SOLAR
ENERGY
TECHNOLOGY

ETC ENERGY

Introduction
Solar Energy Technology

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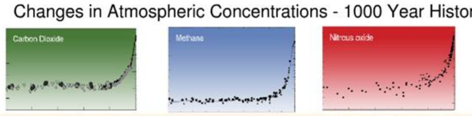
Jakarta
Indonesia

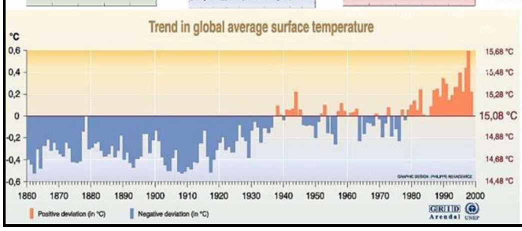
Training Course on Renewable Energy Part II - MEMR
CASINDO

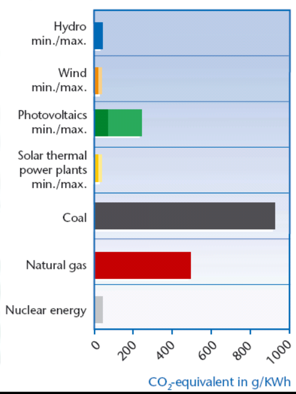
Climate Change

Changes in Atmospheric Concentrations - 1000 Year History



Source NREL

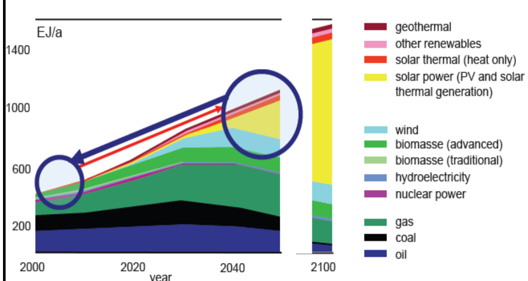




Green House Gas emissions in power generation

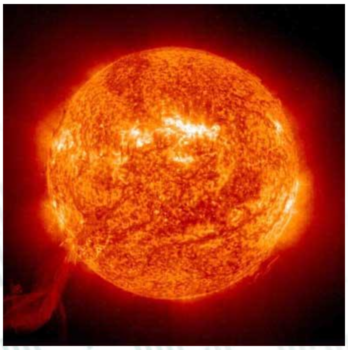
(Source: German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety)

Solar roadmap – Increasing role in the coming years

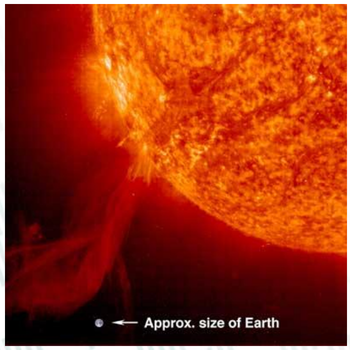


Source: German Advisory Council on Global Change, 2003, www.wbgu.de

Our sun



Our sun



Power from the sun

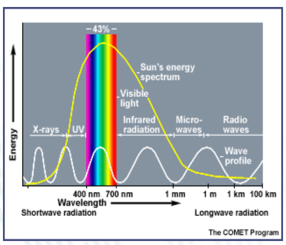
- Solar energy has greatest potential of all the sources of renewable energy
- The solar power where sun hits atmosphere is 10^{17} Watt, where the solar power on earths surface is 10^{16} Watt
- Total world-wide power demand of all needs of civilisation is 10^{13} Watt
- Therefore, the sun gives us 1000 times more power than we need

Sun characteristics

- Diameter: 1.39E9 m (120 x greater than earth)
- Distance from earth = 1.495E11 m (93 million miles)
- Center: Density ≅ 100 x density of water and T>1E6 K
- Powered by hydrogen fusion
- Composed of layers. The outer layer is the photosphere
- Effective blackbody temperature of 5777 K

What is solar energy?

- Originates from the thermonuclear fusion reactions occurring in the sun.
- Represents the entire electromagnetic radiation (visible light, infrared, ultraviolet, x-rays, and radio waves).



Advantages

- All chemical and radioactive polluting byproducts of the thermonuclear reactions remain behind on the sun, while only pure radiant energy reaches the Earth.
- Energy reaching the earth is incredible. By one calculation, 30 days of sunshine striking the Earth have the energy equivalent of the total of all the planet's fossil fuels, both used and unused!

Disadvantages

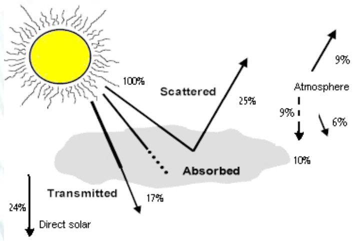
- Sun does not shine consistently
- Solar energy is a diffuse source
- To harness it, we must concentrate it into an amount and form that we can use, such as heat and electricity
- Addressed by approaching the problem through:

  1) collection, 2) conversion, 3) storage

Applications of solar energy

- Heating and cooling of residential building
- Solar water heating
- Solar cookers
- Solar engines for water pumping
- Food refrigeration
- Solar furnaces
- Solar electric power generation by solar ponds, reflectors with lenses
- Solar photovoltaic cells, which can be used for conversion of solar energy directly into electricity

How much solar energy?



The surface receives about 47% of the total solar energy that reaches the Earth. Only this amount is usable.

Solar irradiation availability

Not permanently available

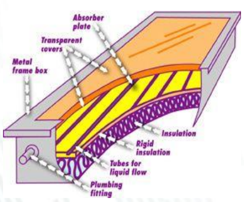
When a constant power supply is important, solar systems need:

– Hybridisation

– Storage capabilities

Putting solar energy to use: Heating water

- Two methods of heating water: passive (no moving parts) and active (pumps)
- In both, a flat-plate collector is used to absorb the sun's energy to heat the water
- The water circulates throughout the closed system due to convection currents
- Tanks of hot water are used as storage.



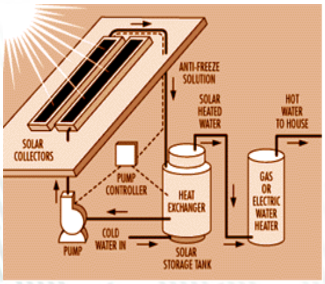
Flat-plate collectors

- They are made in rectangular panels, from about 2 to 3 sq.m in area and relatively simple to construct.
- Flat plates can collect and absorb both direct and diffuse solar radiation
- Flat plate solar collectors may be divided into two main classifications

  1. liquid heating collectors are used for heating water

  2. Air/Gas heating collectors are employed as solar air heater.

Heating water: Active system

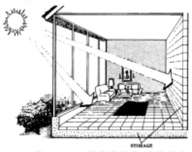


Active System uses antifreeze so that the liquid does not freeze if outside temperature drops below freezing

Heating living spaces

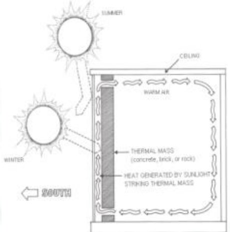
- Best design of a building is for it to act as a solar collector and storage unit. This is achieved through three elements: insulation, collection, and storage.
- Efficient heating starts with proper insulation on external walls, roof, and the floors. The doors, windows, and vents must be designed to minimize heat loss.
- Collection: North or South-facing windows and appropriate landscaping.
- Storage: Thermal mass - holds heat.

Heating living spaces



- Passive solar

- Passively heated home in Colorado



- Trombe wall

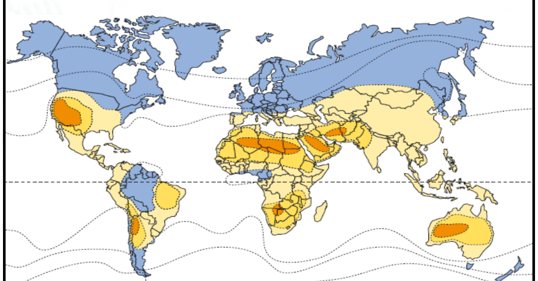
Heating living spaces

- A passively heated home uses about 60-75% of the solar energy that hits its walls and windows
- The Center for Renewable Resources estimates that in almost any climate, a well-designed passive solar home can reduce energy bills by 75% with an added construction cost of only 5-10%
- About 25% of energy is used for water and space heating
- Major factor discouraging solar heating is low energy prices

Solar thermal and concentrating solar systems

1. Solar tower
2. Dish engine
3. Parabolic trough
4. Solar chimney
5. Concentrating PV (CPV)

Where does concentration technology make sense?



Suitability for solar thermal power plants:
Excellent Good Suitable Unsuitable

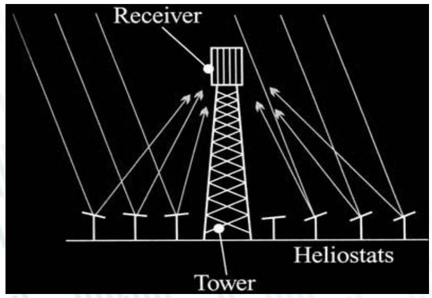
Source : Schott Solar

Solar tower

- Heliostats focus sunlight onto a central, tower mounted receiver
- HTF heats water
- Turbines power generators

In a solar thermal system solar radiation heats a Heat Transfer Fluid (HTF) which is used directly or indirectly to drive a power generator

Solar tower



Solar tower

- General idea is to collect the light from many reflectors spread over a large area at one central point to achieve high temperature.
- Example is the 10-MW solar power plant in Barstow, CA.
  - 1900 heliostats, each 20 ft by 20 ft
  - a central 295 ft tower
- An energy storage system allows it to generate 7 MW of electric power without sunlight.
- Capital cost is greater than coal fired power plant, despite the no cost for fuel, ash disposal, and stack emissions.
- Capital costs are expected to decline as more and more power towers are built with greater technological advances.
- One way to reduce cost is to use the waste steam from the turbine for space heating or other industrial processes.

Solar tower schemes

- Projects in USA, Europe and Russia since 1980's
- "Solar I" in USA 1982 to 1988
- "Solar II" used molten salt as HTF since 1995
- Outputs range from 0.5 to 10 MW

Solar tower

Solar tower in Barstow, California

Solar tower

Advantages
- High concentration = High temp = High efficiency
- Can make use of HTF with high heat capacities
- Suitable for thermal storage systems

Disadvantages
- Not modular
- High O&M costs
- Complex solar tracking hardware
- Start up problems
- High parasitic power requirements

Solar thermal and concentrating solar systems

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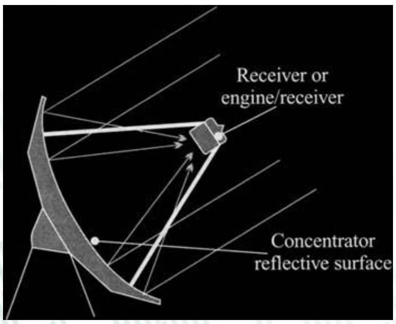
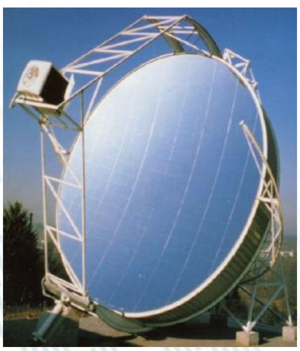
Dish engine system



Parabolic dish engine

- Focus sunlight on a smaller receiver for each device; the heated liquid drives a steam engine to generate electricity.
- The first of these Solar Electric Generating Stations (SEGS) was installed in CA by an Israeli company, Luz International.
- Output was 13.8 MW; cost was $6,000/peak kW and overall efficiency was 25%.
- Through federal and state tax credits, Luz was able to build more SEGS, and improved reduced costs to $3,000/peak kW and the cost of electricity from 25 cents to 8 cents per kWh, barely more than the cost of nuclear or coal-fired facilities.
- The more recent facilities converted a remarkable 25% of sunlight into electricity.



Because they work best under direct sunlight, parabolic dishes must be steered throughout the day in the direction of the sun

25kW Boeing/SES dish engine

Dish engine systems

- Advantages
  - High optical efficiency
  - Low start-up losses
  - Modular design
- Disadvantages
  - Expensive
  - Newest solar thermal technology

Solar thermal and concentrating solar systems

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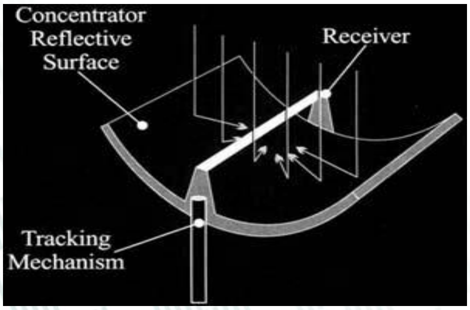
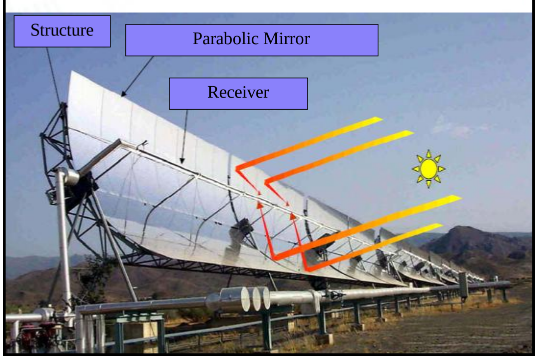
Parabolic trough reflector



Parabolic trough systems

- Parabolic trough-shaped mirrors focus solar energy onto receiver tubes containing the HTF
- Heat exchangers heat water
- Turbines power generators

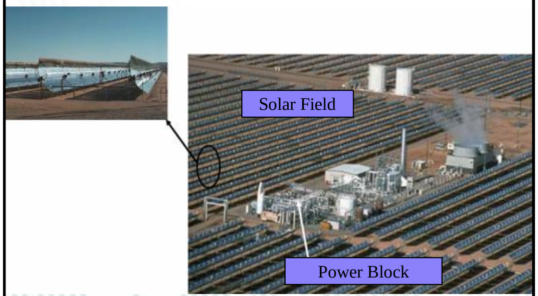


Parabolic trough schemes

- Several systems operational in USA since mid 1980's
- Sized between 14 and 80MW providing >354MW in total
- Typically 25% hybridised with gas

Introduction to Solar Energy Technology

Parabolic trough field



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Parabolic trough fields

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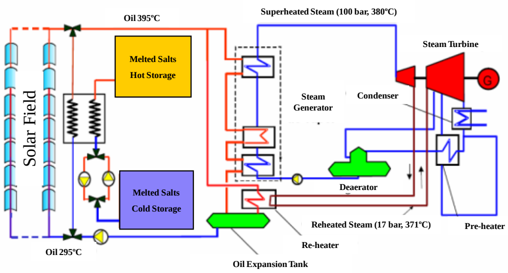
HFT (Heat Transfer Fluid)
Technology in commercial operation



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Parabolic trough systems

- Advantages
  - proven technology
  - least expensive
  - most reliable
- Disadvantages
  - low solar concentration = low efficiency
  - require large area

Introduction to Solar Energy Technology

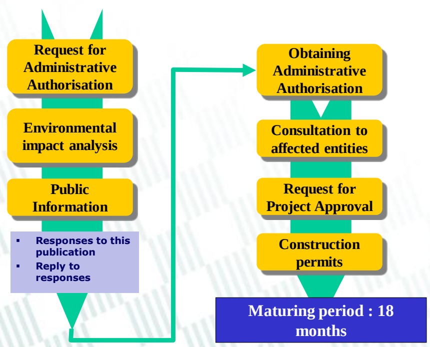
Technology comparison

	Parabolic trough	Solar tower	Dish engine
Power Output (2000-2030)	30-320 MW	10-200 MW	5-25 kW
Operating Temperature (°C)	390	565	750
Peak Efficiency	20%(d)	23%(p)	29.4%(d)
Commercial Status	Commercially Available	Scale-up Demo	Prototype Demo
Technological Maturity	High	Medium	Low
Storage Available	Limited	Yes	Battery
Hybrid Designs	Yes	Yes	Yes

(p) – Predicted (d) – Demonstrated

Introduction to Solar Energy Technology

CSP : Project Development – Administrative issues



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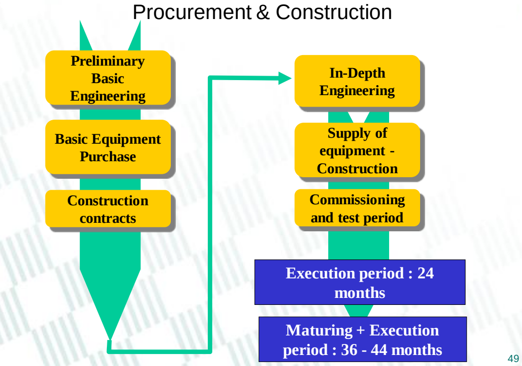
CSP : Project Development – Engineering, Procurement & Construction



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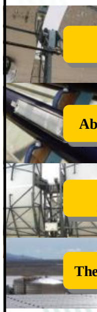
CSP : Project development – Technological issues



Mirrors
- Some companies developing solar projects are developing its own technology, or buying mirror manufacturers

Absorber Tube
- Extremely critical and technical product (lasting vacuum, layers stability, high transmissivity of glass, high absorptivity and low emissivity of absorber, junctions metal/glass, dilatation management…)

Support Structure
- Several structures available in the market
- Continuous evolution to comply with alignment requirements at the lowest cost

Thermal storage
- Liquid salts is the technology used for the moment, but many other are in development

Introduction to Solar Energy Technology

USA

SEGS I	14 MWel	since 1984
SEGS II	30 MWel	since 1985
SEGS III	30 MWel	since 1986
SEGS IV	30 MWel	since 1986
SEGS V	30 MWel	since 1987
SEGS VI	30 MWel	since 1988
SEGS VII	30 MWel	since 1988
SEGS VIII	80 MWel	since 1989
SEGS IX	80 MWel	since 1990
Total output	354 MWel	

(SEGS: solar energy generating system)

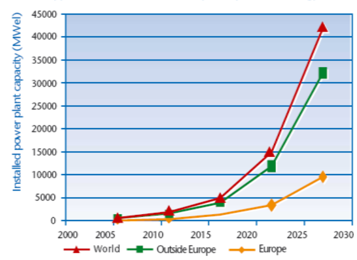
CSP - Support schemes

- April 2008 : Pacific Gas & Electric Company (PG&E) subscribes a firm contract to buy electricity generated by solar plants in Mojave Desert : **500 MW + 400 MW** optional
- February 2008 : Arizona Public Service (APS) signs a contract with Abengoa Solar to buy electricity from a **280 MW** solar power plant
- SEGS series from 80's : more than 300 MW with more than 20 years experience on parabolic trough technology

Introduction to Solar Energy Technology

CSP – Market expectations

Future opportunities for solar thermal power plant technology

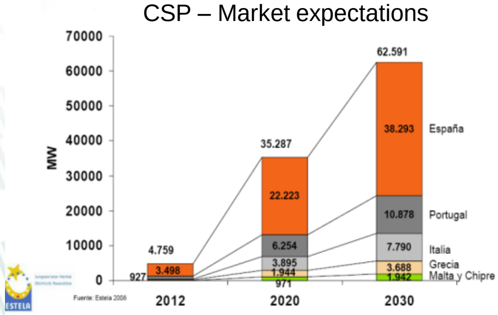


The scenario of the German Aerospace Center (DLR) for expansion in the world

According to German Aerospace Centre (DLR), CSP has a growth potential of 40 GW by 2030

Introduction to Solar Energy Technology

CSP – Market expectations



Much more optimistic, ESTELA, the European Solar Thermal Electricity Association, sees room for 60 GW by 2030 only in Europe…

Introduction to Solar Energy Technology

Solar thermal and concentrating solar systems

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Manzanares solar chimney

Solar chimney

- Very large circular greenhouses with tall central chimneys
- Warm air rises up chimney driving in-line turbines
- Some energy storage possible

Solar chimney schemes

- Experimental plant in Spain 1982 to 1989, 195m high, 240m diameter, 50kW peak
- Government approval granted for 1000m high, 7km diameter, 200MW plant in Australia

Solar chimney

- Advantages
  - Low tech = Low maintenance
  - Use of large greenhouse
- Disadvantages
  - Not tested on large scale
  - Very high capital costs

Solar thermal and concentrating solar systems

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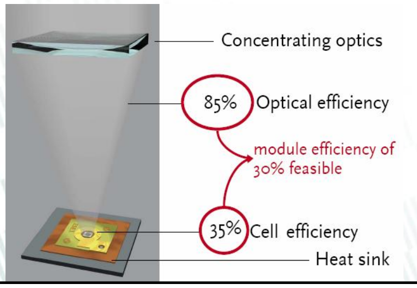
5. **Concentrating PV (CPV)**

Concentrated PV - General features

- In spite of its childhood (much less mature than CSP), already several MW installed around the world
- The big cost reduction is still to come thanks to mass production
- Doesn't need cooling water (except some special applications)
- Modular and scalable technology

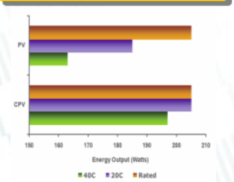
CPV – The strategy

- Substitution of the expensive semiconductor material with a cheap optical system and low-cost mechanics
- Use of best efficiency cells

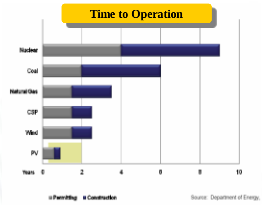


CPV - Advantages

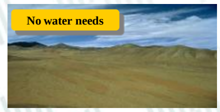
Less sensitive to hot climates



Time to Operation



No water needs



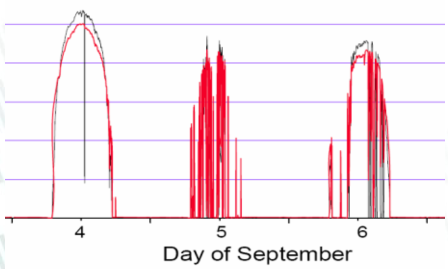
Modular / Scalable

CPV - Disadvantages

Sensitivity to clouds

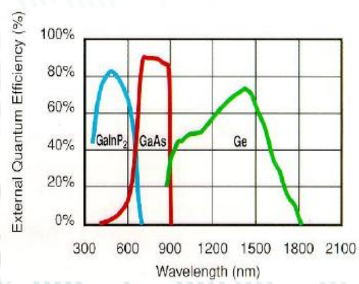
No easy storage ability

- These two issues together should be solved, as TSO cannot accept sharp fluctuations in the generated power



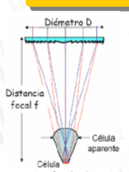
CPV – Components: Triple junction cells

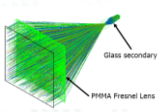
- The principle is that each material operates at different wavelengths, the three covering a large spectrum



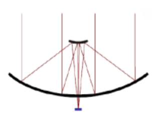
CPV – Components: Concentrator technologies

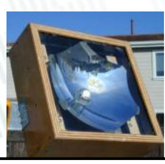
Lens





Mirror



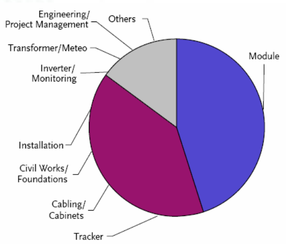


CPV – Components: Tracking system

- Light needs to be focused at the cell, not close to the cell
- The higher concentration ratio, the lower angle tolerance
- In practice, 0.1% accuracy is currently reached
- Solid structures are required
- New structural concepts are being developed

Need for increased accuracy

CPV – Potential for cost reduction



Cost distribution of a flat plate power plant with silicon modules

Flat PV : module reaches 45% of cost share

40% of remaining costs are proportional to area

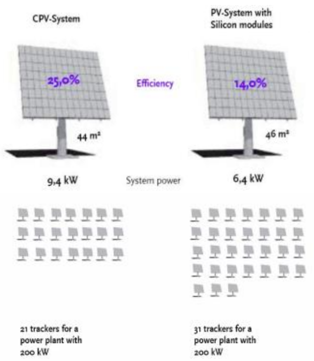
- Reductions in module cost and required area would lead to drastic decrease of cost of energy

Source : Concentrix

CPV Area reduction

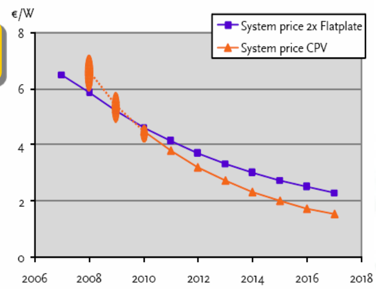
For the same surface, almost 50% more installed power

To reach the same power, 30% less need for materials



CPV – Cost reduction expectations

Investment costs to be cut by 3 in 10 years



Source : Concentrix

PhotoVoltaic Technology Platform

CPV – Cost reduction targets

Rounded figures	1980	Today	2015 / 2020	2030	Long term potential
Typical turn-key system price (2007 €/Wp, excl. VAT)	>30	5 *(range 4~8)*	2.5 / 2.0	1	0.5
Typical electricity generation costs S Europe (2007 €/kWh)	>2	0.30	0.15 / 0.12 *(competitive with retail electricity)*	0.06 *(competitive with wholesale electricity)*	0.03
Typical commercial *flat-plate* module efficiencies (total area)	up to 8%	up to 15%	Up to 20%	up to 25%	up to 40%
Typical commercial *concentrator* module efficiencies	(~10%)	up to 25%	Up to 30%	up to 40%	up to 60%
Typical system energy pay-back time Southern Europe (yrs)	>10	2	1	0.5	0.25

CSP-CPV comparison

	Parabolic troughs	Central tower	Stirling parabolic dish	CPV
Power Range	20 – 300 MW	20 – 100 MW	5 – 40 kW per dish. Scalable	10 kW – 20 kW per tracker. Scalable
Operating Temperature	395ºC	600ºC	700ºC	PV effect, no thermal
System Efficiency (electricity / solar)	21%	23%	31%	Current : 25 % Soon : > 30 %
Commercially available	Yes	Soon	Only prototypes	Yes, with huge amounts of MW available in coming years
Integrated Storage	Thermal : Possible	Thermal : Possible	?	No
Hybrid design	Possible (any fuel)	Possible (any fuel)	Possible (any fuel)	No
Water consumption	6 m3/MWh	Similar to parabolic trough	No water	No water
Land use (Ha / MW)	2,5 – 3 (more if storage)	2 – 2,5 (more if storage)	2	2

CSP-CPV comparison

	Parabolic troughs	Central tower	Stirling parabolic dish	CPV
Current investment cost	4 – 6 €/W (according to storage size)	4 – 6,5 €/W	14 €/W	6 – 7 €/W
Current LCOE (Levelized Cost of Energy)	260 €/MWh in South Europe – 180 €/MWh in MENA	?	?	300 €/MWh in South Europe. Lower in sunnier locations
Expected LCOE by 2020	200 €/MWh in South Europe. Lower in sunnier locations	In line with parabolic troughs	In line with parabolic troughs	120 – 150 €/MWh in South Europe. Lower in sunnier locations

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Levelized Cost of Energy

$$\text{LCOE} = \frac{\text{Total Life Cycle Cost}}{\text{Total Lifetime Energy Production}}$$

$$= \frac{\text{Initial Investment} - \sum_{n=1}^{N} \frac{\text{Depreciation}^n}{(1+\text{Discount Rate})^n} \times (\text{Tax Rate}) + \sum_{n=1}^{N} \frac{\text{Annual Costs}^n}{(1+\text{Discount Rate})^n} \times (1-\text{Tax Rate}) - \frac{\text{Residual Value}}{(1+\text{Discount Rate})^n}}{\sum_{n=1}^{N} \frac{\text{Initial kWh/kWp} \times (1 - \text{System Degradation Rate})^n}{(1 + \text{Discount Rate})^n}}$$

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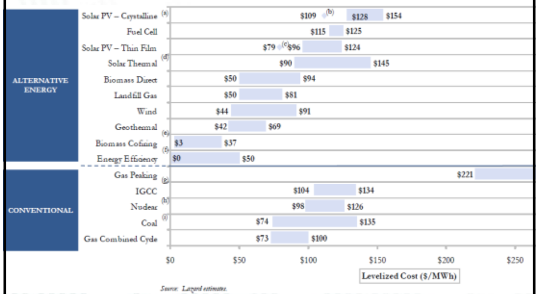
Levelized Cost of Energy comparison



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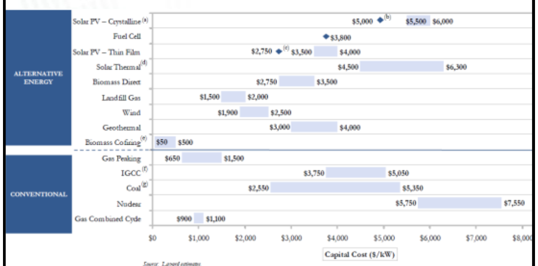
Captial Cost comparison



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CSP-CPV comparison

	Parabolic troughs	Central tower	Stirling parabolic dish	CPV
Current investment cost	4 – 6 €/W (according to storage size)	4 – 6,5 €/W	14 €/W	6 – 7 €/W
Current LCOE (Levelized Cost of Energy)	260 €/MWh in South Europe – 180 €/MWh in MENA	?	?	300 €/MWh in South Europe. Lower in sunnier locations
Expected LCOE by 2020	200 €/MWh in South Europe. Lower in sunnier locations	In line with parabolic troughs	In line with parabolic troughs	120 – 150 €/MWh in South Europe. Lower in sunnier locations

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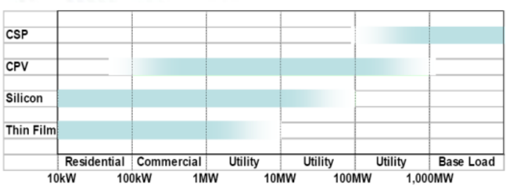
Solar technologies and market share



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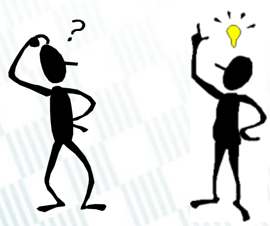
QUESTIONS ?



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