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Solar Power CSP Key Note

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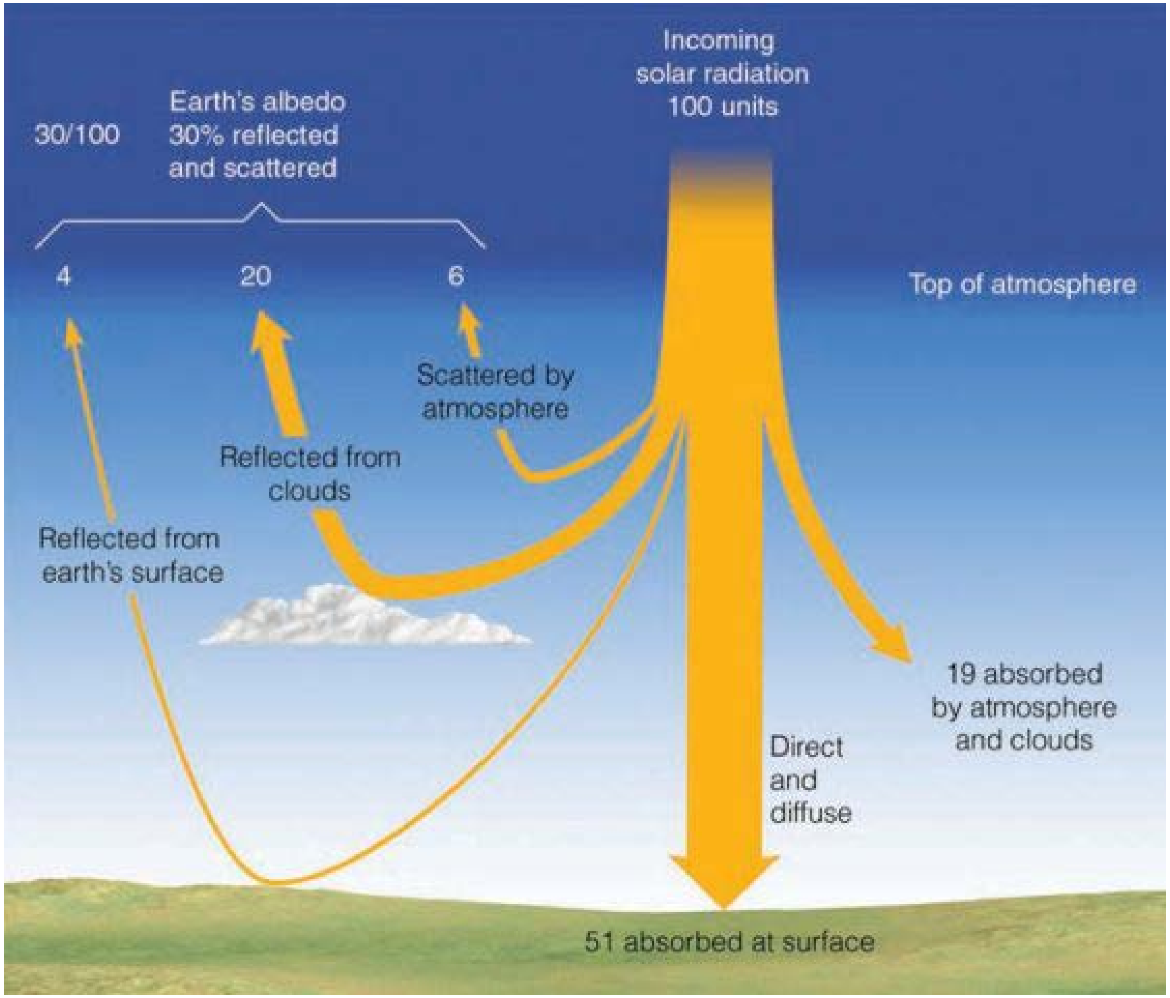
Solar Basics

During passage through Earth's atmosphere, partial flux is scattered or absorbed



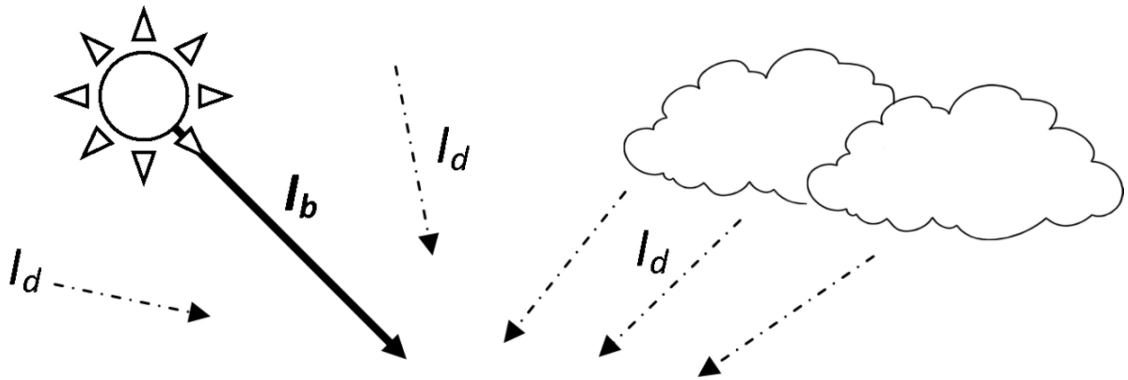
Even on a clear day, up to 30% of the incoming radiation is absorbed

The peak flux at the Earth's surface is approx. ***1kW/m²***

Largest losses result from absorption and reflection

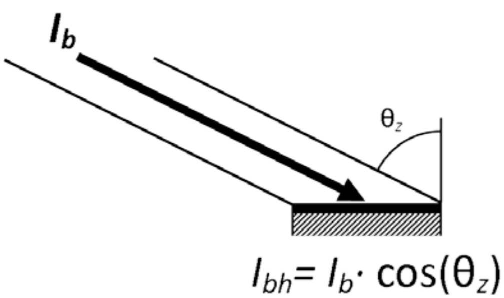
Solar Basics: Radiation Components

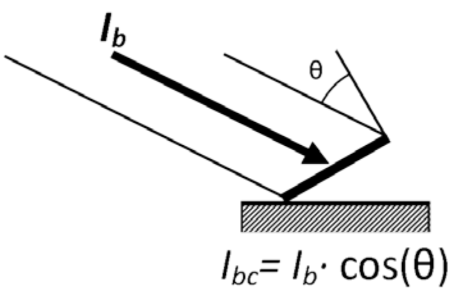
Beneath Earth's atmosphere, Solar flux is divided into two components: Beam and Diffuse radiation, which sum is known as the Global Irradiation



$$I_{global} = I_{beam} + I_{diffuse}$$

Beam radiation intensity is strongly dependent on the orientation of the surface which intercepts it





Solar Thermal Systems

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Solar Thermal System: ***A process that harnesses solar radiation as a power source through the conversion of the incident solar flux into useful heat***

Classified in two types depending on the level of temperature at which the heat is to be delivered:

Non-Concentrating

Harnesses the Incoming Flux Directly

Low Temperature (<120°C)

Concentrating

Concentrates the Incoming Flux

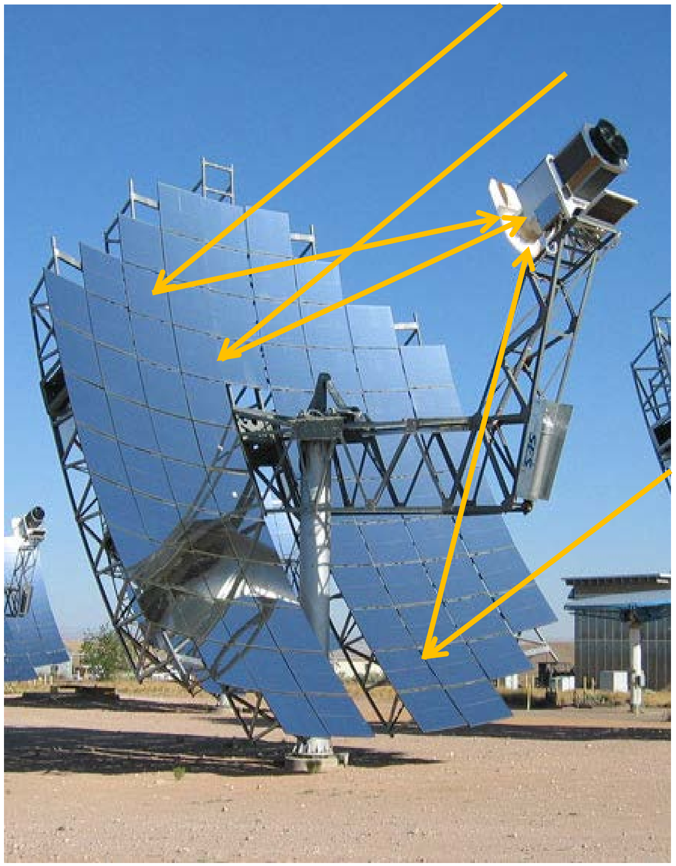
Higher Temperatures (120 – 3000°C)

Concentrating Solar Power

Solar thermal systems in which:

*Solar radiation is concentrated to create a **high-temperature heat** source, which can then be used to drive **conventional power generation** cycles*

Introduction – Working Principle



Mirror directed normal to solar irradiation

Light is reflected (concentrated) to a focal spot

Light in focal spot is captured in receiver

Light is absorbet in medium and transformed into heat

Heat is used to drive heat to power conversion process

Conversion process is Stirling, Rankine or Bryton cycle

Concentrating Solar Power

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Remember: The Concentration Ratio

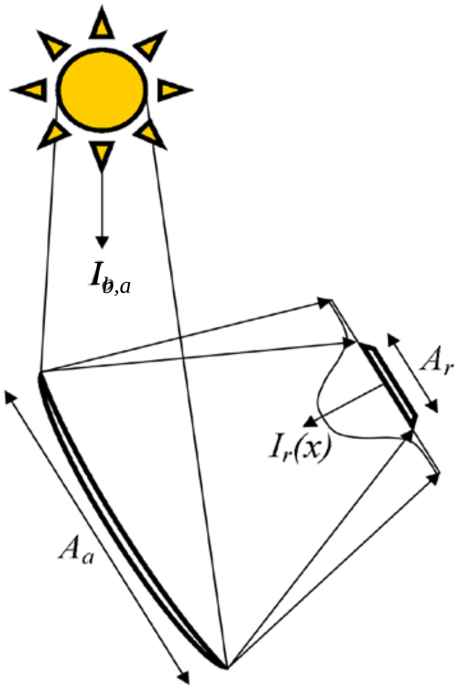
Concentration increases density of the radiant energy flux, allowing more power to be absorbed for a given surface area and thus a more effective receiver operation at higher temperatures

Geometric CR:

$$CR_g = \frac{A_a}{A_r}$$

Optical CR:

$$CR_o = \frac{\frac{1}{A_r}\int I_r \delta A_r}{I_{b,a}}$$



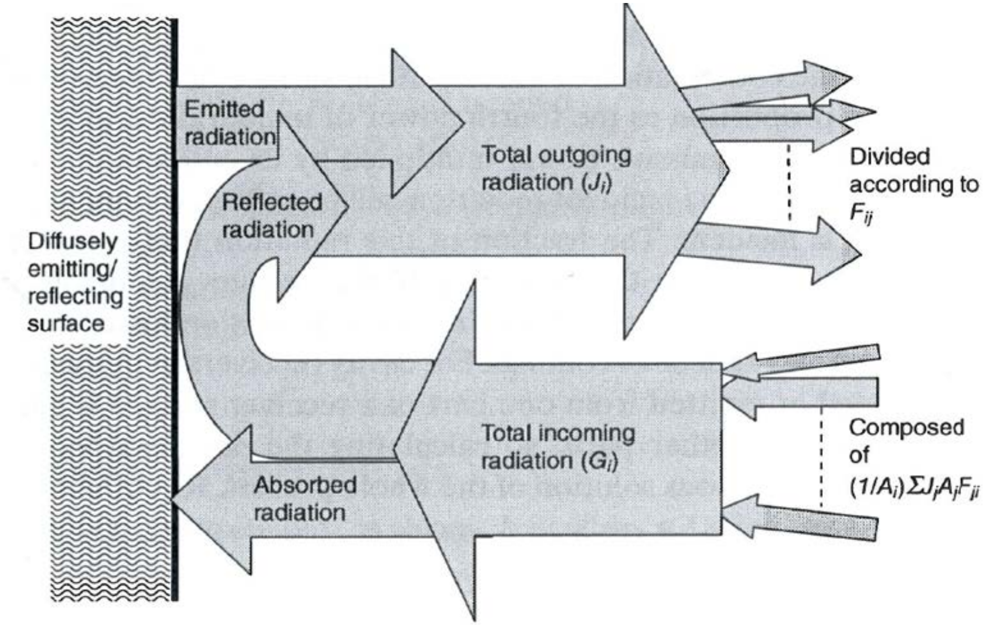
$$CR_o = \eta_{opt} CR_g$$

Collector Optical Efficiency

Receiver Efficiency

$$Q_{rad} = \sigma A \varepsilon F_{re}(T^4 rec - T^4 env)$$

$$\eta_{tot} = \eta_{ref}\eta_{rad}\eta_{conv}\eta_{cond}$$



2.13 Radiation energy balance on a diffusely emitting and reflecting surface.

Ref: Concentrating Solar Power Technology, Lovegrove and Stein, Woodhead Publishing, 2012

Concentrating Solar Power

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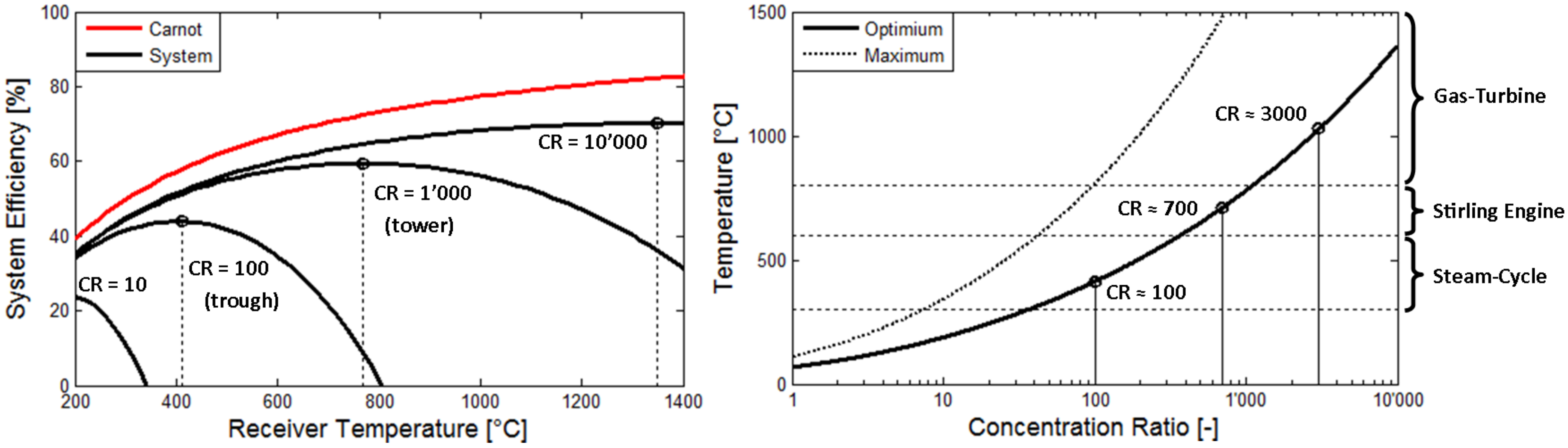

The CR varies depending on the technology and is an indicator of the system efficiency. The CR is connected to reachable temperatures and thus to identifying suitable power cycles.

Concentrating Solar Power

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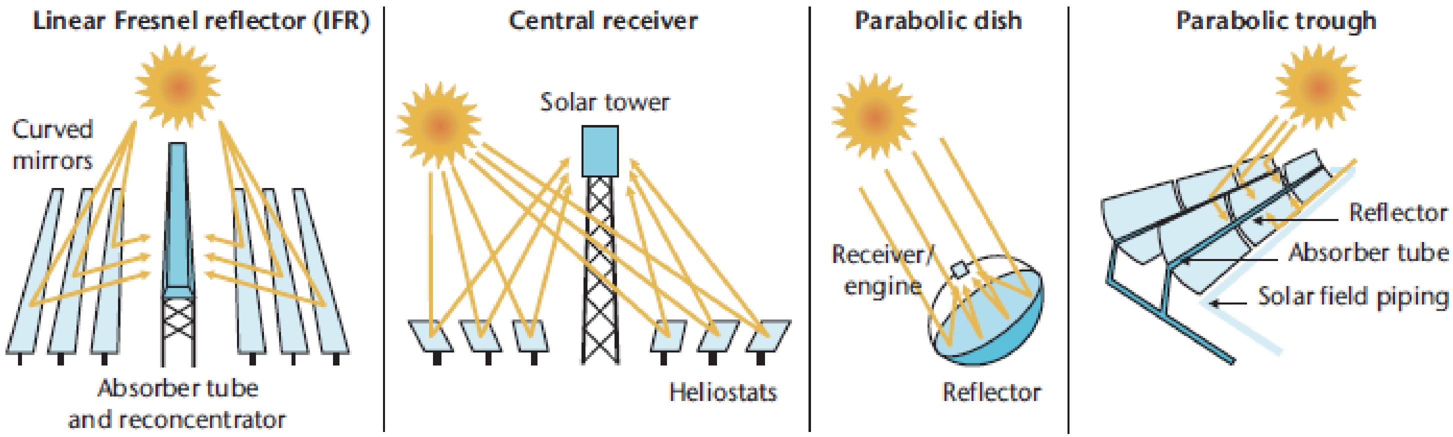
Main Technologies for CSP

Solar Energy → *High Temperature Heat*



	Fresnel	Tower	Dish	Trough
Maturity	Early commercial projects going online	Proven (First large projects)	Demonstration Projects	Proven (most mature)
Tracking	No tracking	2 axes tracking	2 axes tracking	1 axis tracking
Receiver	Linear – Fixed	Point - Fixed	Point - Movable	Linear - Movable
Storage	Available, not proven	Commercially Available	Probable – not yet available	Commercially Available

Concentrating Solar Power

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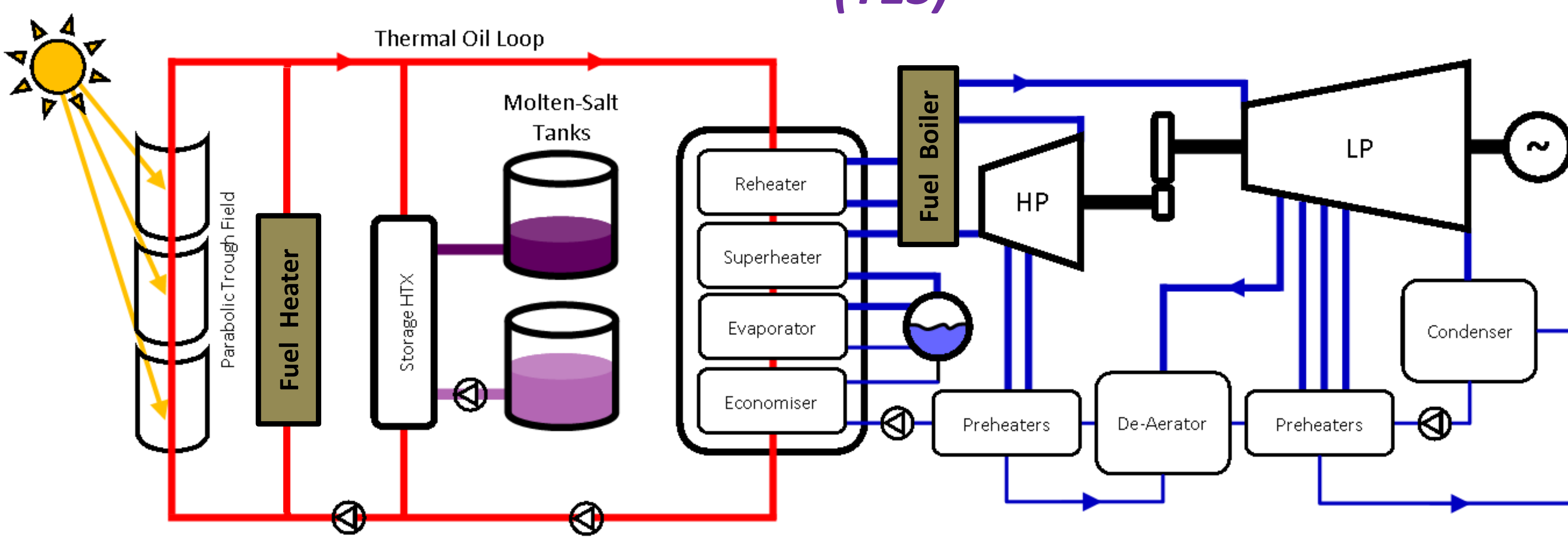
A simple schematics with energy conversion in a CSP plant:

Solar Energy → *High Temperature Heat* → *Electricity*

Additional Heat Source ⇢ *High Temperature Heat*

High Temperature Heat ⇄ *Thermal Energy Storage (TES)*



Market Situation

By May 2014, there were close to ***4GW$_e$*** of installed capacity

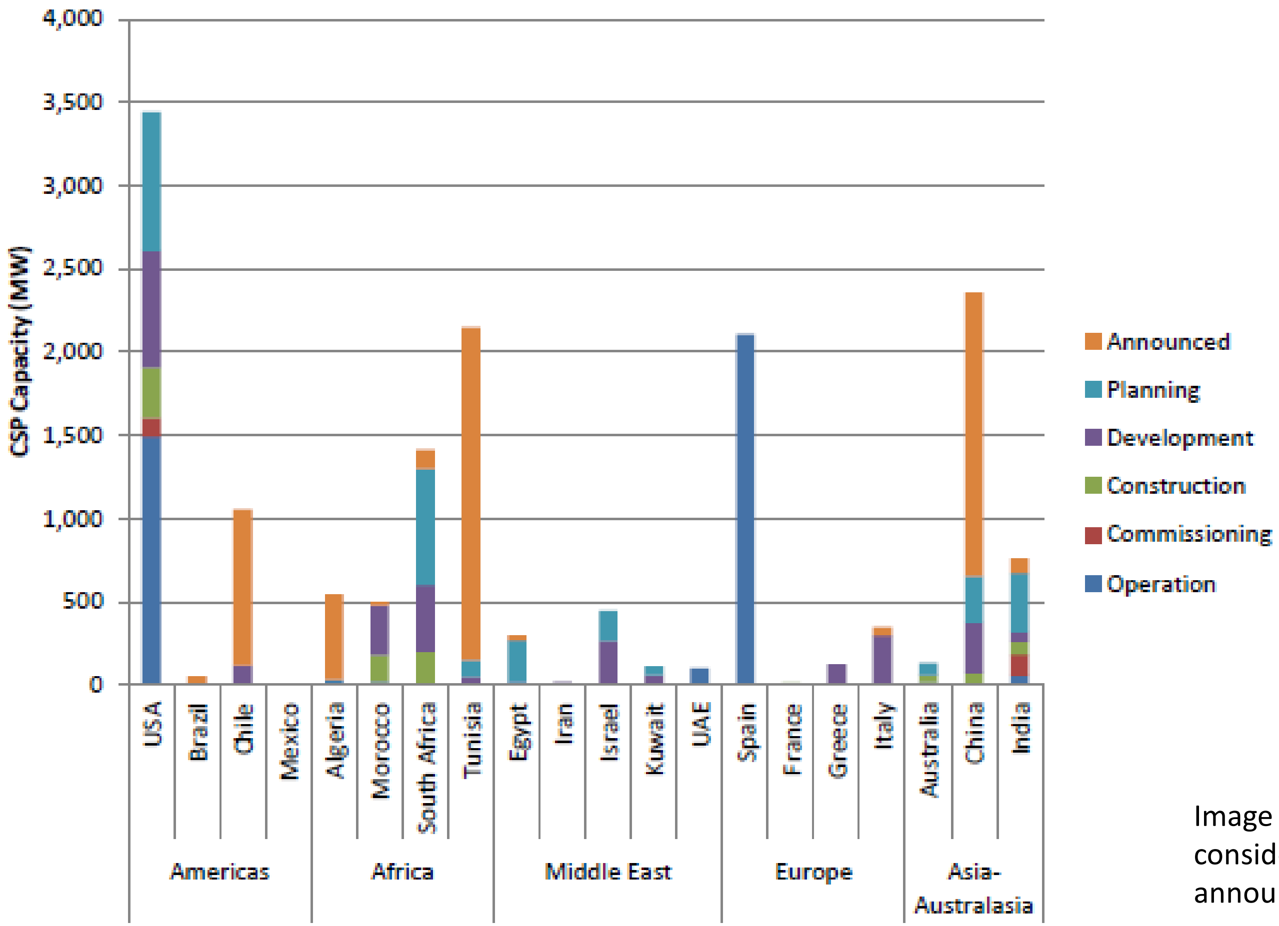


Image source: CSPToday. Data does not consider government plans or announcements.

Market Situation

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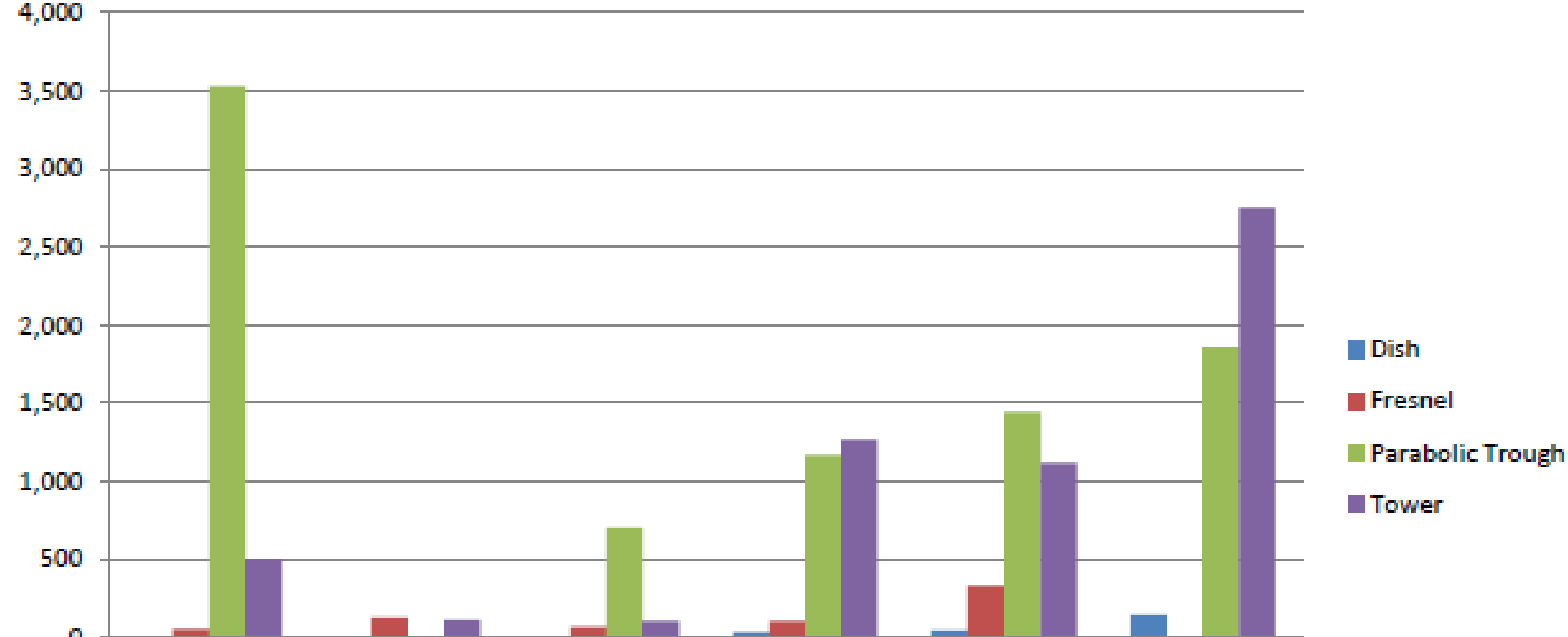


	Operation	Commissioning	Construction	Development	Planning	Announced
Dish	1	1.5	1	32.5	43.5	140.1
Fresnel	53	125	63.5	101	330	0
Parabolic Trough	3,531	0	697	1,165	1,441	1,855
Tower	497	110	101	1,262	1,117	2,750

Image Source: CSPToday. Data does not consider government plans or announcements.

Challenges for CSP

_2014: 4 GW_ → _2050: + 1000 GW ?_

A number of ***future challenges*** can be identified for solar thermal power technologies which must be addressed

- Increasing economic competitiveness
- Reducing/Eliminating water consumption
- Increasing availability/dispatchability of CSP Plants
- Improving flexibility (cycling), safety and O&M requirements

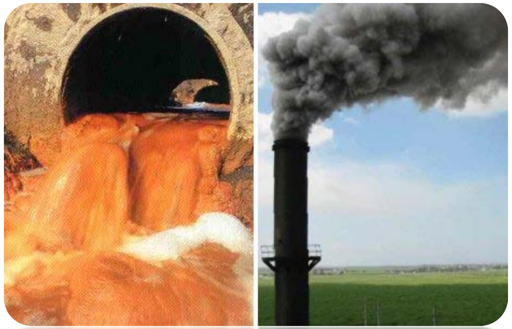
In short: The ***VALUE*** of CSP needs to be increased

VALUES of a CSP Plant

The **main value** of a CSP plant is providing electricity at a competitive price.

Value is **NOT** only linked to the notion of money, can also be:

- Reduction in emissions (CO_2, NO_x, O_3, etc.)
- Water savings (especially in arid areas)
- Energy independence (reduced fuel usage)



Design Objectives

The design of energy system usually involves ***conflicting objectives***

- Economics: low investment cost, low operating cost
- Thermodynamic: high efficiency, low exergy destruction
- Environmental: low pollutant emissions, low CO2 emissions
- Political: low energy dependence

It is extremely rare that all the objectives can be met simultaneously, so ***trade-offs*** must be considered

Performance Indicators

In order to objectively compare different the performance of different power generation systems performance indicators need to be defined

- Thermodynamic: conversion efficiency, net electrical output
- Economics: net present value, levelized cost of electricity, internal rate of return
- Environmental: specific CO_2 emission, solar share

For concentrating solar power plants an specific design parameter is introduced

- Solar multiple

Predictions of Cost Reduction

Though promising, solar power is ***not yet economically competitive*** with conventional power generation technologies

- Actual cost reductions were much less than initially predicted!!
- Revised cost predictions made in 2004 at the DLR (Germany)

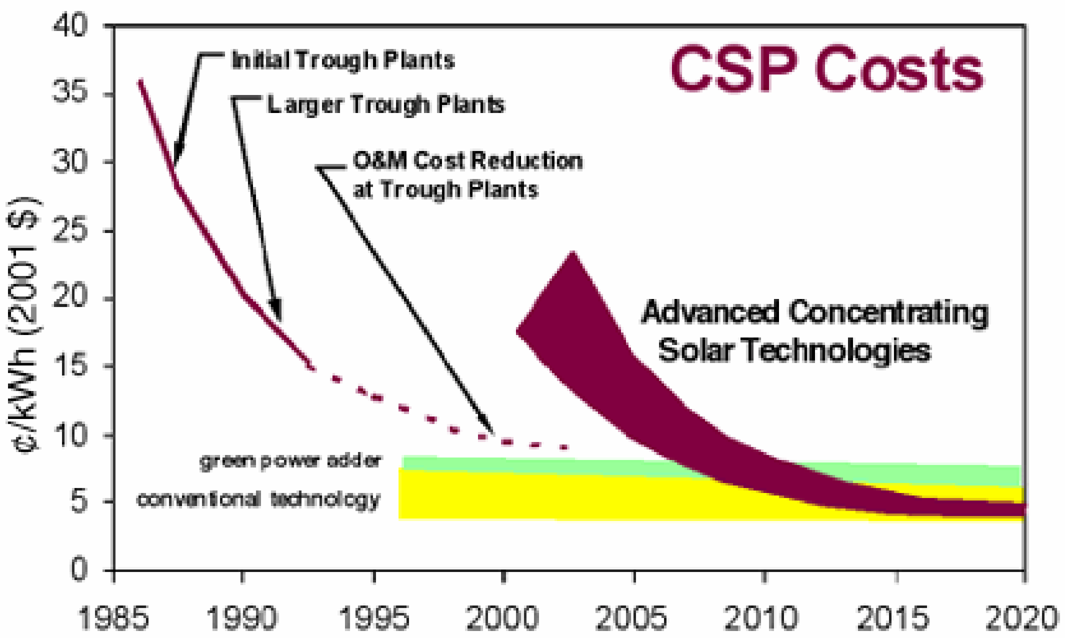


Image Source: US National Renewable Energy Laboratory, 1991

Economics of CSP

On a cost basis, CSP is and will be ***more costly*** than other technologies

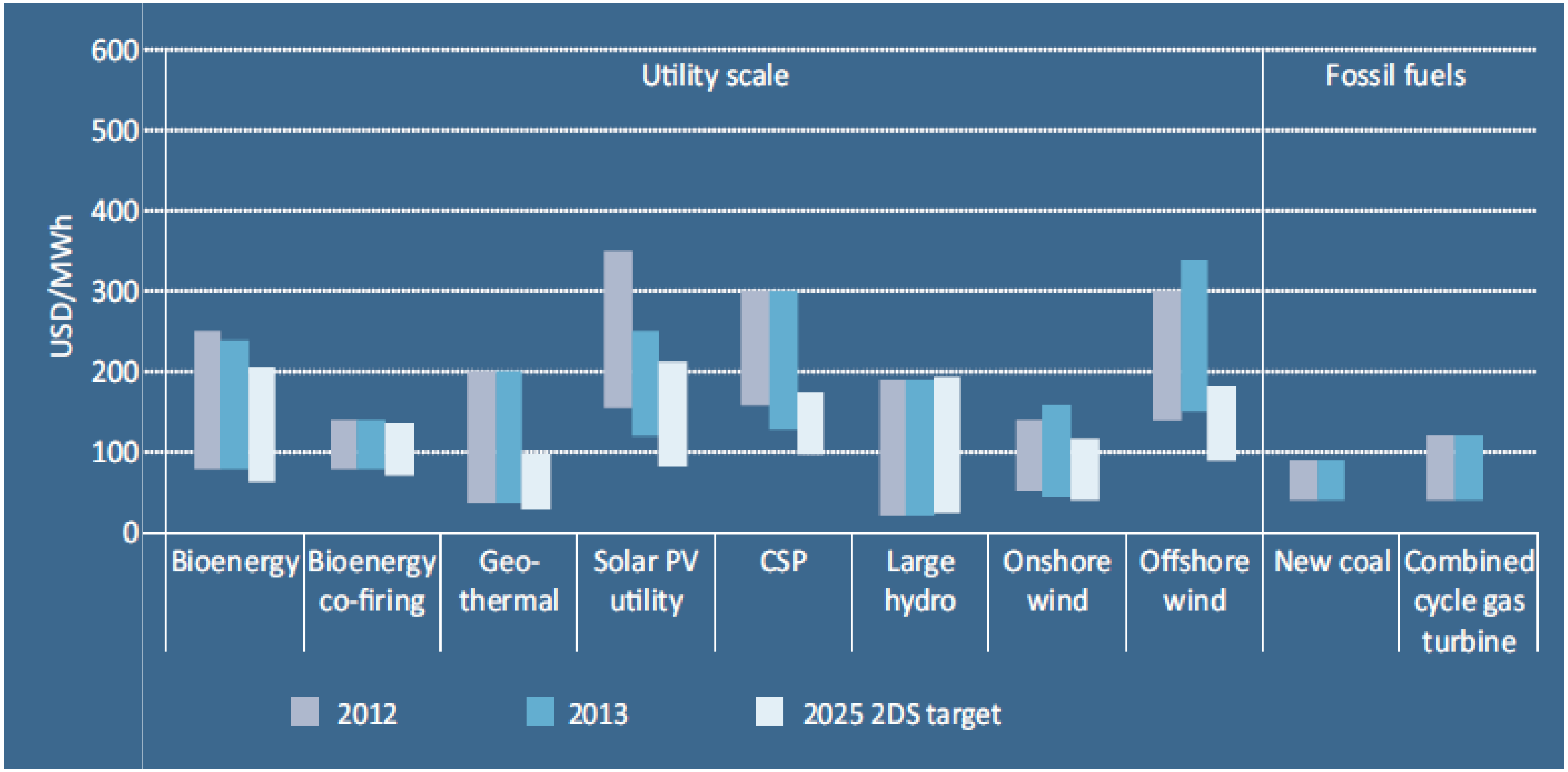
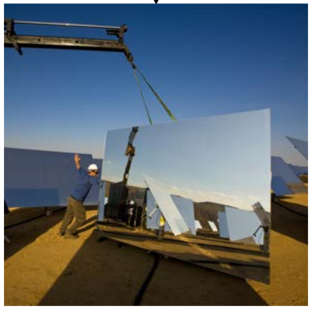


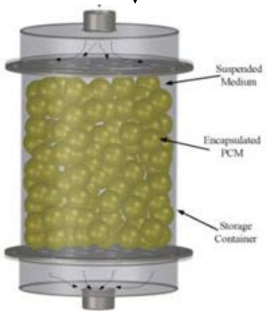
Image source: IEA Energy Technologies, 2014

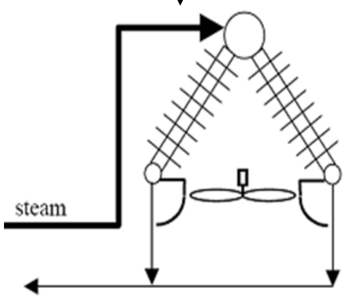
Economics of CSP

For achieving cost reduction ***improvements*** are needed

At component level: Technology







Solar Field ***Storage*** ***Power Block***

Optimizing Integration of each: solar field, TES and power block

At plant level: layout and operation

Image source: IEA Energy Technologies, 2014

CSP vs PV

Dispatchability is the key advantage of solar thermal power systems

- Two types of power generation systems can be distinguished
  - Dispatchable: able to supply power on demand

    hydro (with dam), solar thermal, geothermal
  - Non-dispatchable: no control over power output

    hydro (run-of river), wind, PV, wave
- Non-dispatchable sources complicate operation of the electricity grid

  Production = Consumption (at every moment)

When fluctuations occurs in PV or wind, must respond instantly

CSP vs PV

Replacing conventional power plants will non-dispatchable renewables does not provide the desired level of emissions reductions

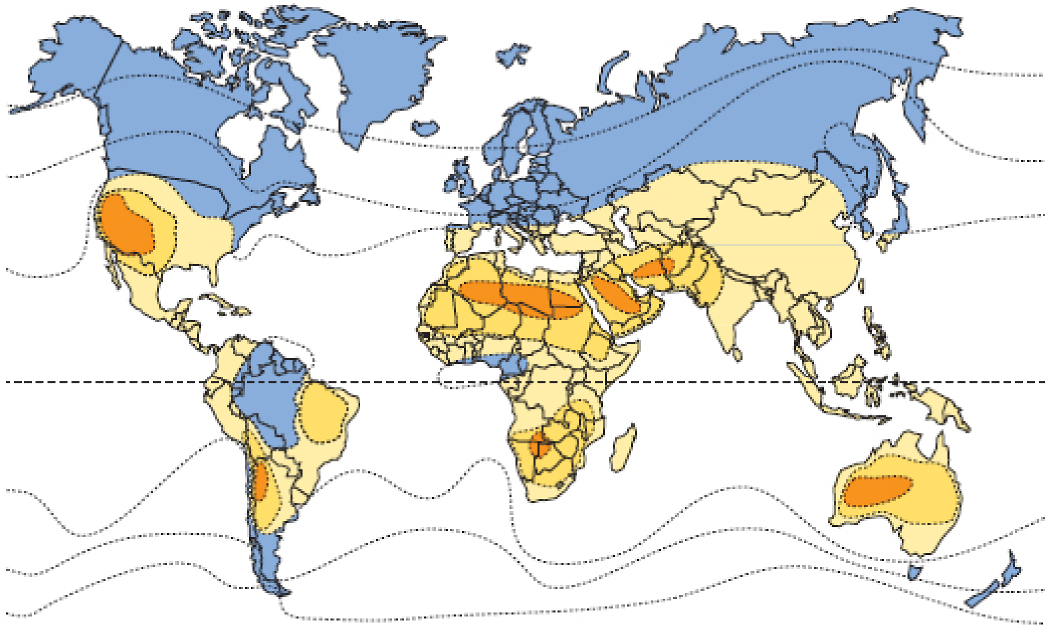
How can we make CSP plants more competitive/increase their value?

- By means of hybridization with other fossil fuel based power plants.
- Integrating Thermal Energy Storage (TES) systems

Typical CSP Locations

High potential areas for solar thermal power deployment are concentrated in desert areas:

- ➢ Clear skies and high direct normal irradiation



Water consumption will ***limit the number*** of sites for deployment

Water Consumption

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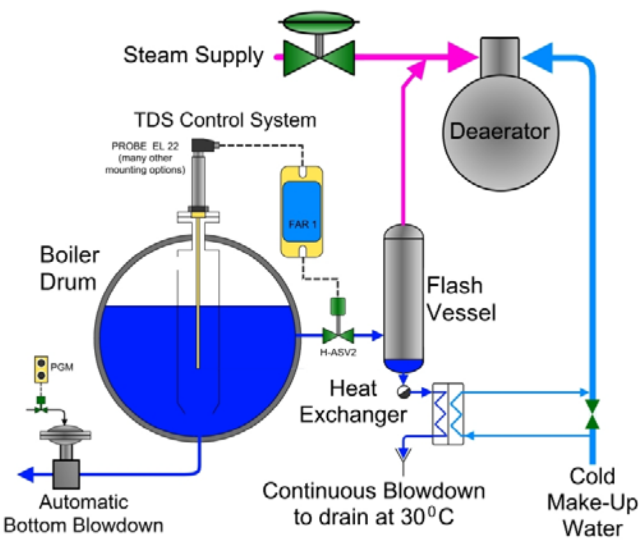
Solar thermal power plants based on conventional steam-cycle technology consume water for a number of purposes

- Evaporative cooling of the vacuum condenser
- Steam-drum blowdown (both continuous and intermittent)
- Mirror washing



Water consumption will ***limit the number*** of sites for deployment

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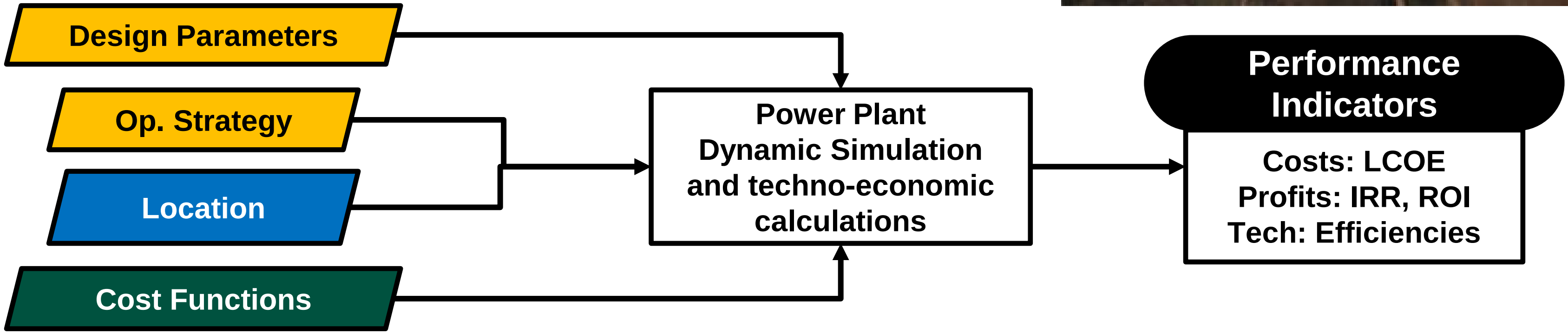
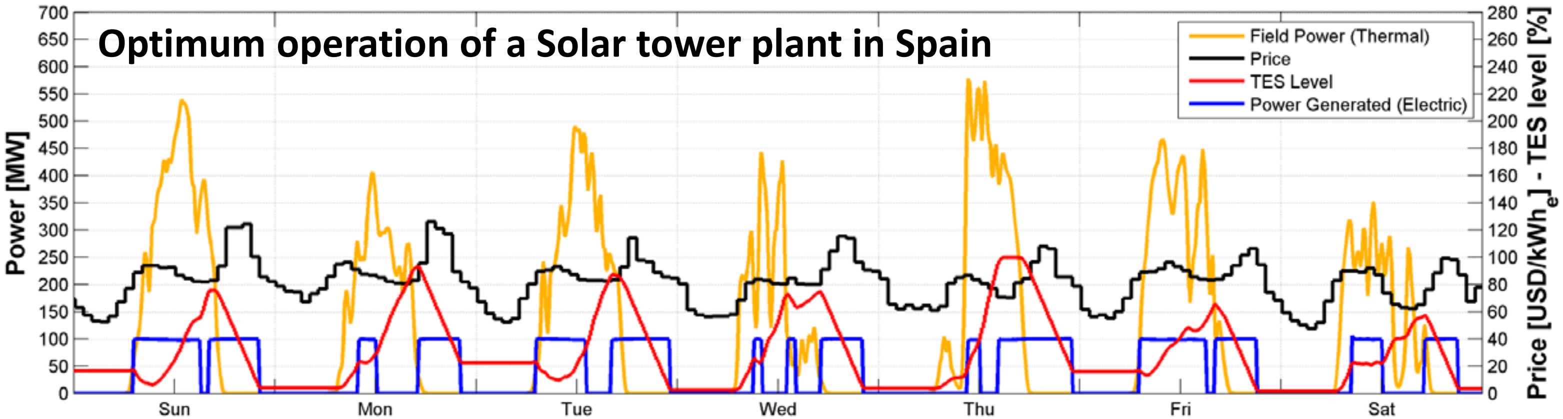
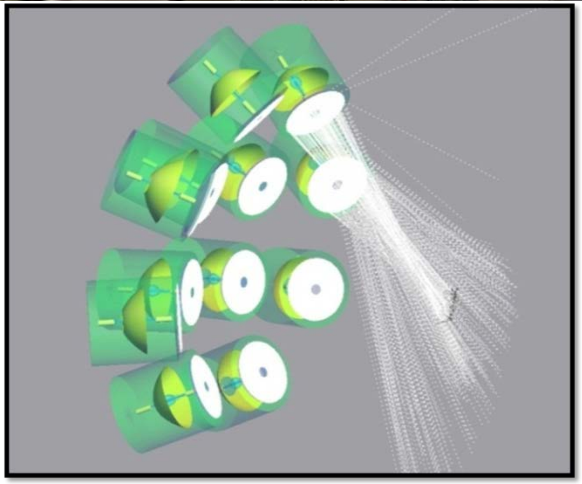
Techno-economic Decision Making

Providing the argument for R&D and market effort of new technologies





Solar Laboratory



Unique facility (only 3 other Universities have comparable facility world wide)

96 kW Sun simulator with concentrated flux density of 8 MW/m2 on target

Providing a stable high temperature heat source for:

a. Investigating thermochemical processes and solar reactors

b. Testing advanced high temperature materials

Providing an experiment platform for R&D of high temperature solar receivers

Providing a possibility for experimental investigation of thermodynamic cycles for high concentration CSP power generation

Utilization as power source for solar driven processes in polygeneration lab

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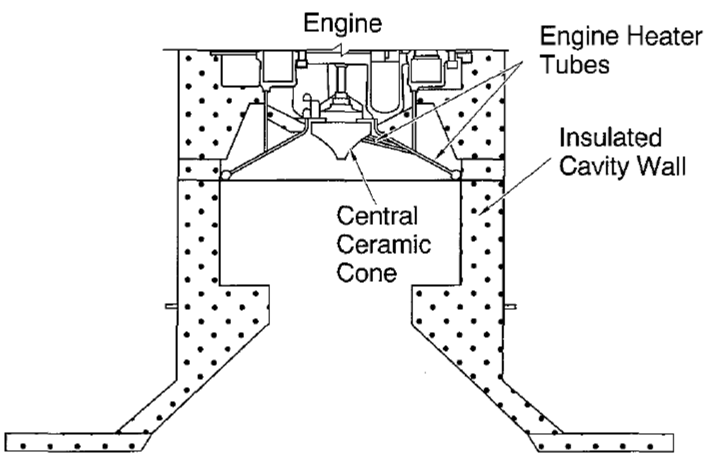
Dish Stirling Receiver Design



Justification

Dish-Stirling technology has provided demonstrated solar-to-electricity efficiencies around 30% but a significant drop in the overall price has to be achieved

Objective

Design a 13 kW cost-competitive Dish-Stirling with the specifications:

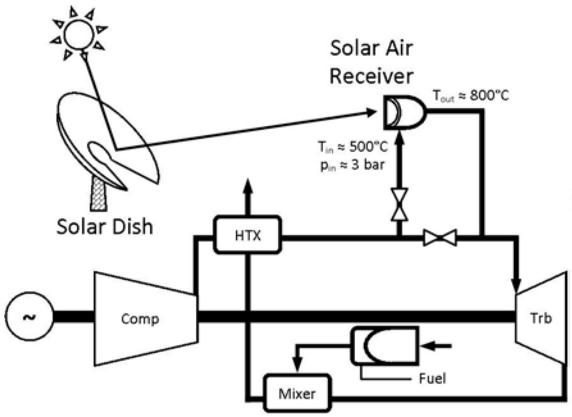
- **Sun-to-heat collection efficiency of 80%**
- **Operating temperature of 850 °C**
- **Component lifetime of at least 15,000 equivalent operational hours**

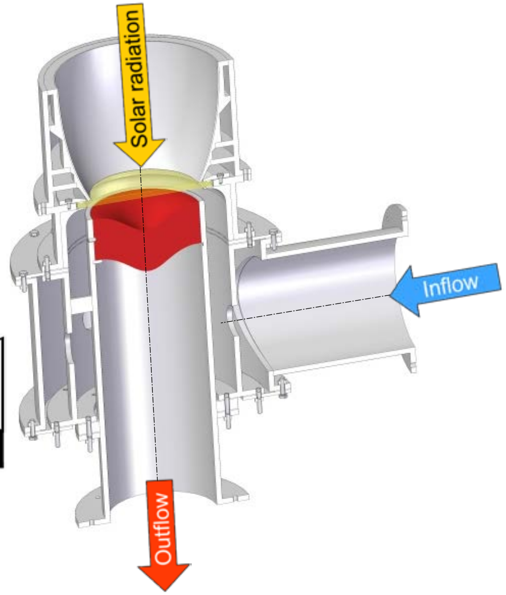
Methodology

- **System modeling**
- **Lab and full scale measurements and testing**

Solar GT Receiver Development

High-temperature solar receiver design and experimental verification for micro gas-turbine based solar dish systems as part of OMSoP





High-flux solar simulator design and implementation of a test bed for solar receiver tests