalination, process heat, district cooling & air-conditioning.
- Can be employed on a residential or industrial scale.
- Local content manufacturing.
- Modularity for installation and maintenance
- Efficient land use.

Concentrated Solar Power (CSP)

FORECAST BY COUNTRIES (2010-2014)



Source: Emerging Energy Research

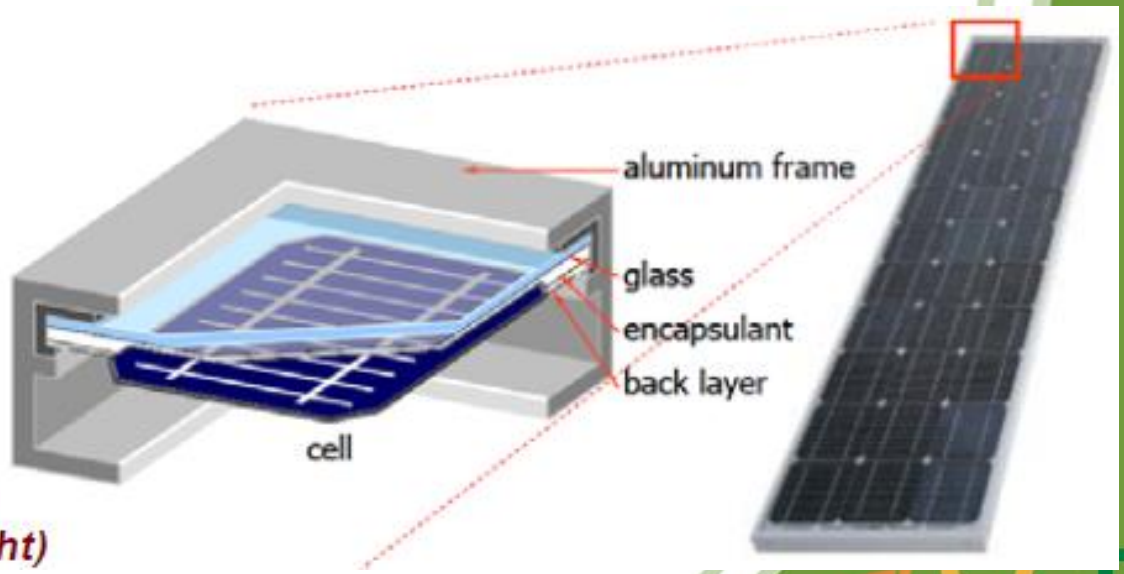
Solar PV Technologies

- Basics
- PV Families
- Photovoltaic Power Worldwide
- Concentrating PV
- Comparison between CSP & PV Technologies

Solar PV Technologies

Basics

- The photovoltaic effect was first discovered in 1839
- Electricity first produced by a PV cell in 1880.
- Very matured technology now with Solar PV cells having an operating life of 25+ years
- There are no moving parts in a solar PV system, so operating costs are very low
- Fastest emerging renewable energy technology

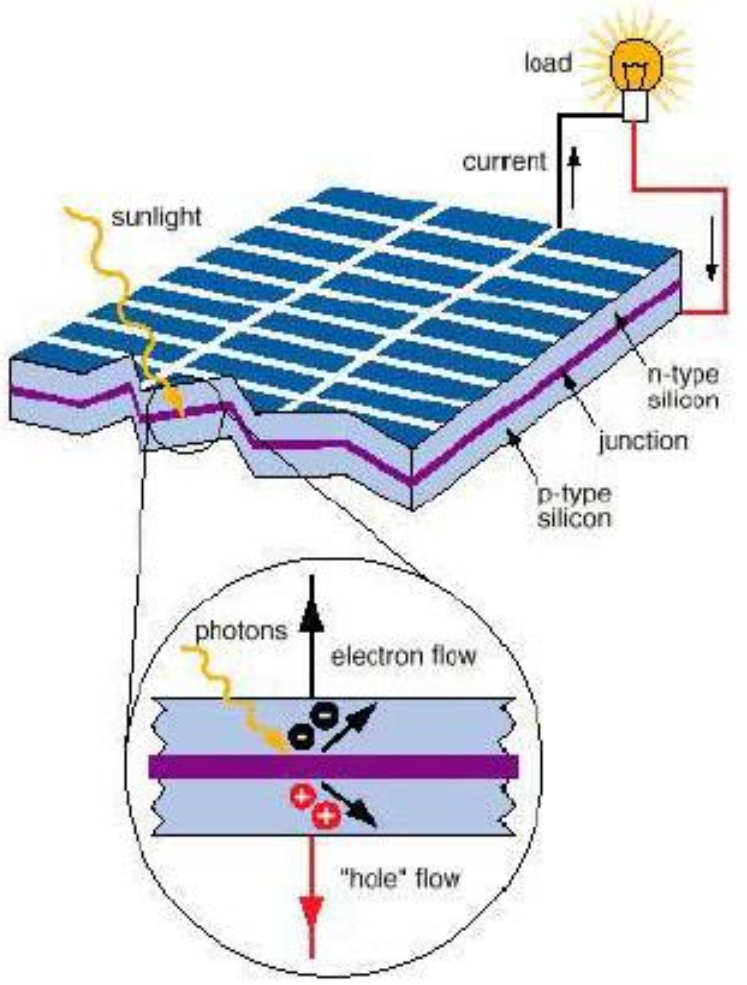


Single PV cell (left) and constructive details of a photovoltaic module (right)

Solar PV Technologies

Principle

- Solar absorbed light is transferred to the electrons of the PV cell atoms exiting them and producing the electrical current with the help of a "built-in electric field" which provides the needed voltage.
- The "built-in electrical field" is created by two layers of semiconductor material: n-type with excess of negative electrons and p-type with excess of positive holes.
- Most commonly used of semiconductor material is silicon and, when n- and p-type silicon come into contact, at the p/n junction excess electrons move from the n-type side to the p-type side, resulting in a positive charge in the n-type side of the interface and a buildup of negative charge in the p-type side.
- Two types of semiconductor (n and p) are created by doping the silicon with an external element that has either extra electrons or lack of electrons, respectively.



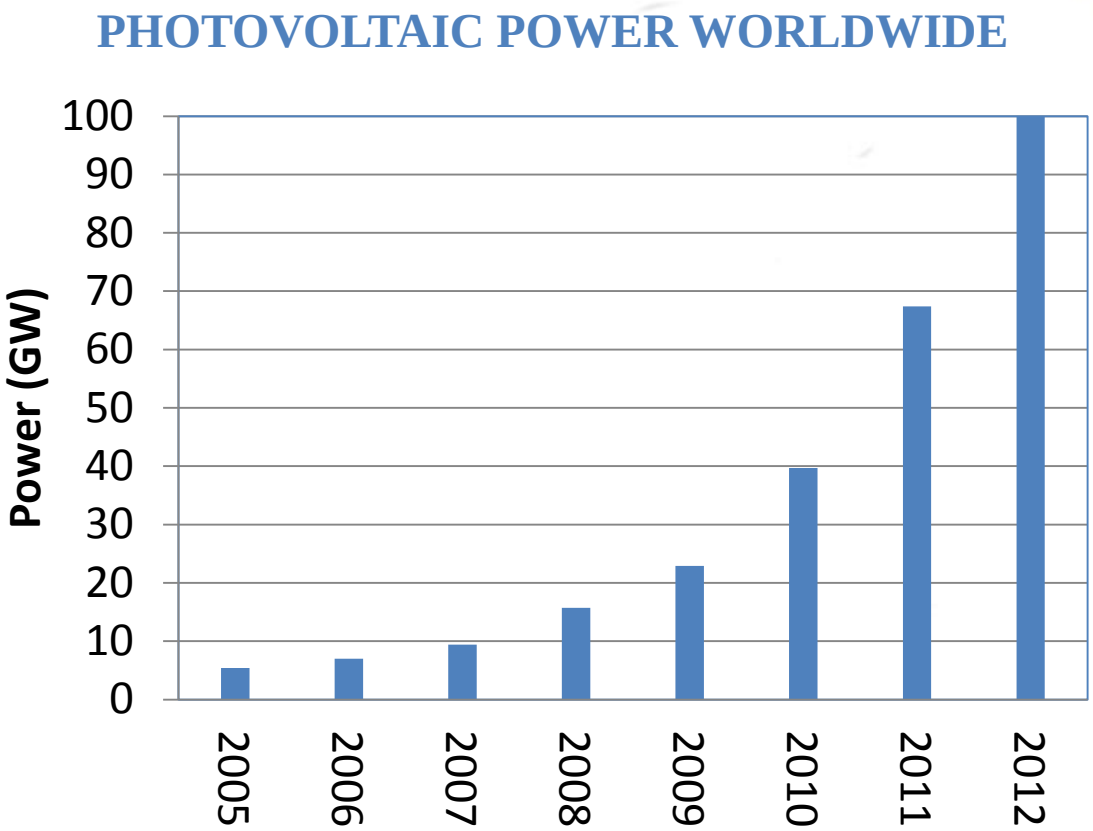
Solar PV Technologies

Families of Solar PVs

1. **Wafer-based crystalline Silicon**
   - 50 years manufacturing history
   - 15 – 20 % module efficiency
   - More than 70% market share
2. **Thin-film technologies**
   - Lower production cost
   - Lower efficiencies
   - 15% market share
3. **Multi-junction cells**
   - High efficiency (25 – 40%) with using optical systems to concentrate the light (CPV)
   - Require locations with high DNI values
   - Cost is still high
4. **Novel and emerging PV technologies**
   - Includes advanced thin-films, organic solar cells, dye solar cells, etc.
   - R&D is aimed at high efficiencies and low cost of manufacturing

Wafer-based c-Si		Thin Films		
Mono-Si	Multi-Si	a-Si; a-Si/μc-Si	CdTe	CIS/CIGS
15-20%	15-17%	6-9%	9-11%	10-12%

Solar PV Technologies



- Has become 3rd most important renewable energy source in terms of globally installed capacity after hydro and wind.
- Levelised cost of electricity (LCOE) from PV is competitive with conventional electricity sources in an expanding list of geographic regions.

Solar PV Technologies

PHOTOVOLTAIC POWER WORLDWIDE

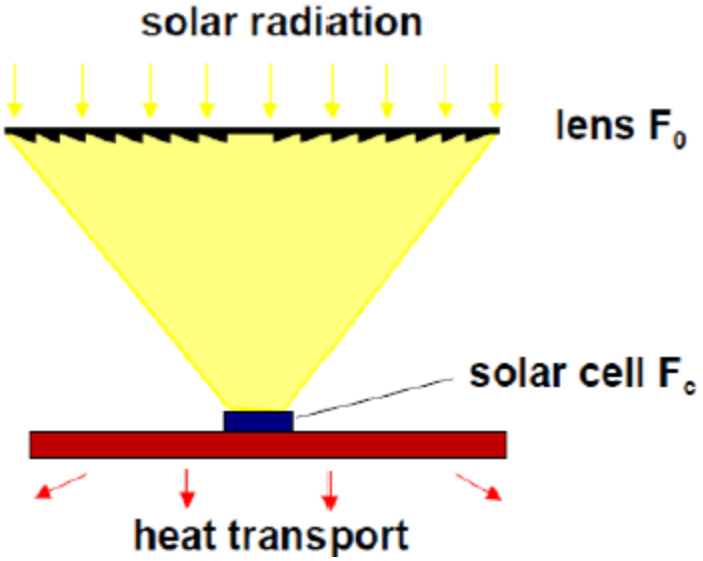
Photovoltaic Power Station	Country	Nominal Power (MW)	Notes
Agua Caliente Solar	USA	250 AC	397 MW DC when completed
Charanka Solar Park	India	214	Collection of 17 co-located power plants, of which the largest is 25MW
Golmud Solar Park	China	200	Completed October 2011 within a group of 570 MW of co-located plants
Solarpark Meuro	Germany	166	70 MW completed 2011, 166 MW in 2012
Copper Mountain Solar Facility	USA	150	Phase 1 completed in December 2010. Phase 2 completed in January 2013
Mesquite Solar project	USA	150	up to 700 MW when complete
Neuhardenberg Solar Park	Germany	145	Completed September 2012. A group of 11 co-located plants
California Valley Solar Ranch	USA	130	252 MW when completed
Templin Solar Park	Germany	128.48	Completed September 2012
Toul-Rosières Solar Park	France	115	Completed July 2012

Project Helios in Greece will be the biggest PV plant with planned capacity of 10GW (2020)

Solar PV Technologies

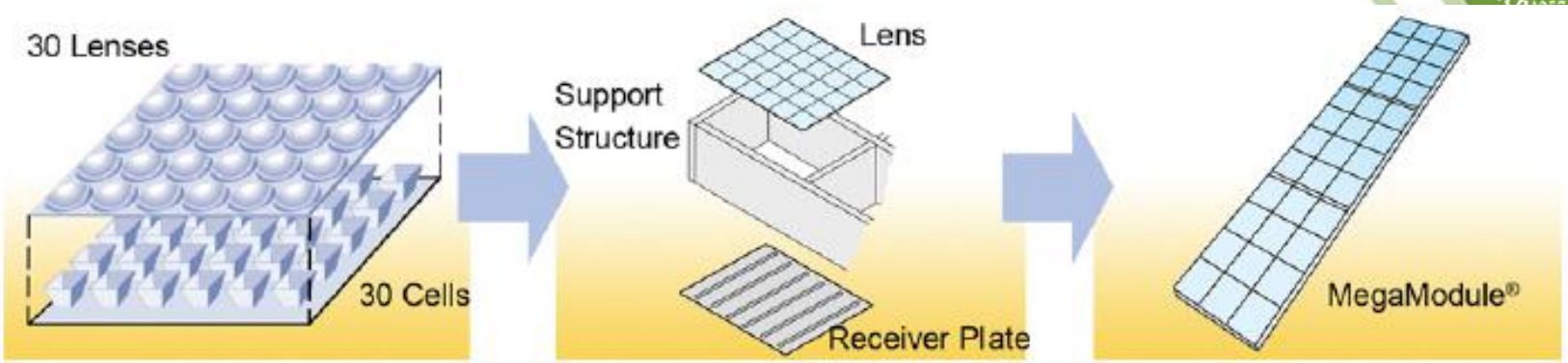
CONCENTRATING PV (CPV)

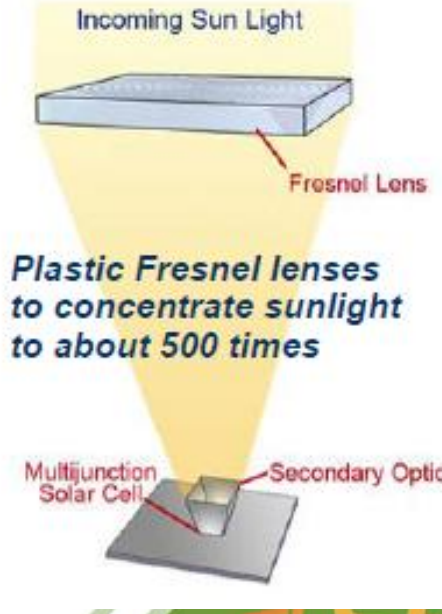
- It uses optics such as lenses or curved mirrors to concentrate a large amount of sunlight onto a small area of PV cells.
- Very High Efficiency (25-30%)
- Expensive as extra money is required on concentrating optics (lenses or mirrors), solar trackers, and cooling systems.



Solar PV Technologies

CONCENTRATING PV (CPV)





Solar PV Technologies

Comparison between CSP & PV Technologies

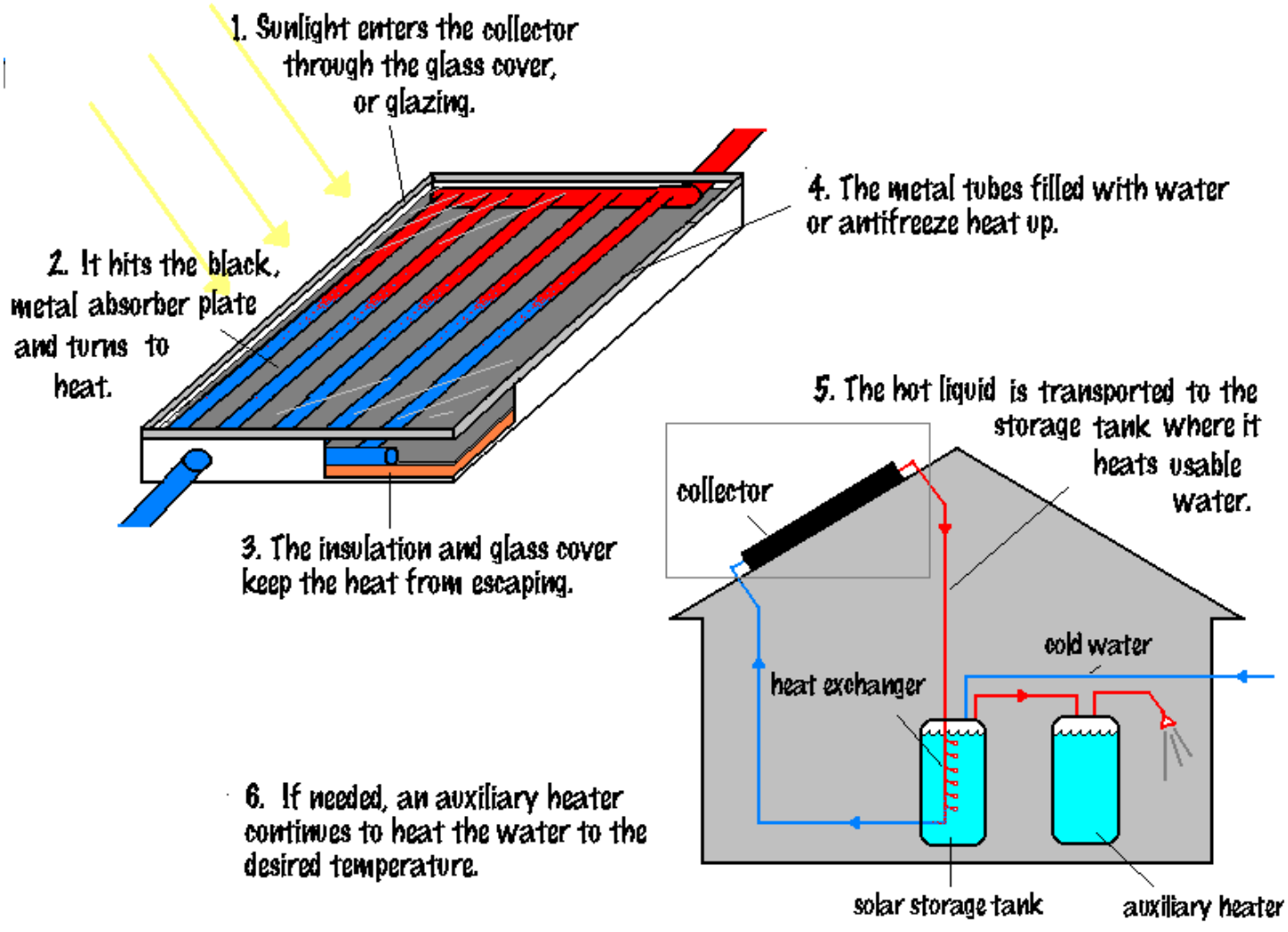
Technology	Reference hours / year	Capacity Factor
Central tower with 15h molten salt thermal storage	6450	73.63%
Parabolic trough with 9h molten salts thermal storage	4000	45.66%
Parabolic trough with 7h molten salts thermal storage	3950	45.09%
Parabolic trough with 4h molten salts thermal storage	3450	39.38%
Parabolic trough without thermal storage	2855	32.59%
Central tower working with saturated steam	2750	31.39%
Fresnel	2450	27.97%
Dish-Stirling	2350	26.83%
PV with One-Axis suntracking	2000	22.83%
PV static	1400	15.98%

Solar PV Technologies

Comparison between CSP & PV Technologies

- There are pros and cons to photovoltaic and concentrated solar power.
- Photovoltaic is cheaper to build and use, but CSP is newer and rapidly improving.
- CSP can store power for several hours and has a high thermal efficiency.
- Photovoltaic is the best choice for now. Research is still being done to continually improve efficiency.

Solar Water Heating System

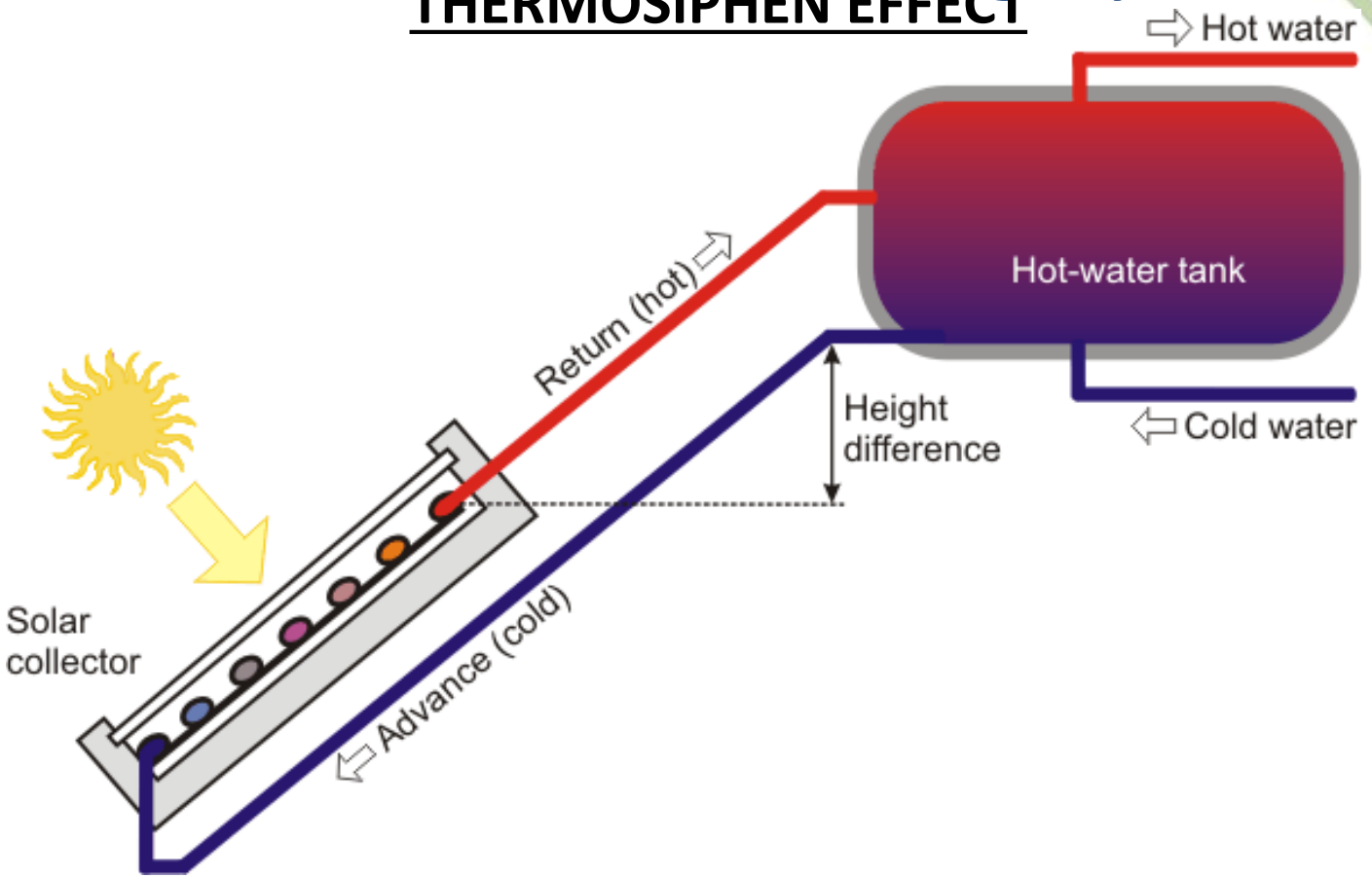


Solar Water Heating System

- Advantages
  - Replacing or supplementing other water heating methods: natural gas, electricity
- Disadvantages
  - More expensive in cooler climates

Solar Water Heating System

THERMOSIPHEN EFFECT



- This method places the storage tank above the solar collector.
- Cold water is put into the bottom of the storage tank where it is circulated through a density gradient into the top of the storage tank. The heated water can then be taken from the top and used.

Thank you