CERN Academic Training Programme 2005-2006

Towards Sustainable Energy Systems ?

Geneve, 28-31 March, 2006

Plataforma Solar de Almería: The European Solar Thermal Test Centre

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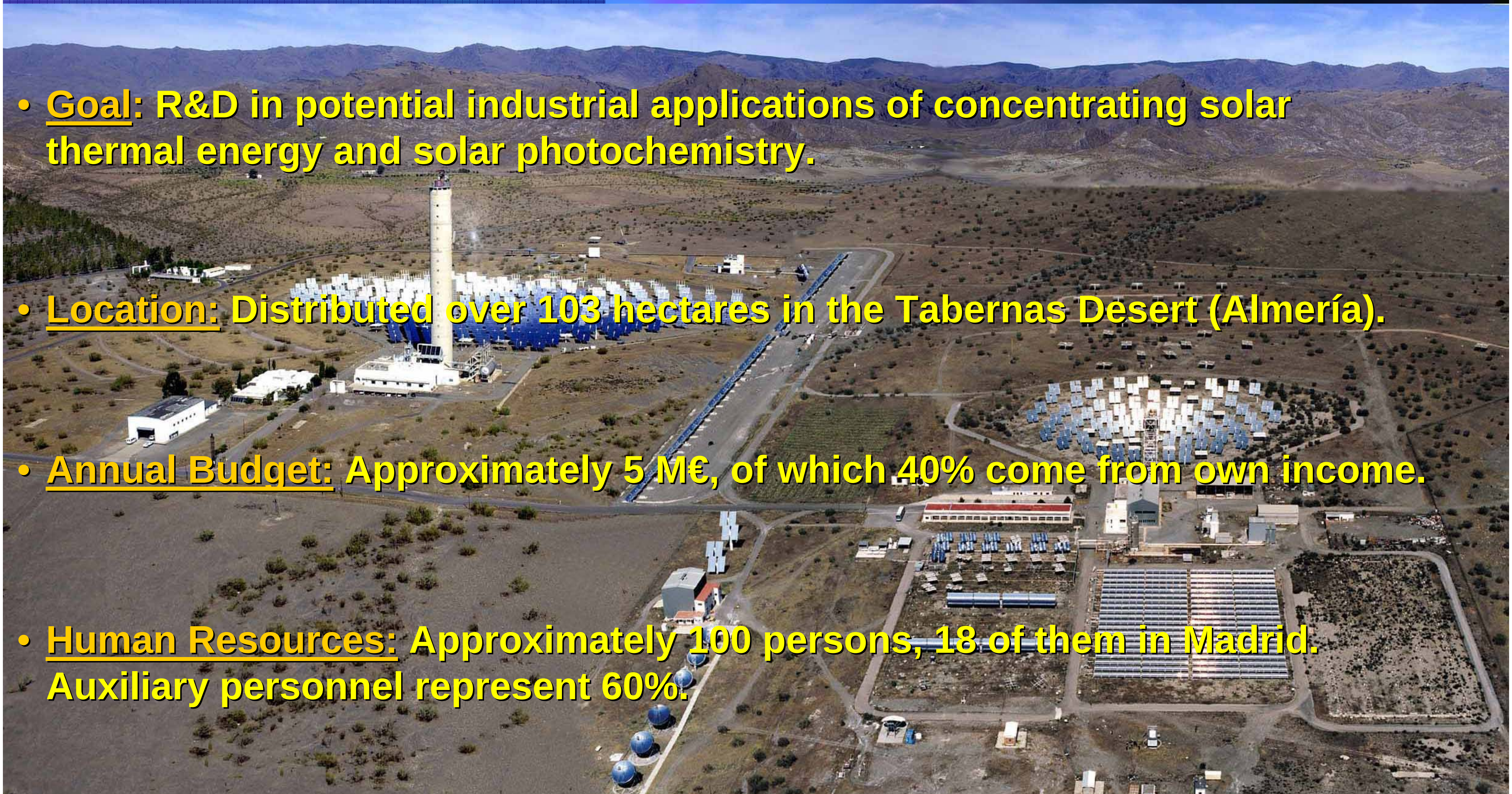
Plataforma Solar de Almería

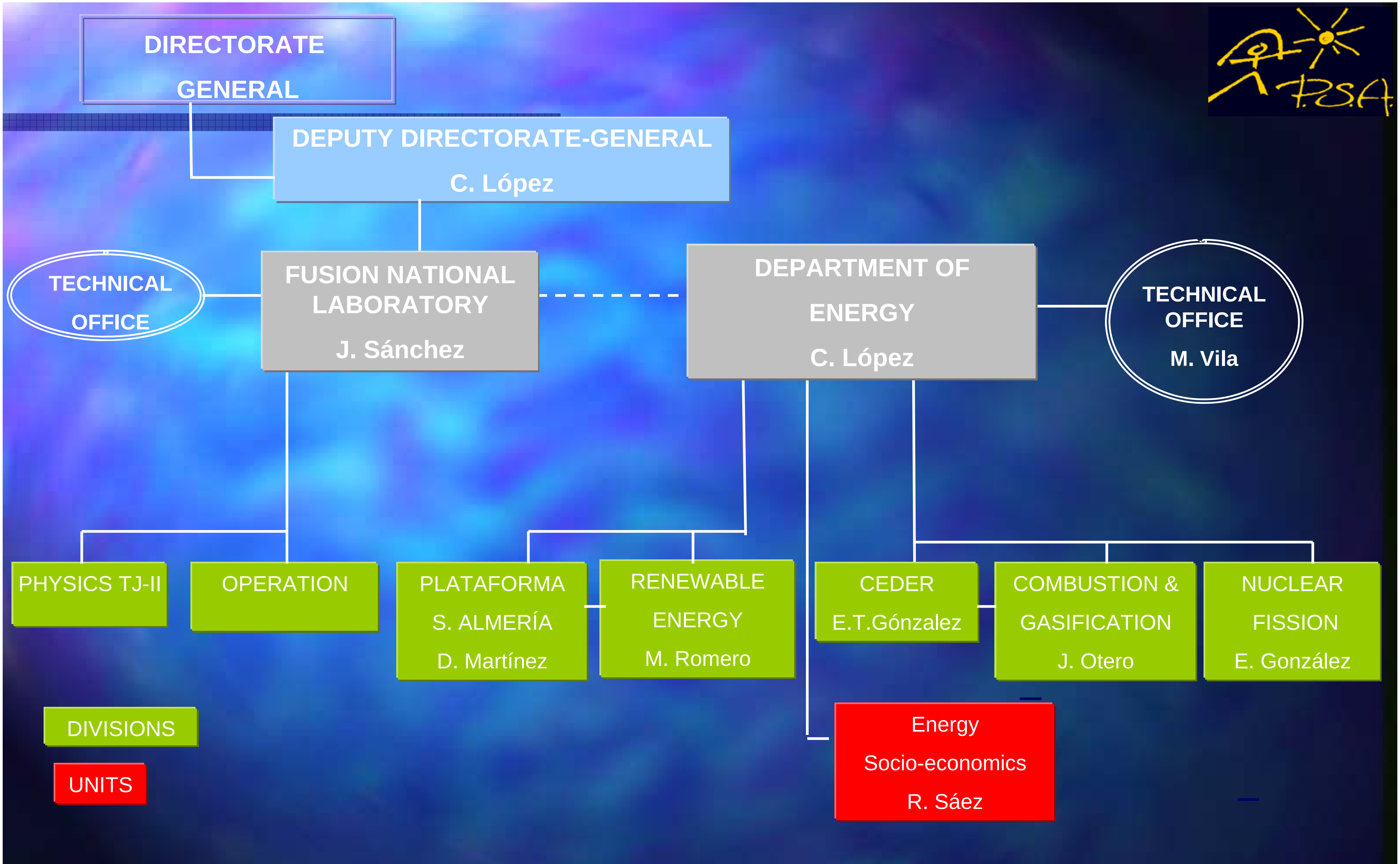
MINISTERIO DE EDUCACIÓN Y CIENCIA

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

BASIC DATA



- **Goal: R&D in potential industrial applications of concentrating solar thermal energy and solar photochemistry.**
- **Location: Distributed over 103 hectares in the Tabernas Desert (Almería).**
- **Annual Budget: Approximately 5 M€, of which 40% come from own income.**
- **Human Resources: Approximately 100 persons, 18 of them in Madrid. Auxiliary personnel represent 60%.**


DIRECTORATE GENERAL
DEPUTY DIRECTORATE-GENERAL
C. López
TECHNICAL OFFICE
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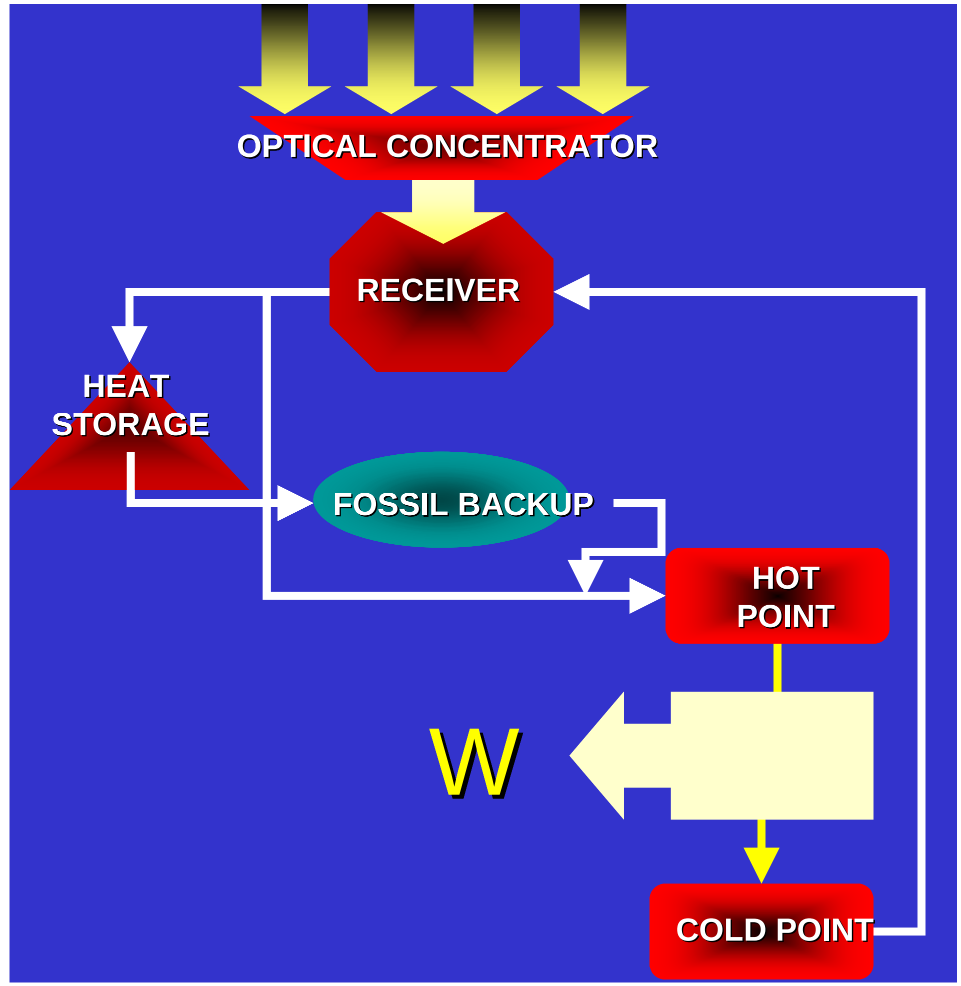
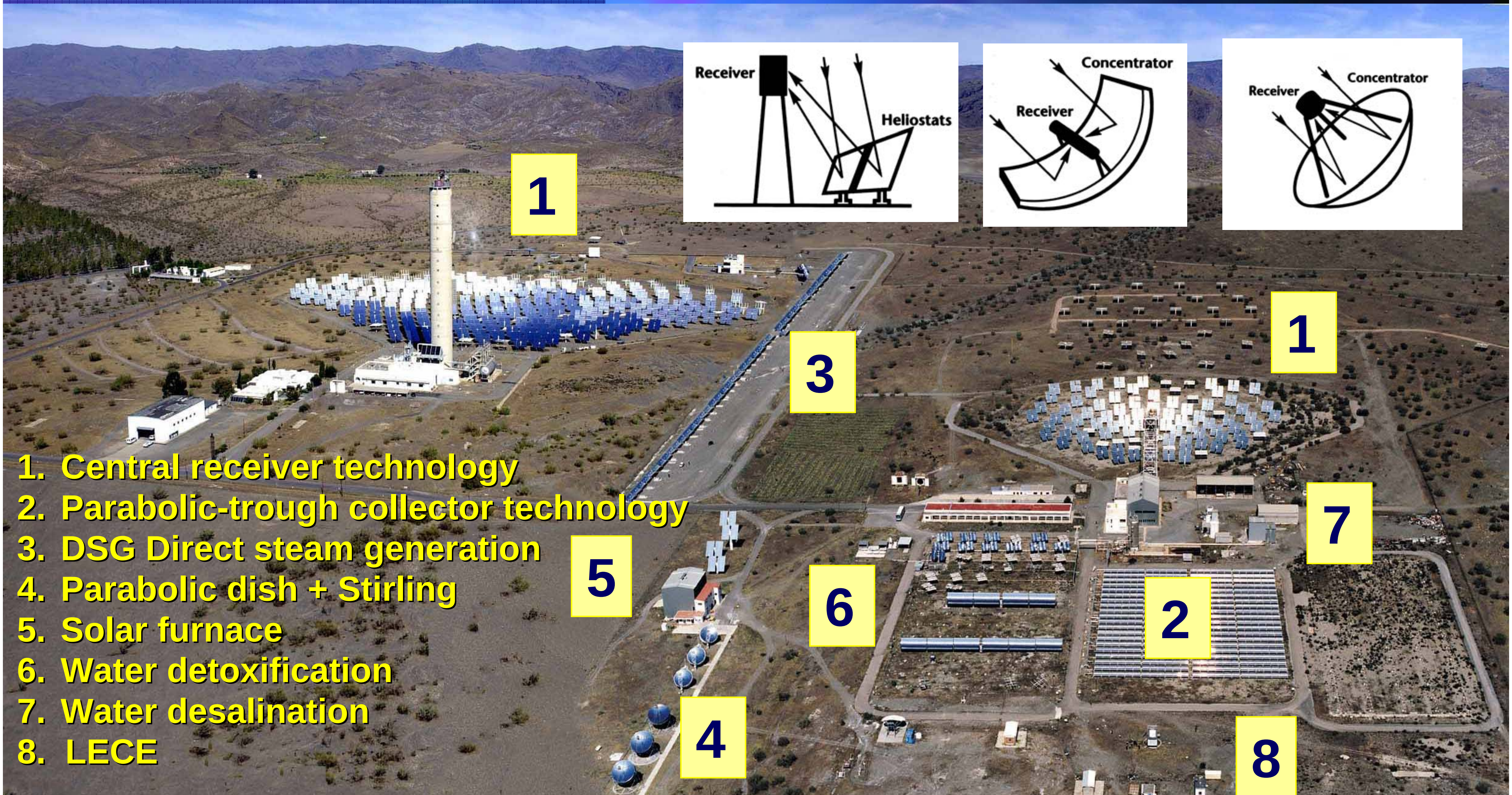
Energy Socio-economics
R. Sáez
DIVISIONS
UNITS

Concentration and thermal conversion

- **The inherent advantage of STP technologies is their unique integrability into conventional thermal plants: All of them can be integrated as "a solar burner" in parallel to a fossil burner into conventional thermal cycles**
- **With thermal storage or fossil fuel backup solar thermal plants can provide firm capacity without the need of separate backup power plants and without stochastic perturbations of the grid.**
- **Solar thermal can supply peak power in summer heat periods when hydro and wind are scarce**
- **Solar thermal creates jobs in local Small and Medium Enterprises**



TEST FACILITIES



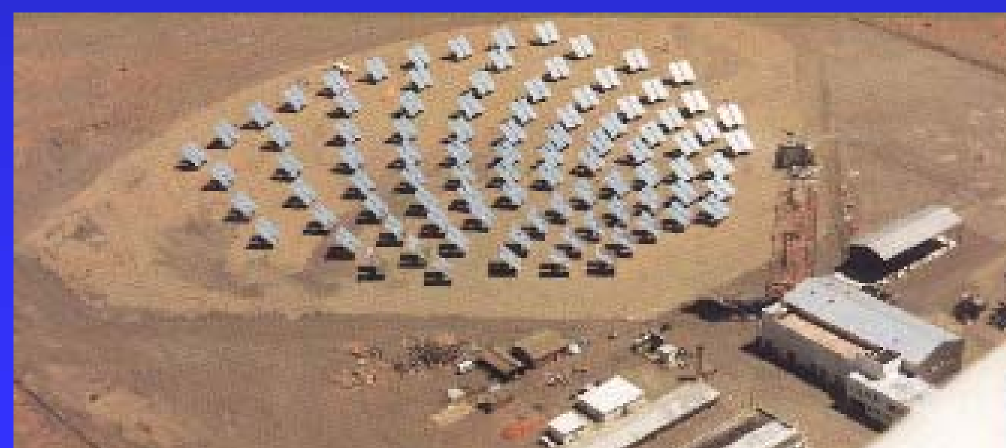
1. Central receiver technology
2. Parabolic-trough collector technology
3. DSG Direct steam generation
4. Parabolic dish + Stirling
5. Solar furnace
6. Water detoxification
7. Water desalination
8. LECE

CESA-1

- Thermal power: 7 MW.
- 300-heliostat field.
- 80 m.-high tower with 3 testing platforms.
- Testing area for newly designed heliostats.

CRS: Central Receiver System

- Thermal power: 2,7 MW
- 111-heliostat field.
- 43 m.-high tower with two testing platforms.



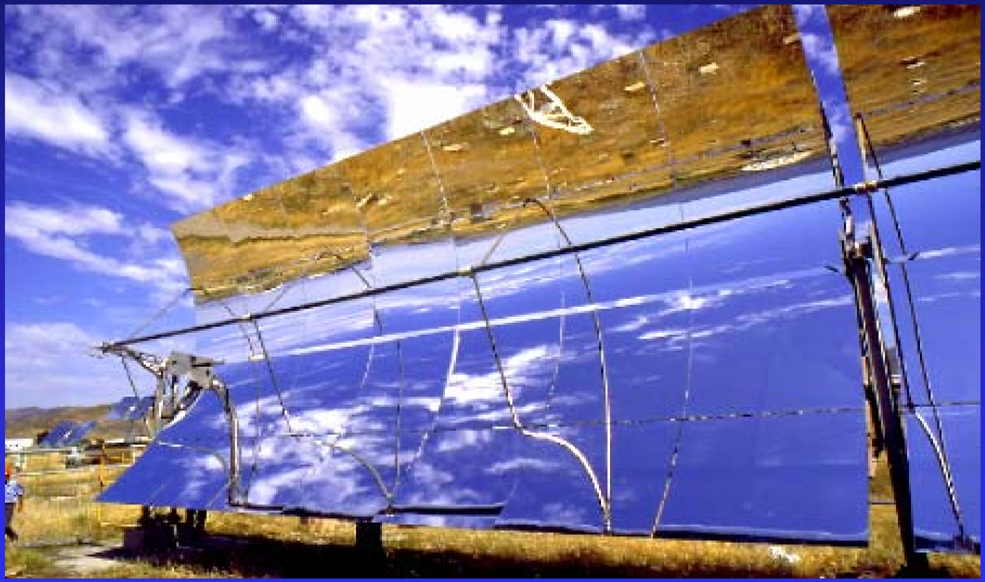
DCS: Distributed Collector System

- Thermal power: 1,2 MW
- Heat storage: 5 MWh
- Coupled to a MED plant: 3 m^3/h

DISS: Direct Solar Steam

- Thermal power: 1,8 MW
- Steam flow rate: 1 kg/s
- T max = 400 ºC
- P max = 100 bar
- 650 m.-long collectors in two rows.

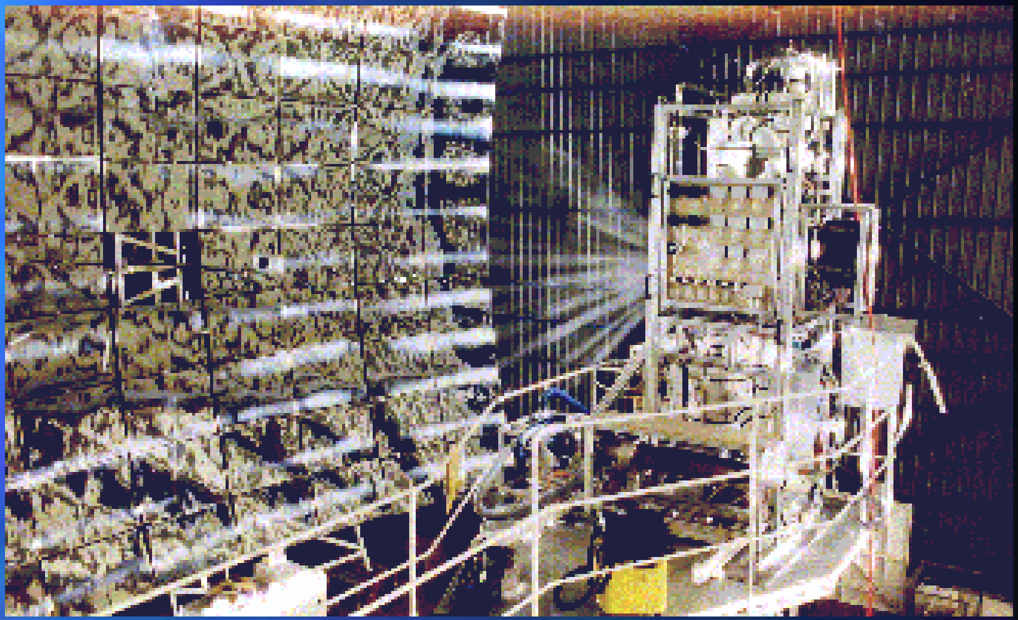
HTF: Heat Transfer Fluid



- LS-3 and EuroTrough collectors in two parallel rows.
- Used for testing of components.
- Thermal power: 345 kW

- Working fluid is a synthetic thermal oil.
- T max: 420ºC
- Currently coupled to a thermal storage testing loop.

SOLAR FURNACE



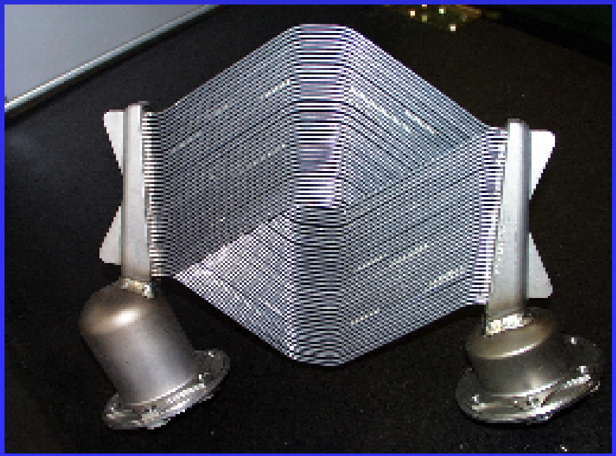
- ✓ Tool for achieving high flux and high temperatures (T > 2000 ºC).
- ✓ Peak flux: 3000 suns. Power: 58 kW. Concentrating area: 98,5 m^2.
- ✓ Focus diameter: 23 cm. Gaussian energy profile.
- ✓ Up to now, thermal materials surface treatment applications.
- ✓ New applications: high temperature chemical processes, industrial process heat.

PARABOLIC DISHES

- ✓ Stand-alone electricity generation (P < 25 kW) for remote sites, with Stirling engines.
- ✓ At the present time, several companies are developing their own first commercial demonstration products (40,000 hours of experience accumulated at the PSA).
- ✓ EURODISH/ENVIRODISH Projects: Design of new dish, price goal of 5,000 €/kWe
- ✓ Other key points: <u>hybridization, automation, reliability</u>.

DISTAL: Dish-Stirling Almeria

- 6 units / 3 generations
- Direct solar tracking
- Thermal power: 50 kW
- Electric power: 10 kW



DETOX: Detoxification Loop

- Set of 6 CPC for water detoxification by UV.
- Total volume: 405 l.
- Aperture area: 33 m2

- Set of 4 two-axis tracking PTC.
- Working flow:
- 400-5000 l/h.
- Aperture area: 128 m2

LECE: SOLAR ENERGY IN BUILDINGS

- ✓ LECE (Energy Testing of Building Components) consists of 4 16-m^3 thermally insulated test cells with one wall prepared for testing architectural components.
- ✓ These tests allow component thermal losses and some optical properties as transmissivity of light, etc., to be evaluated.
- ✓ This laboratory has been quality-certified by ENAC

Meteo Station

- Target: To become a member of the BSRN.
- Special spectroradiometer available: 200 – 2500 nm, global, direct, diffuse solar radiation.

MAIN HISTORICAL MILESTONES

1977 Birth of the PSA: Beginning of the CESA-1 and SSPS projects.

1981 Solar thermal electricity supplied to the grid for the first time: CRS-SSPS project.

1985 Merging of the different facilities into the PSA.

1987 Signature of Spanish-German Agreement DLR-CIEMAT.

1990 Recognition as a 'Large European Scientific Installation'.

1999 Official inauguration of the direct steam generation (DISS) loop.

ORGANIZATION

- Director
  - Administration Dept.
  - Director's Office
  - R&D UNITS
    - Concentrating Solar Systems
    - Environmental Applications of Solar Energy
  - PSA MANAGEMENT UNIT
    - Maintenance
    - IT Services
    - Civil Engineering
    - Instrumentation
    - Operation

R & D UNIT

SOLAR CONCENTRATING SYSTEMS

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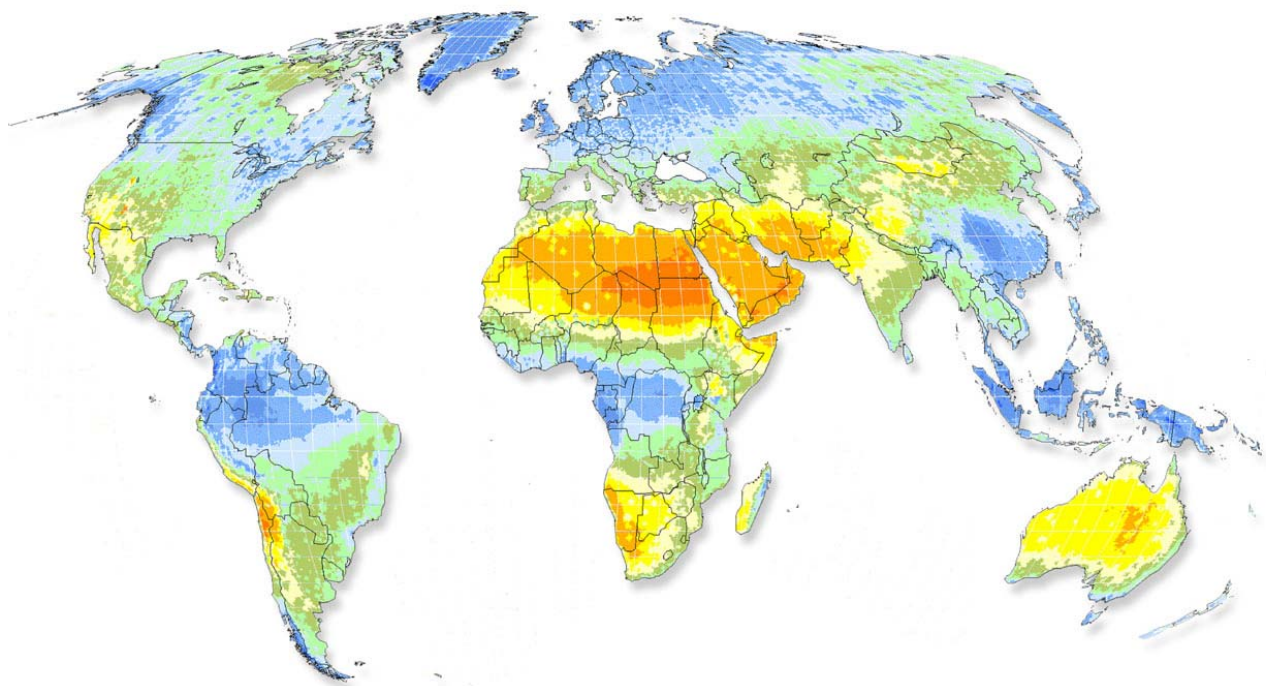
Plataforma Solar de Almería:
The European Solar Thermal Test Centre.
Geneve. 30 March, 2006

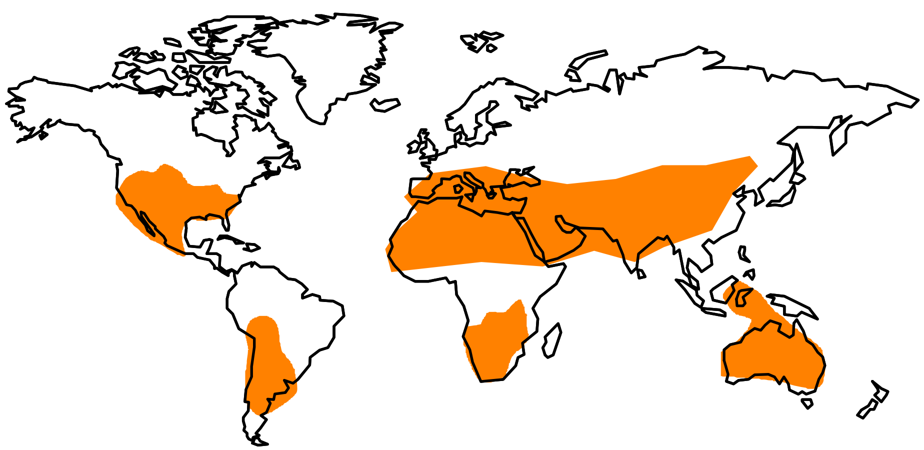
Zones of interest for deployment of STPP



- Desserts of North and South Africa,
- Mediterranean region
- Arabian Peninsula and Near East,
- Different areas of India,
- Northwest and central part of Australia,
- High plains of Andean Countries,
- North-East of Brazil,
- North of Mexico, and
- Southwest of USA.

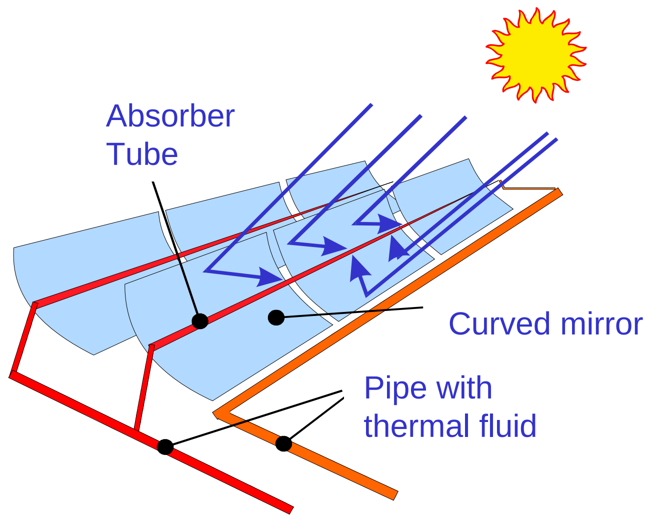
Potential of STPP

1% of arid and semi-arid areas are enough to supply annual World demand of electricity

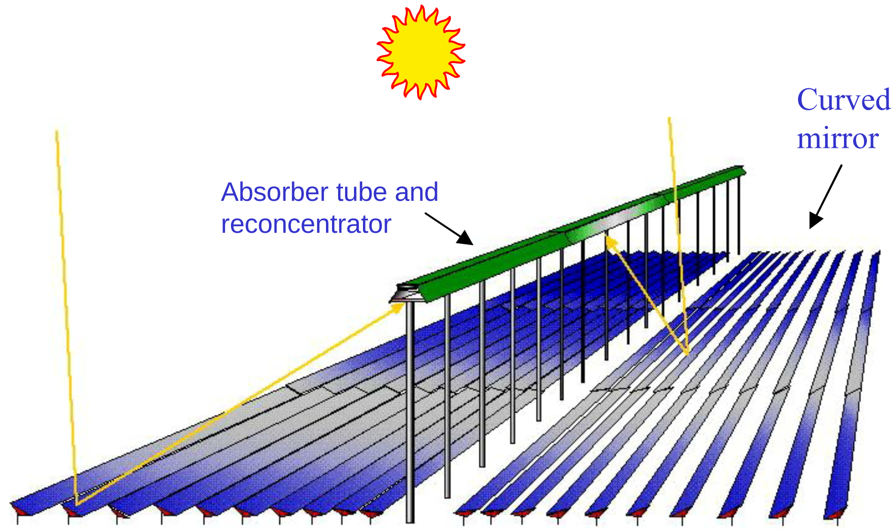


1. Global solar radiation on earth	(TWh/year)	$240 * 10^6$
2. Dessertic areas (7% of earth surface)	(TWh/year)	$16 * 10^6$
3. Solar fraction of DNI available (70%)	(TWh/year)	$11,2 * 10^6$
4. Efficiency of CSP plants (15%)	(TWh/year)	$1,68 * 10^6$
5. Percentage of area with good infrastructures (1% of dessert areas)	(TWh/year)	$16,8 * 10^3$
6. World electricity demand year 2000	(TWh/year)	$15 * 10^3$

Solar Thermal Power Plants: 2D

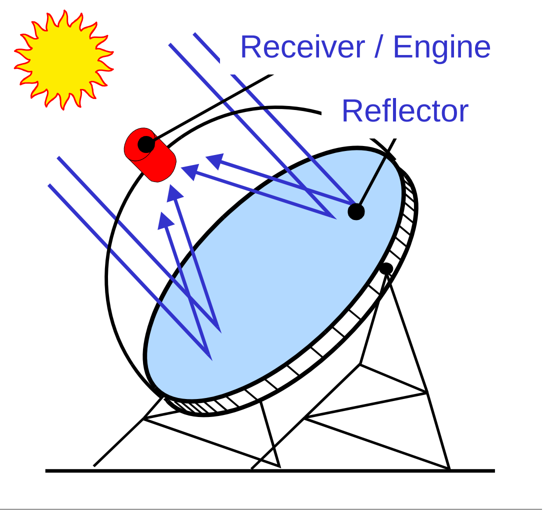


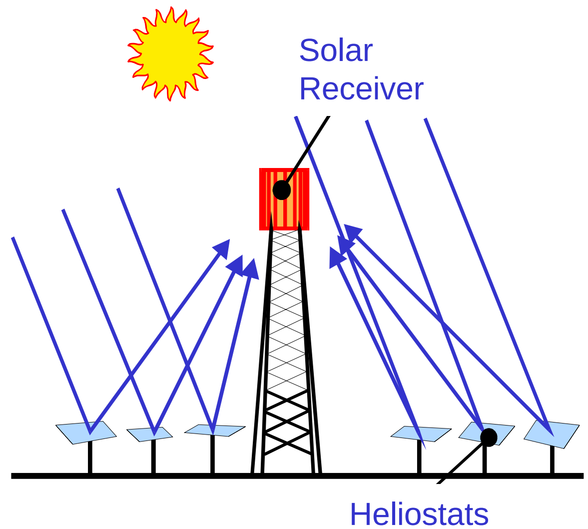
Parabolic troughs



Linear Fresnel reflector

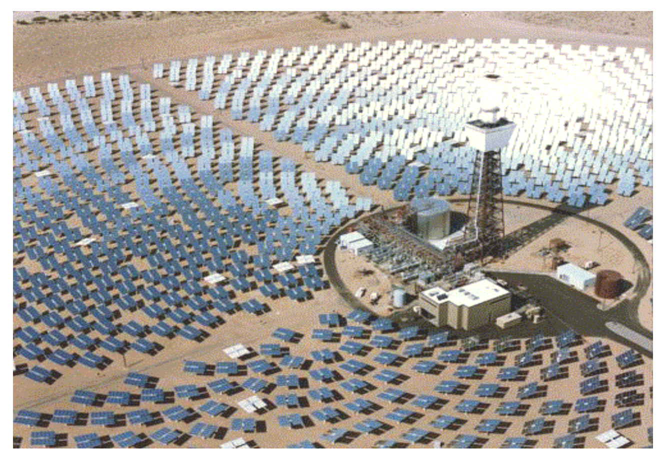
Solar Thermal Power Plants: 3D





Parabolic dishes

Central Receiver



The keys for efficiency

$$\eta = 1 - \frac{T_2}{T_1}$$

$$q = \sigma \varepsilon T^4$$

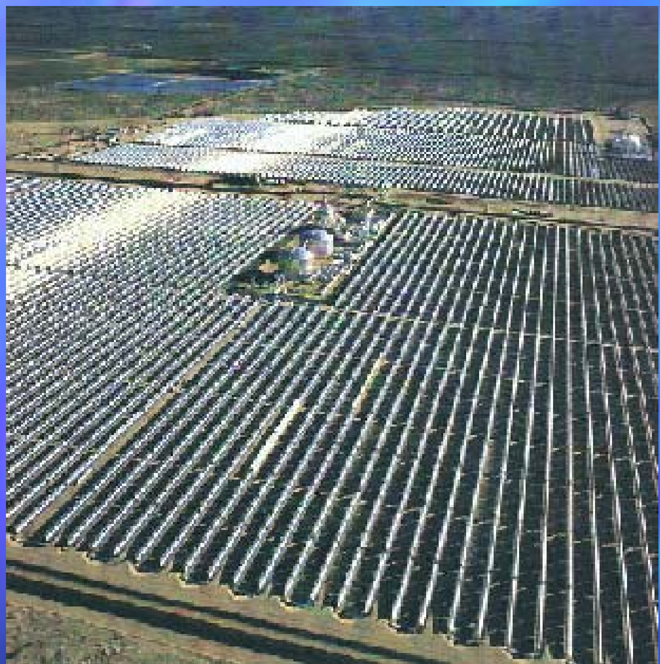
$$\eta = \eta_C * \eta_R * \eta_{Gen} = \frac{P}{A_C * I}$$

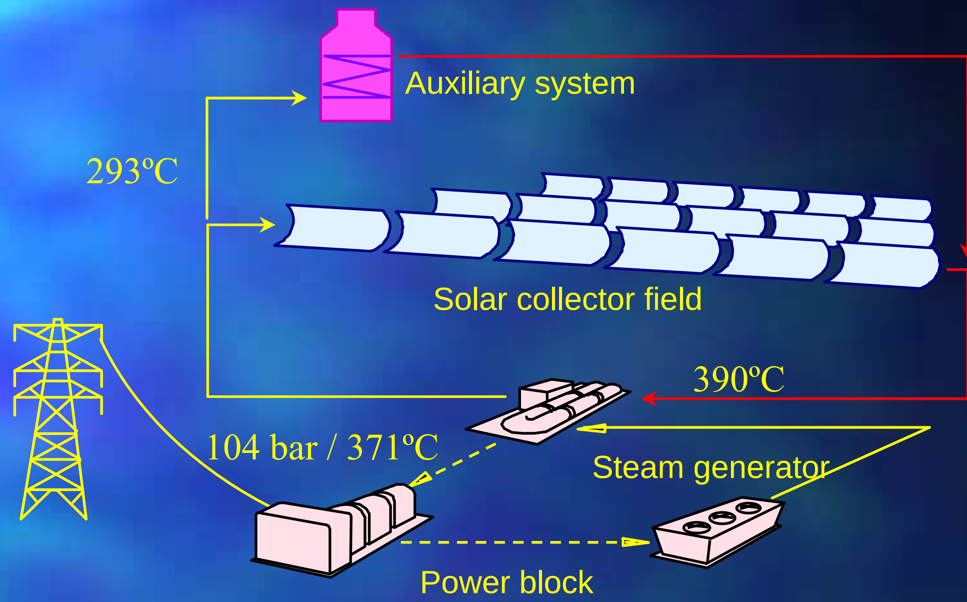
Comparison of technologies

	Parabolic troughs	Central Receiver	Dish-Stirling
Power	30-320 MW	10-200 MW	5-25 kW
Operation temperature	390-500 ºC	565-800 ºC	750 ºC
Annual capacity factor	23-50 %	20-77 %	25 %
Peak efficiency	20 %	18-23 %	29.4 %
Net annual efficiency	11-16 %	15-20 %	12-25 %
Commercial status	Commercial	Demonstration	Prototypes-demonstration
Technical risk	Low	Medium	High
Storage availability	Limited	Yes	Batteries
Hybrid designs	Yes	Yes	Yes
Cost kW installed EURO/kW	2 300-2 500	2 500-2 900	5 000-8 000

*When comparing installed costs special attention should be given to Solar Multiple and Design Point values for each project.

PARABOLIC TROUGH COLLECTOR TECHNOLOGY

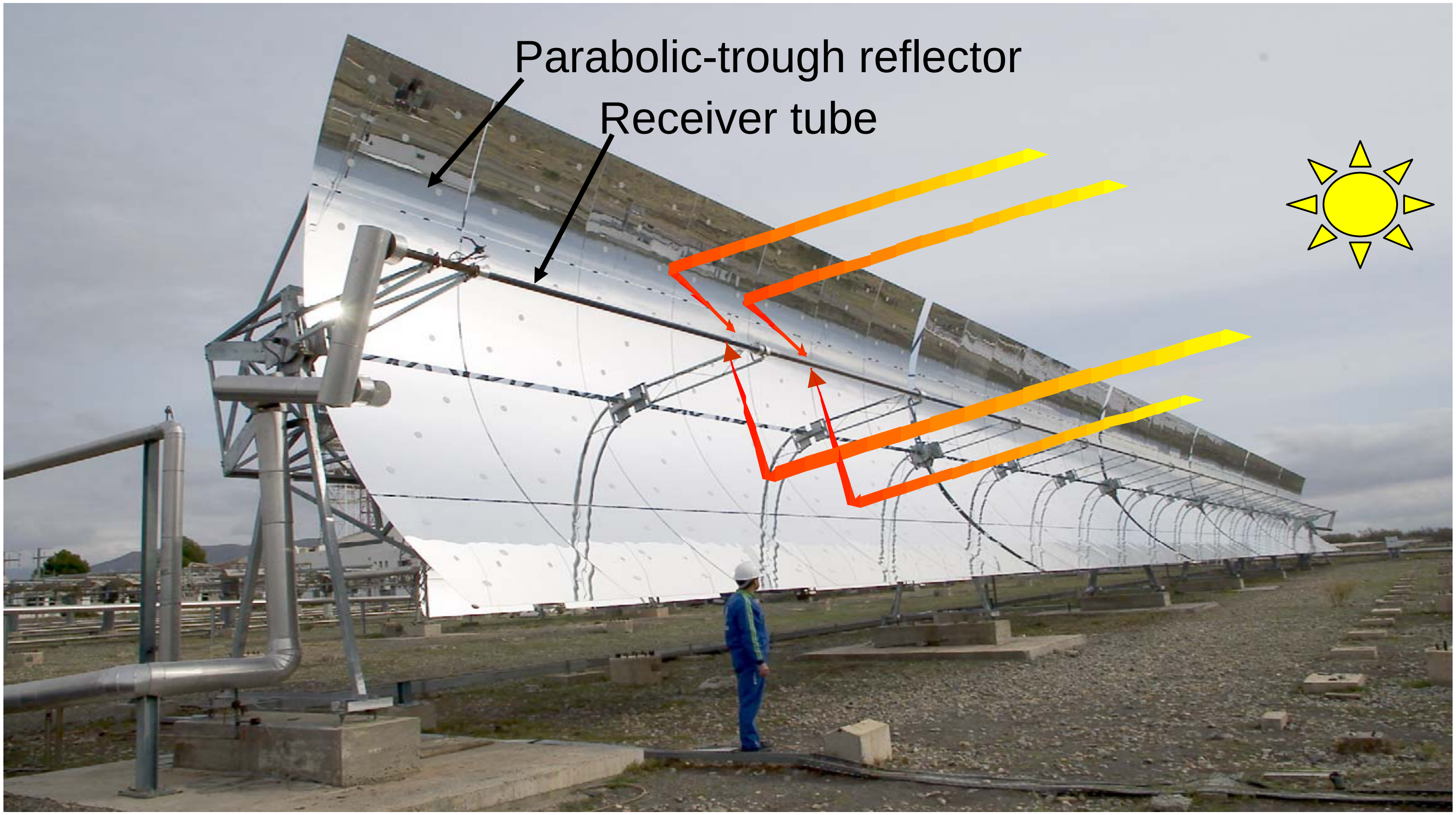




- ✓ **Objective: Development of improved parabolic-trough collector components seeking cost reduction and improved efficiency.**
- ✓ **This technology concerns medium-temperature applications: 125º< T < 400ºC**
- ✓ **Only commercial CSP technology, so far: 354 MWe in operation at the plants SEGS I to IX, in California.**

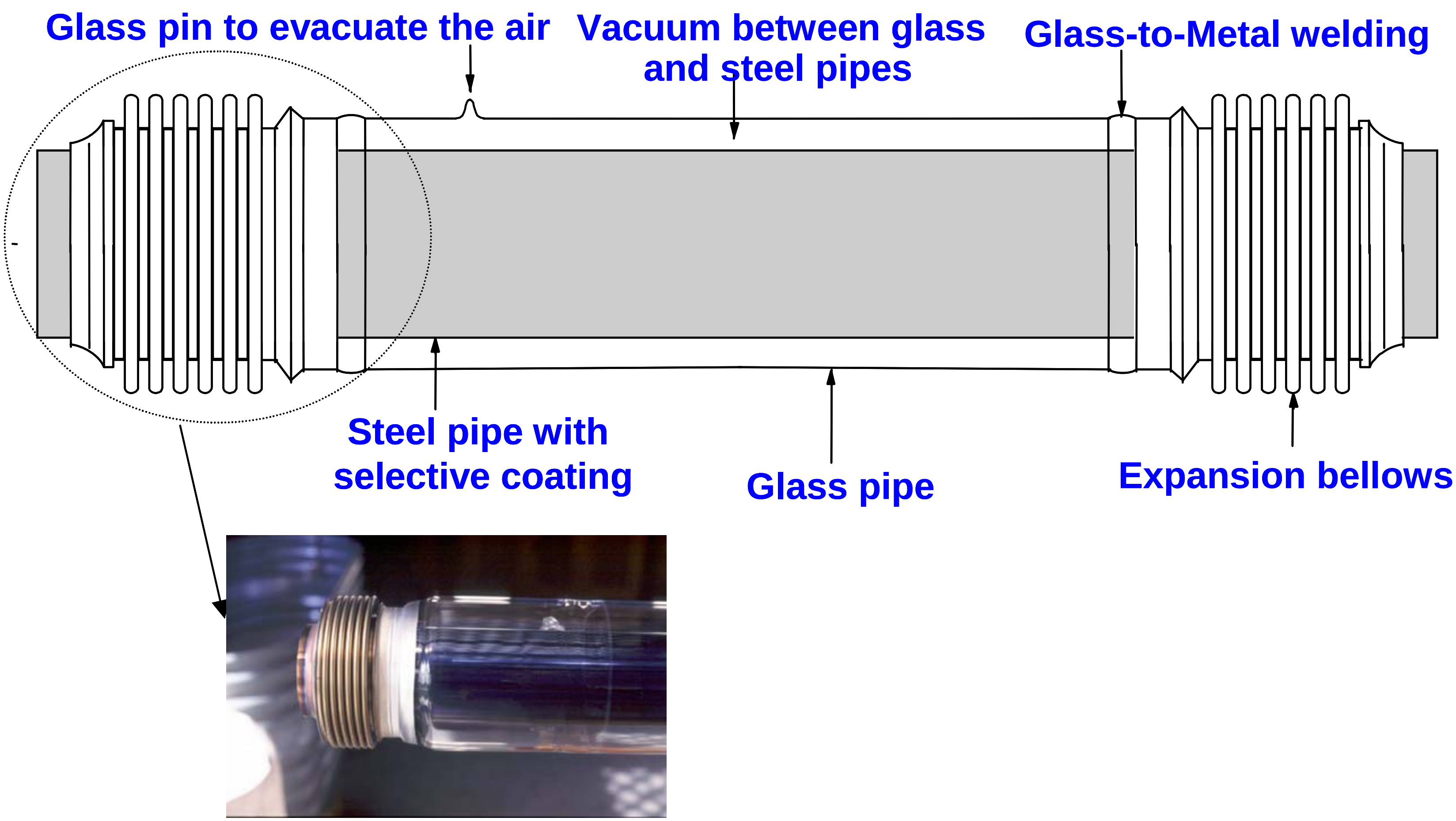
The Parabolic-trough Collector (PTC)

Components and principle

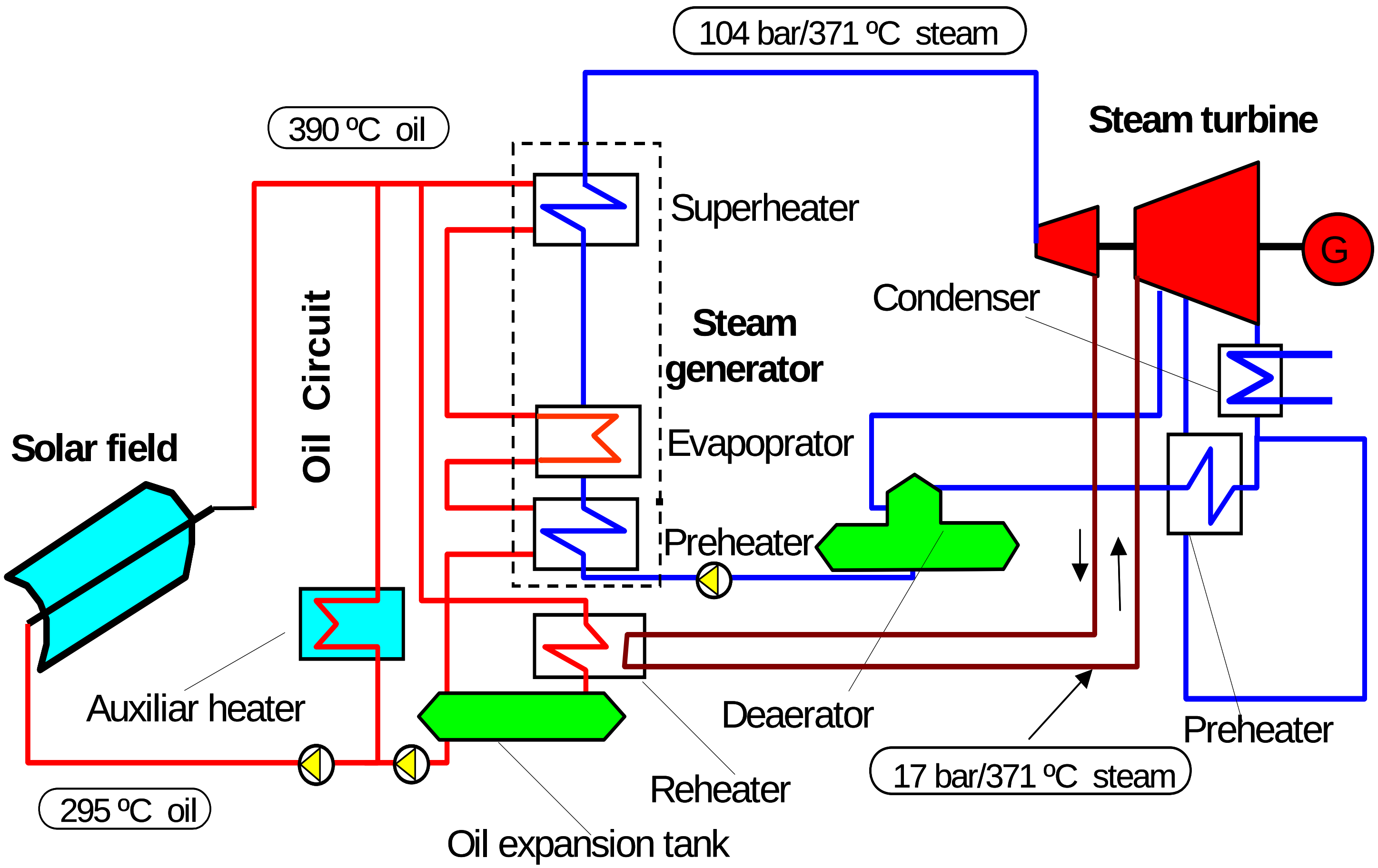


The Parabolic-trough Collector (PTC)

Typical receiver tube

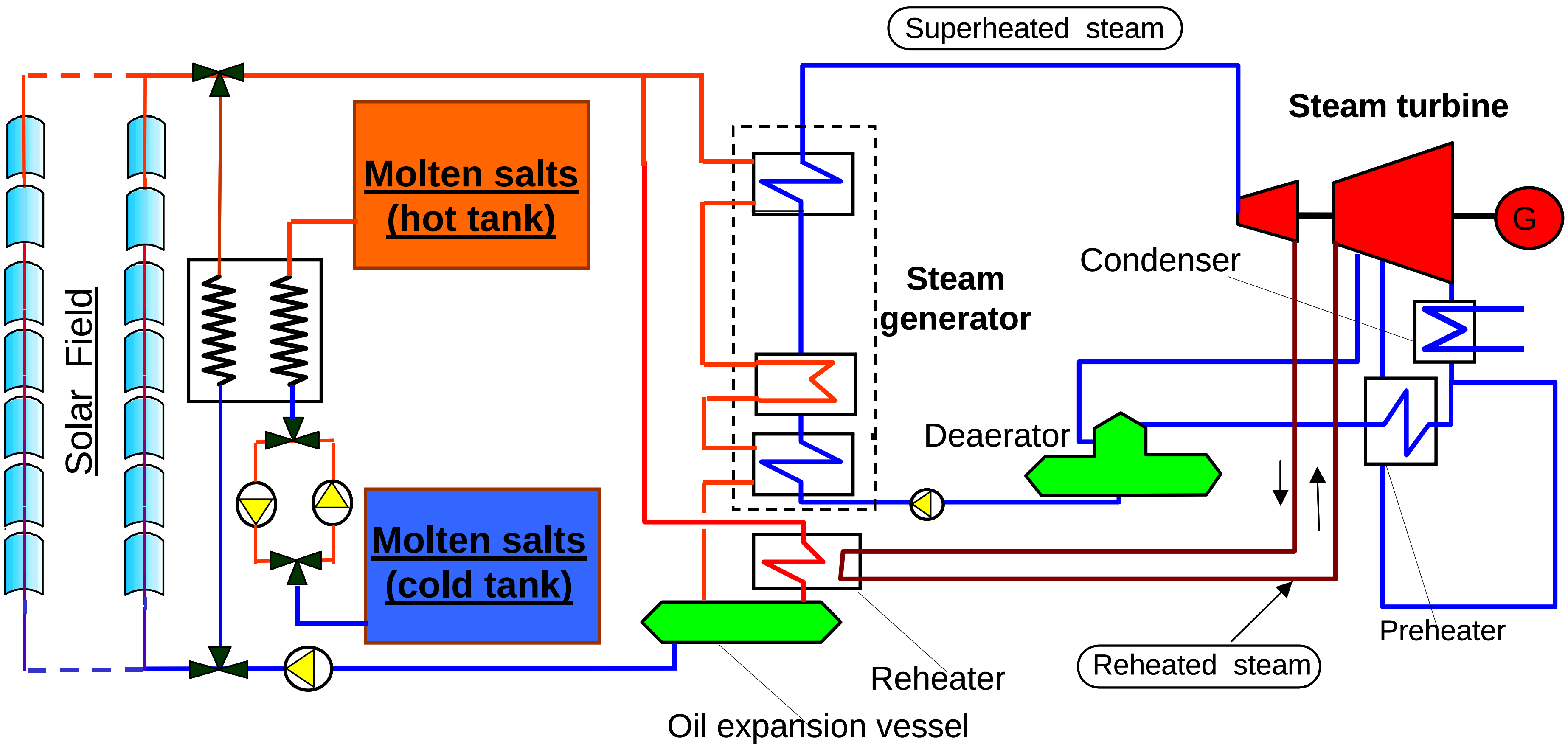


Simplified scheme of a solar power plant with PTCs

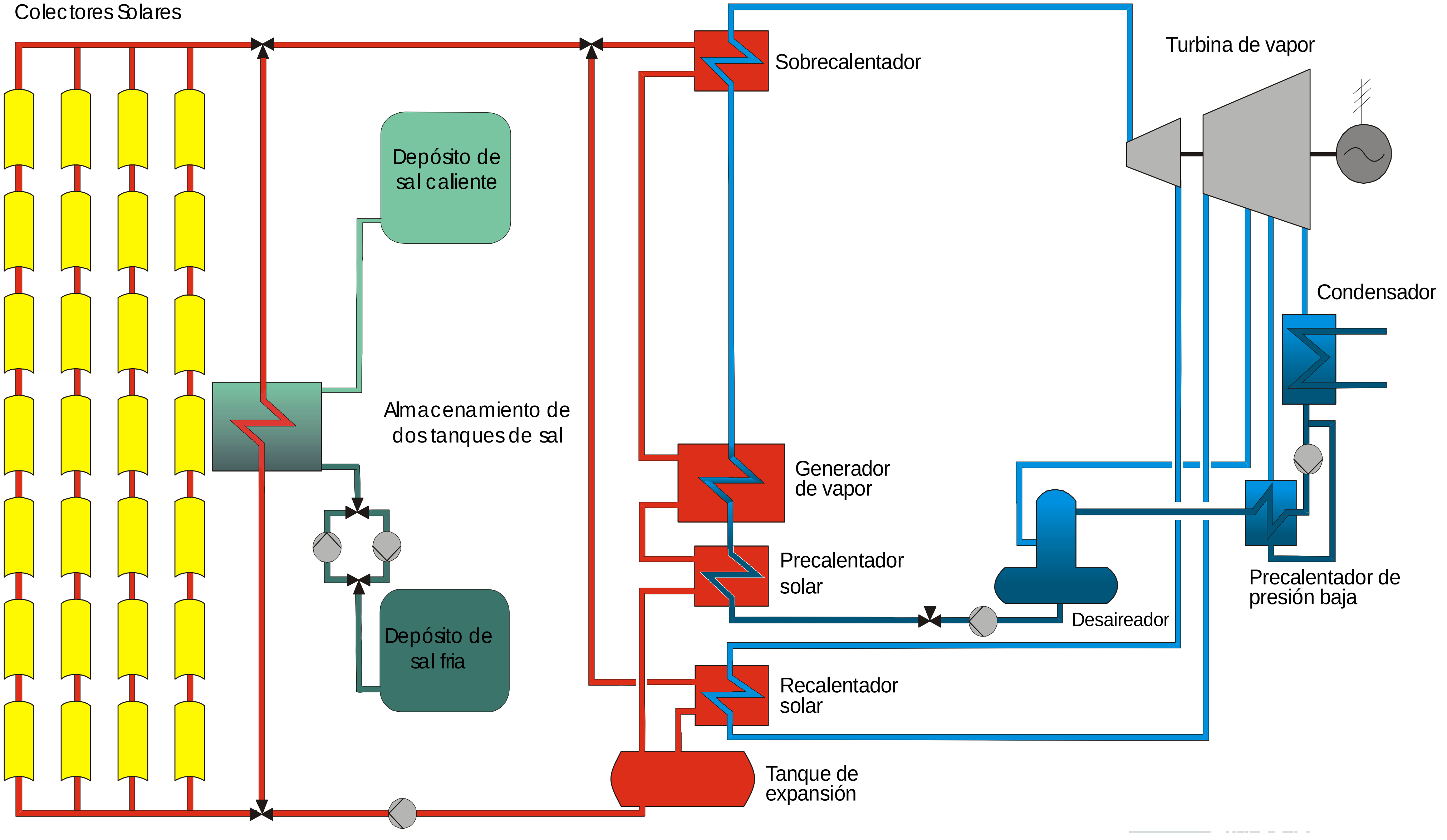


Electricity Generation with PTCs

Solar power plant with PTCs and thermal storage system



The ‘Andasol’ Commercial Project



‘Andasol’: Some figures

	50 MW_e Solar Only 7.5 h heat storage
Required land (km^2)	1.2
Investment cost	240 Mio €
Annual electricity production (GWh_e)	181.7
LEC (€/kWh_e)	0.15

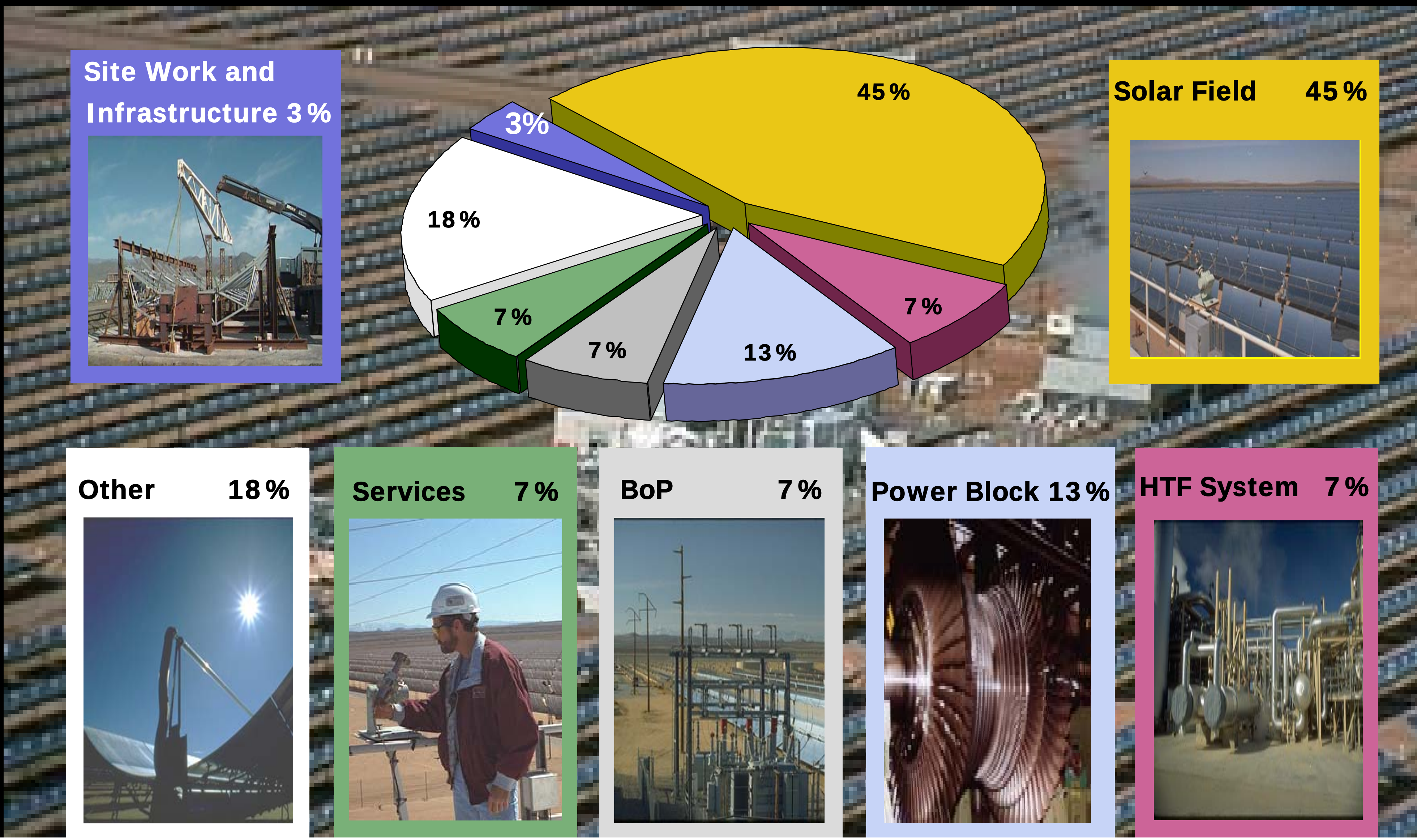
- ❑ 58 qualified new permanent jobs per plant
- ❑ 1 000 people employed during construction phase.

ANDASOL 50 MW will avoid:

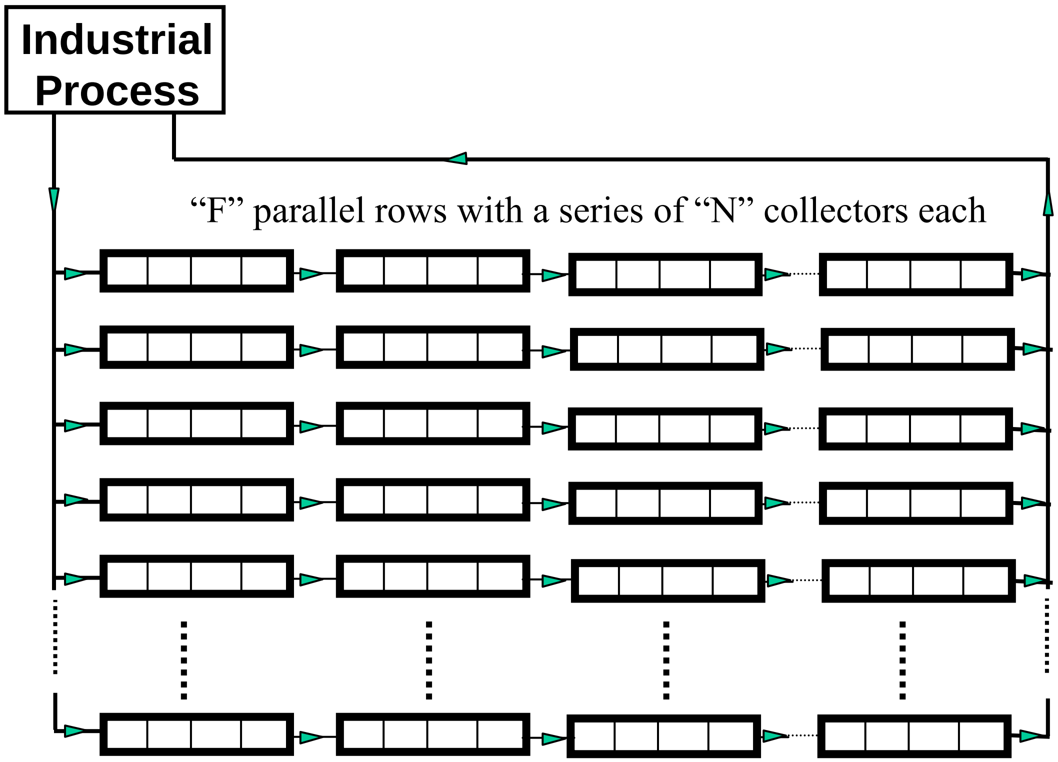
- Consumption of 35 920 tons of coal per year.
- Emission of 89 314 tons of CO_2 per year.
- Emission of 291 tons of NOx per year.

- **672 EUROTrough collectors**
- **150 m long each**
- **8 m aperture diameter**

Breakdown of Investment Cost for a 50MW SEGS



The Solar Field Configuration



Heat Storage Systems

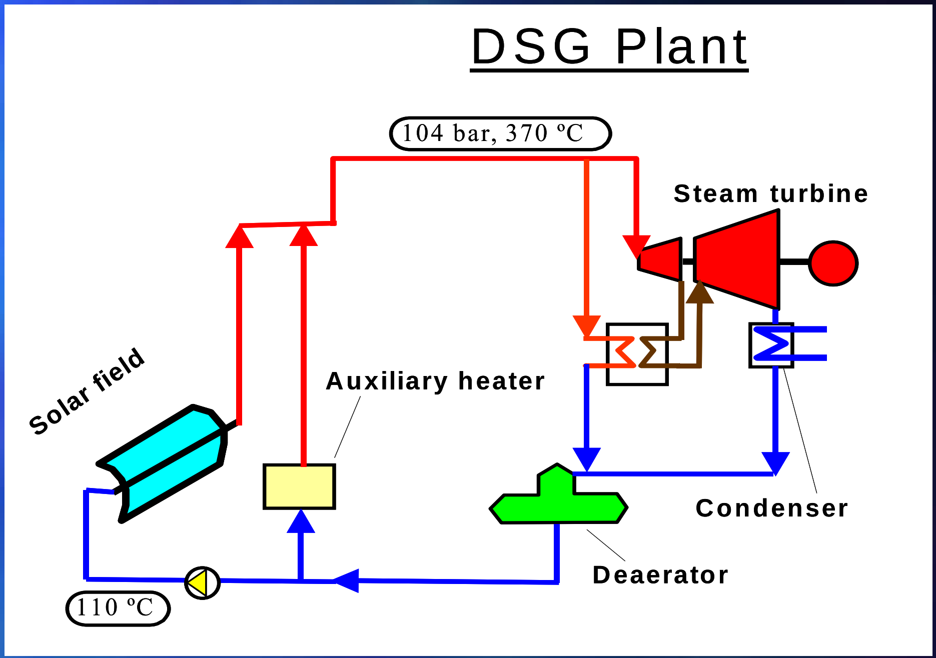
Thermocline tank

Dual Media Storage Tank

State-of-the-Art and Conclusions

- Parabolic-troughs are the cheapest way to produce electricity with solar energy
- Eight SEGS plants currently in operation with a total power of 340 MWe are the best commercial example of this technology:
  - plant availability > 98%
  - 22% peak efficency
  - annual solar-to-electric efficiency between 14% and 18%
- Investment cost is within the range 2400 – 4000 $/kWe
- A specific cost of 0,08$/kWe seems feasible in a medium to long-term
- At present, tax incentives or premiums are required to become profitable
- Many projects currently underway in Spain, USA, Egypt, Mexico and Morocco
- DSG technology is expected to become commercially available by 2010

PARABOLIC TROUGH COLLECTOR TECHNOLOGY



✓ **Development of the <u>Direct Steam Generation process (DSG)</u> to replace thermal oil with water as the heat transfer fluid in power production plants.**

- **New absorber tubes**
- **Heat storage for steam**

The Direct Steam Generation Process

Comparison between the DSG technology and the HTF (oil) technology

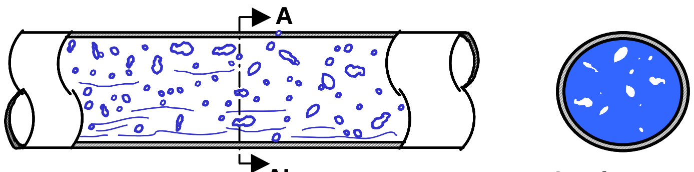
Advantages of the DSG technology:

- Smaller environmental risks because oil is replaced by water
- Higher steam temperature (maximun steam temperature with oil = 380ºC)
- The overall plant configuration is simpler
- Lower pressure losses and parasitics → higher plant efficiency
- Lower investment and O&M costs

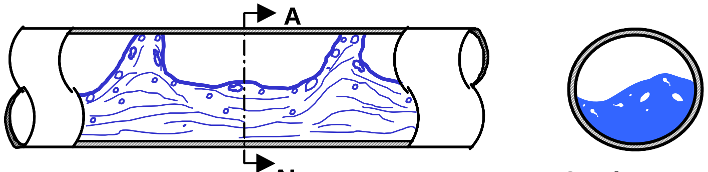
DSG uncertainties that have been solved and clarified:

- Solar field control under solar radiation transients
- Unstability of the two-phase flow inside the receiver tubes
- Temperature gradients at the receiver pipes

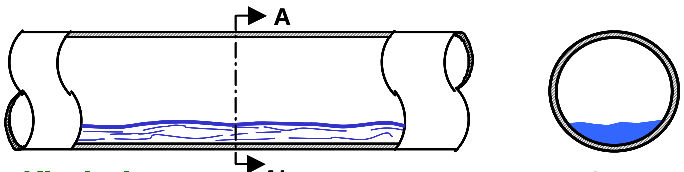
Water/steam flow pattern configurations



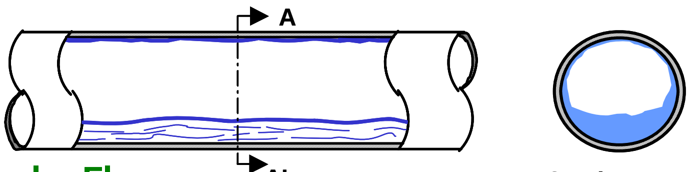
Bubbly Flow



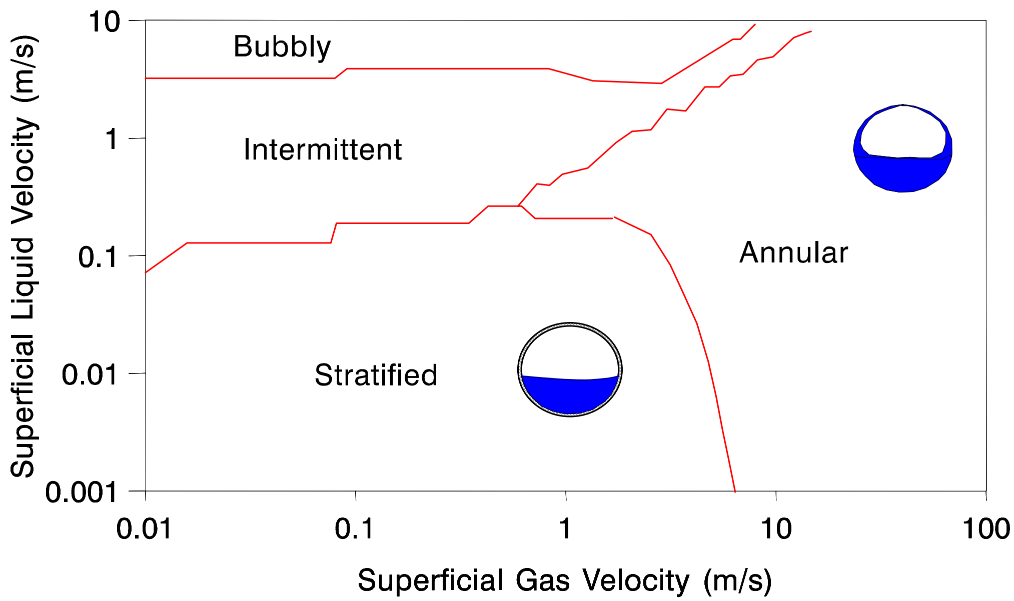
Intermittent Flow



Stratified Flow

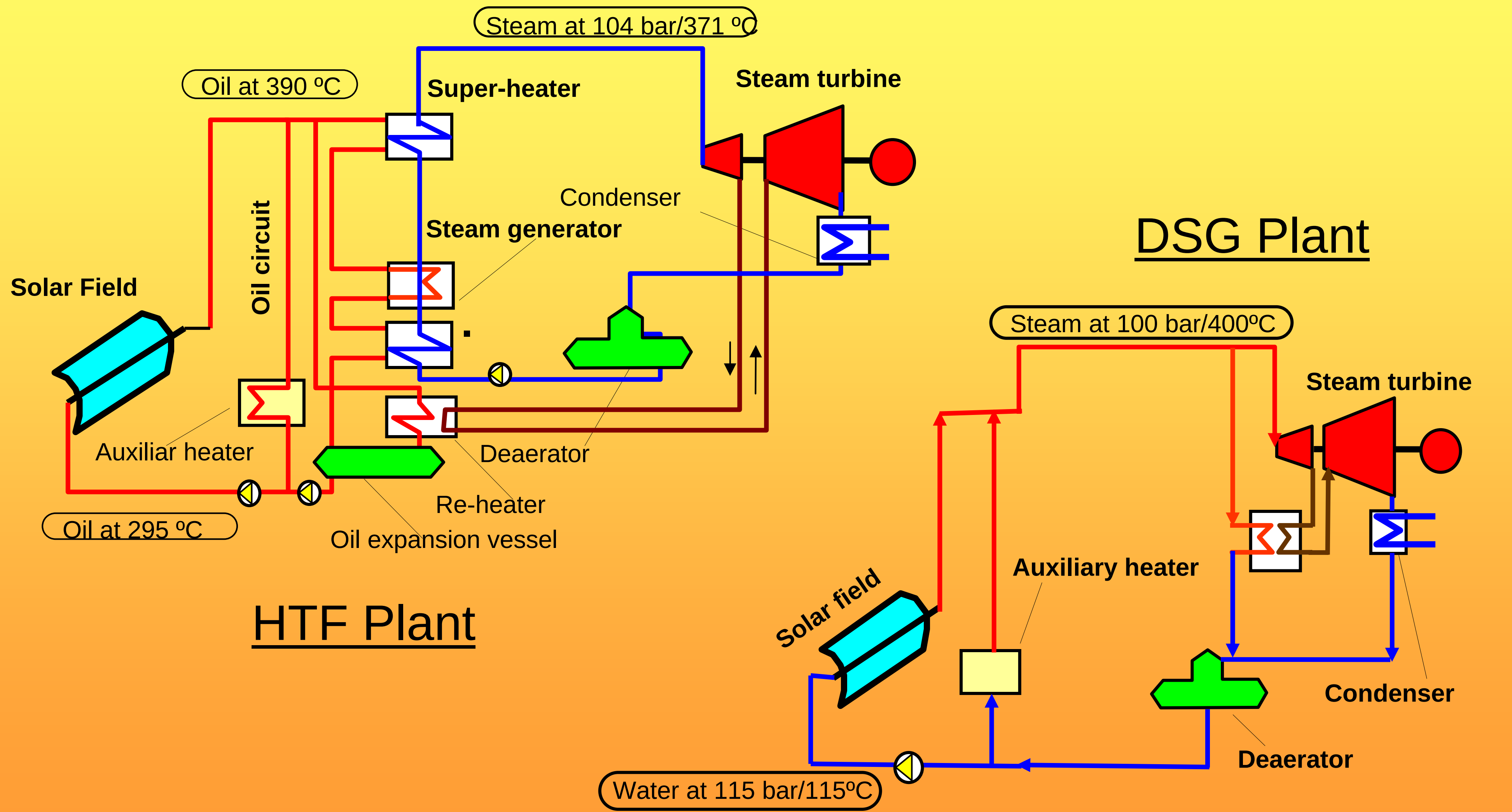


Annular Flow



Typical two-phase flow pattern map for horizontal pipe

Typical plant schemes for DSG and HTF plants



The Project *INDITEP*

(Integration of DSG Technology for Electricity Production)

- ***PROJECT OBJECTIVES:***

Activities planned in INDITEP are the continuation of the DISS project. There are three objectives:

1. *Detail design of a pre-commercial DSG power plant, using the know-how gained in DISS*
2. *Development and evaluation of optimised components for DSG (water/steam separators and ball joints), as well as a selective coating stable at 550ºC and a buffer storage unit.*
3. *Socio-economic study to identify potential market niches for DSG power plants and to asses the integration potential of this technology*

- ***PROJECT DURATION AND PARTNERS:***

Duration: from July 2002 to June 2005

Partners: CIEMAT, DLR, GES, IBERINCO, INABENSA, INITEC, FLAGSOL, FRAMATONE, ZSW

The European Commission is giving financial support to INDITEP within the 5th Framework Program (contract nº. ENK5-CT-2001-00540)

The Project *INDITEP*

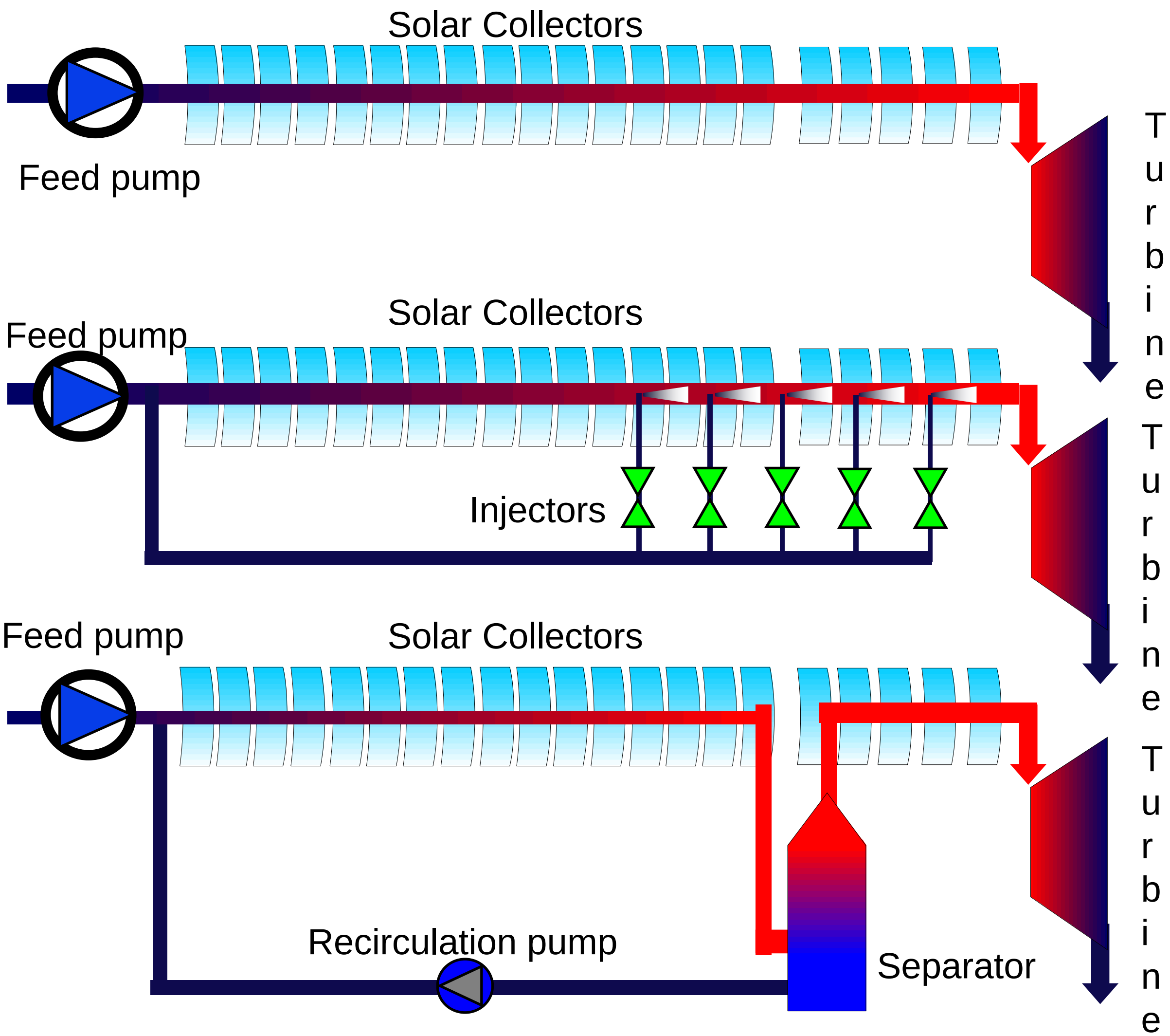
DETAIL DESIGN OF THE FIRST DSG PRE-COMMERCIAL SOLAR POWER PLANT

➢ ***BASIC REQUIREMENTS***

Three basic requirements were defined for the design of this first DSG power plant:

1. *The Power Block must be robust and reliable. Efficiency is of lower priority for this plant.*
2. *The size must be:*
   a) big enough to demonstrate commercial feasibility of larger DSG plants
   b) small enough to limit the financial risk for investors.
3. *The DSG solar field will operate in recirculation mode.*

The Three DSG Basic Options



Once Through Boiler

- Lowest Costs
- Least complexity
- Best Performance
- Controllability ?
- Flow Stability ?

Injection Process

- Better Controllability
- Flow stability equally good
- More complex
- Higher investment costs

Recirculation Process

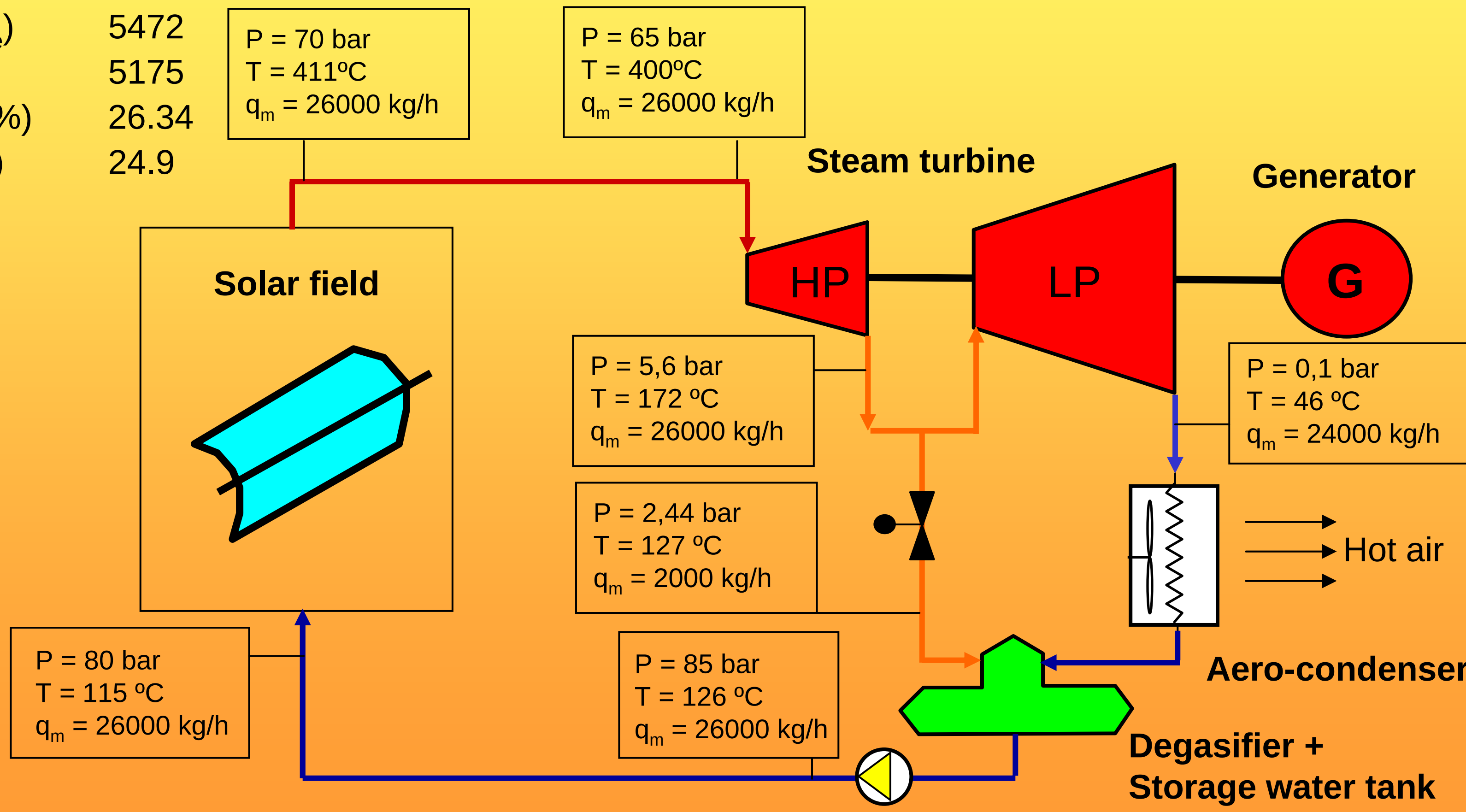
- Better Flow Stability
- Better Controllability
- More complex
- Higher investment costs
- Higher parasitics

The First DSG Pre-commercial Solar Plant

Simplified Scheme of the Power Block with Air Condenser

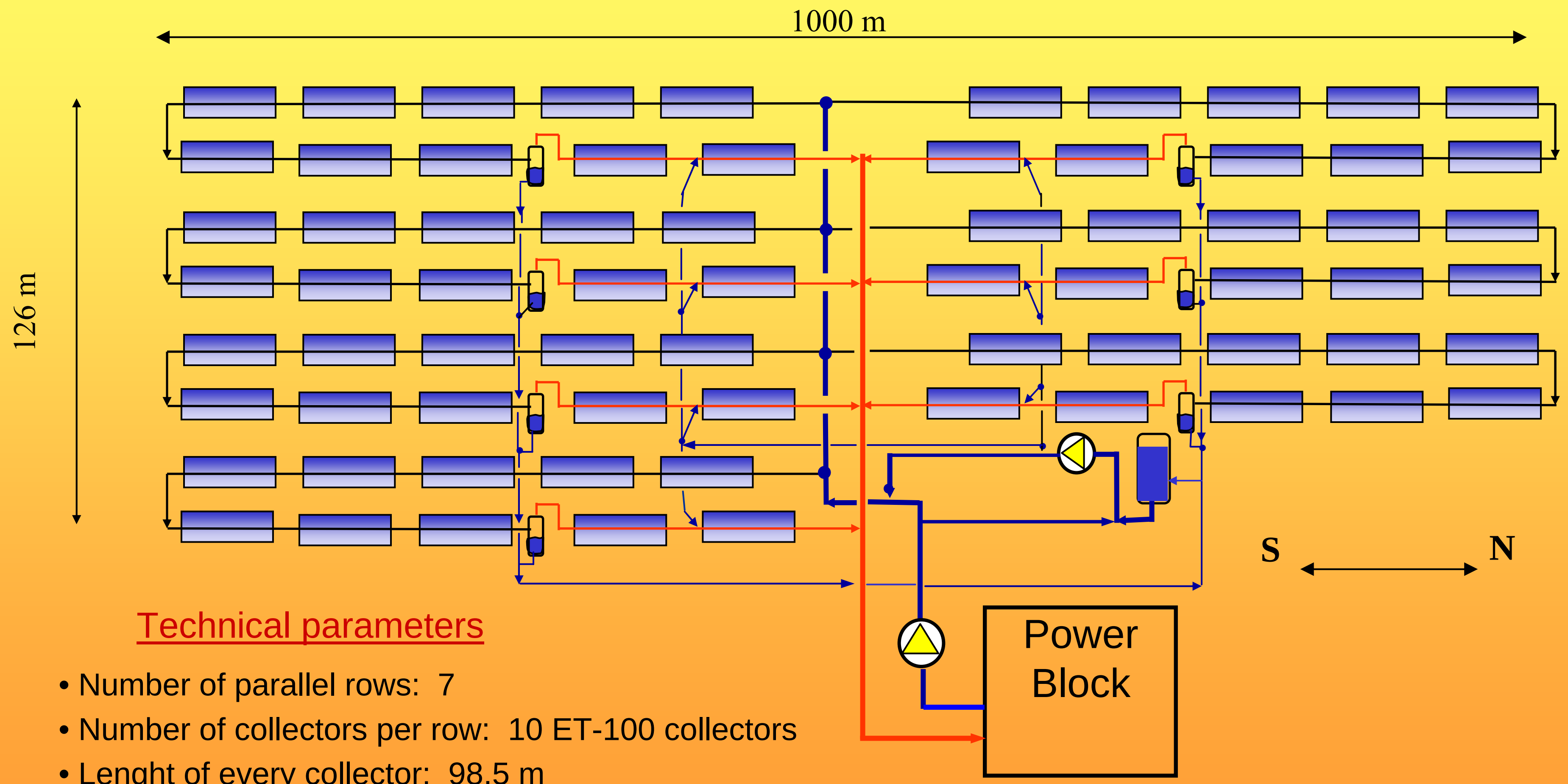
Power block parameters

Manufacturer	KKK
Gross power (kW_e)	5472
Net power (kW_e)	5175
Gross efficiency (%)	26.34
Net efficiency (%)	24.9



The First DSG Pre-commercial Solar Plant

Simplified Scheme of the Solar Field

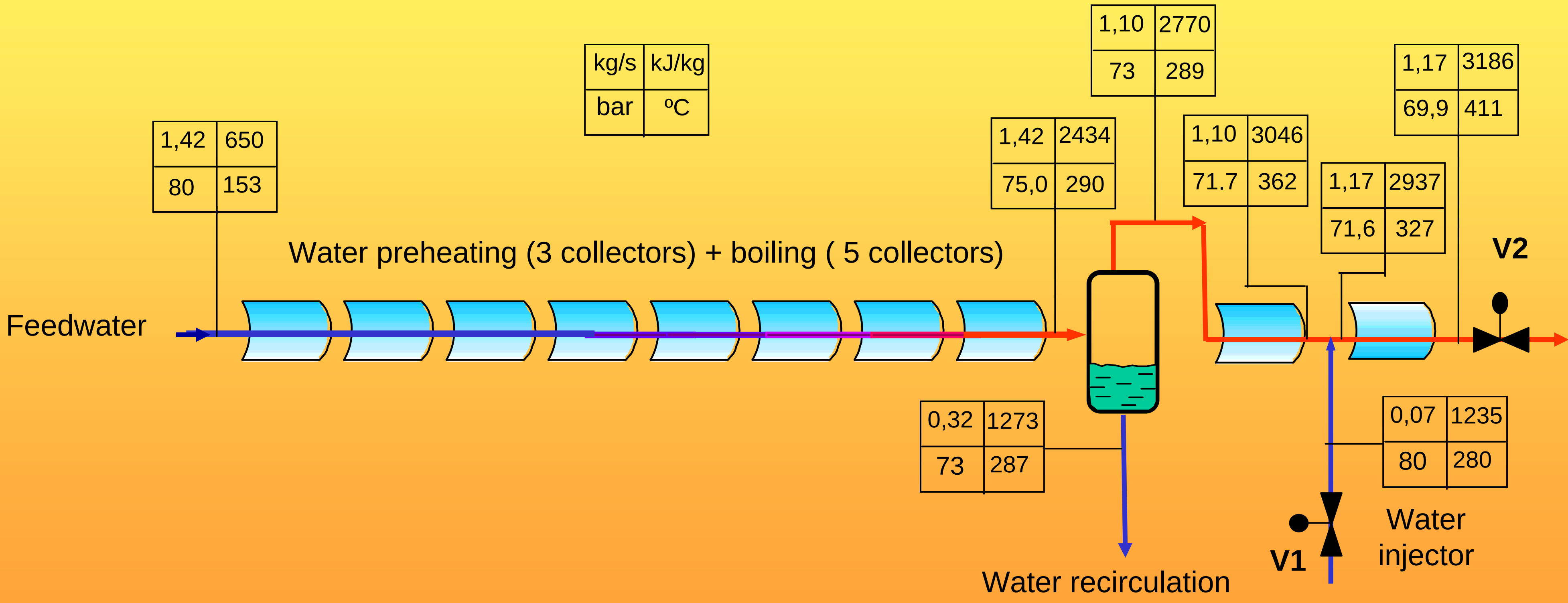


Technical parameters

- Number of parallel rows: 7
- Number of collectors per row: 10 ET-100 collectors
- Lenght of every collector: 98,5 m
- Parabola width: 5.76 m
- Total aperture area: 38384 m^2
- Peak Thermal power (E_d=1kW/m^2): 25 MW

The First DSG Pre-commercial Solar Plant

Scheme of a typical row of collectors

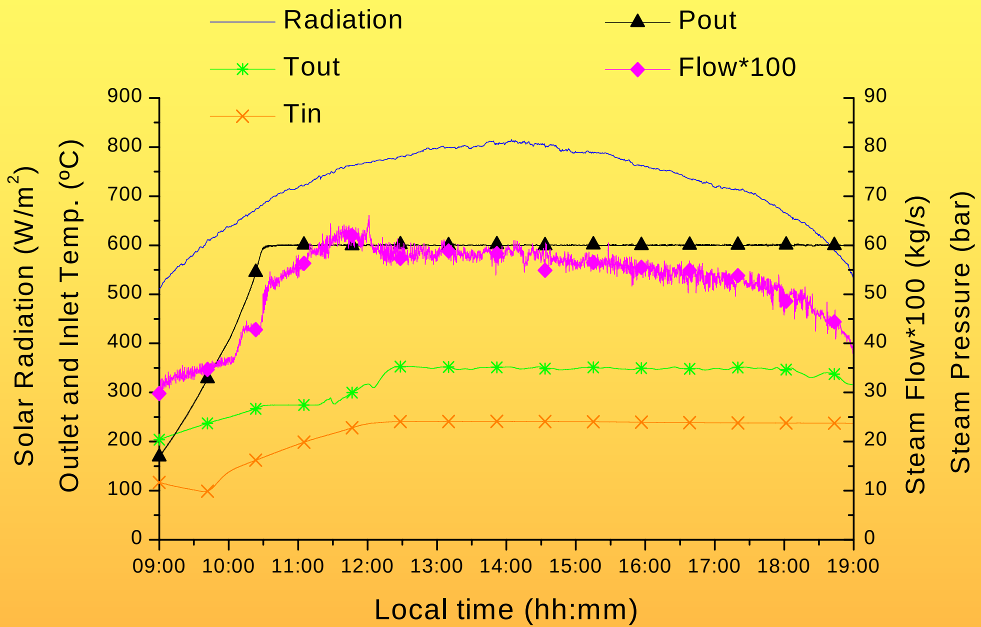


Simulation Results

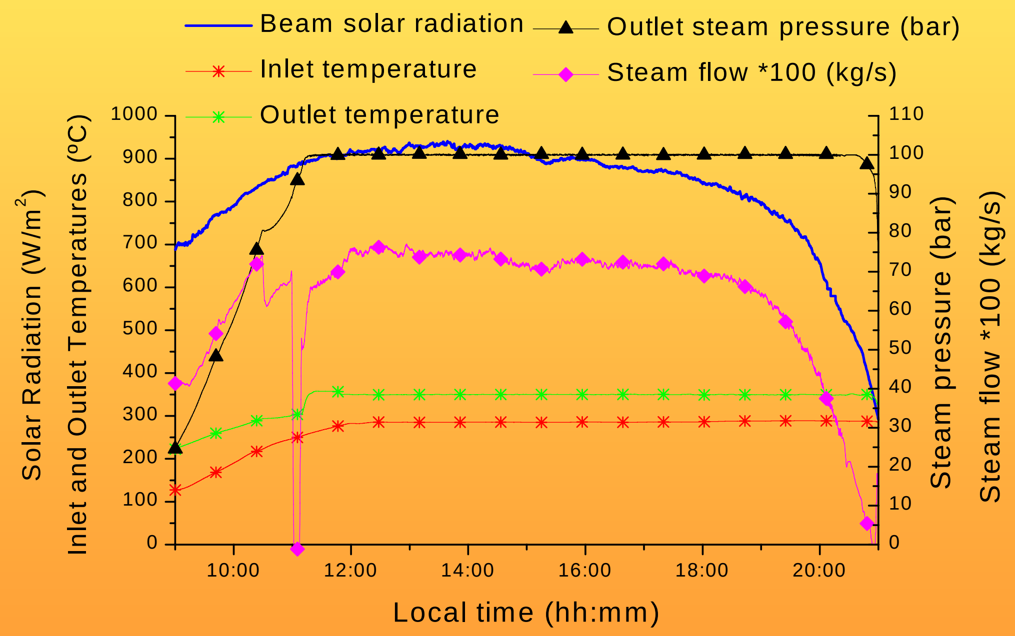
(Plant electrical net output power: 4,8 MWe)

- Yearly insolation (beam solar radiation): 2008 kWh/m^2
- Yearly number of sunlight hours: 3685 hours
- Yearly number of solar field operating hours: 2559
- Yearly net electricity production: 9431 MWh
- Equivalent full-load operating hours: 1949 hours
- Solar field average efficiency: between 61% (Summer) and 30% (Winter)
- Average steam production at the DSG solar field: 5,1 kg/s (70,6% of nominal value)

Steam Parameters Control



Steam Production at 60 bar (11/07/2001)



Steam Production at 100bar (05/07/2001)

CENTRAL RECEIVER TECHNOLOGY

OBJECTIVES:

- ✓ This technology concerns high-temperature applications: T > 400ºC
- ✓ Improve the overall economics of solar power tower plants by reducing the costs of the main system components and simplifying O&M procedures.

CENTRAL RECEIVER TECHNOLOGY

OBJECTIVES:

- **Development of low-cost heliostats:**
  - ✓ **Prices under 140 €/m²**
  - ✓ **Reflected beam quality better than 2.4 mrad**
  - ✓ **New stand-alone concepts in wireless communications and photovoltaic energy supply**

CENTRAL RECEIVER TECHNOLOGY

OBJECTIVES:

- **Development of volumetric air receivers:**

  - TSA volumetric receiver, 2.5 MW based on metal mesh;

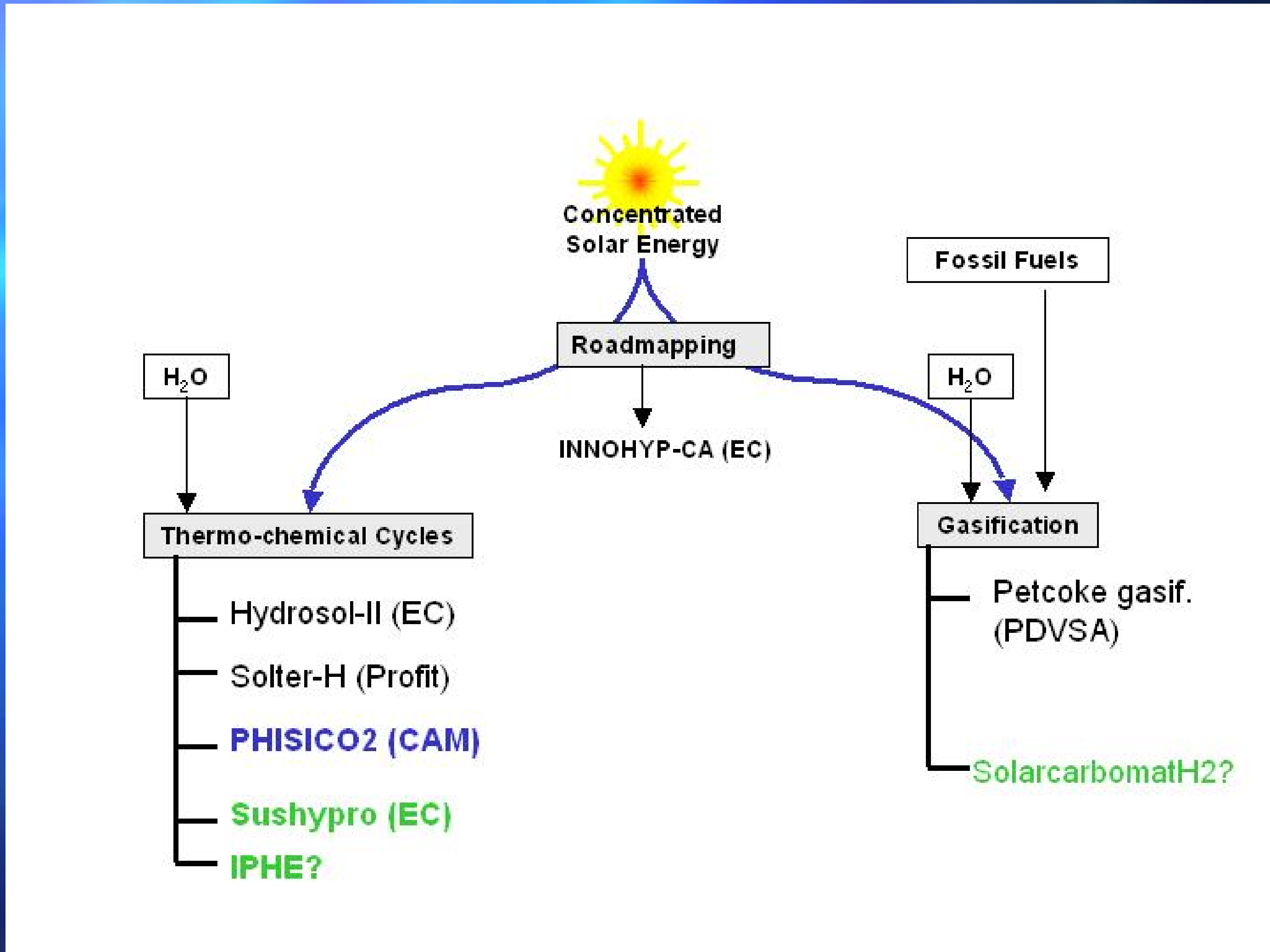
  - SOLAIR high-flux, atmospheric-pressure ceramic receiver (1000ºC) at 250 kW and 3 MW;

  - REFOS pressurized-air receiver (15 bar / 850ºC) and integration of gas turbine: SOLGATE/HST

- **Development of molten salt receivers**

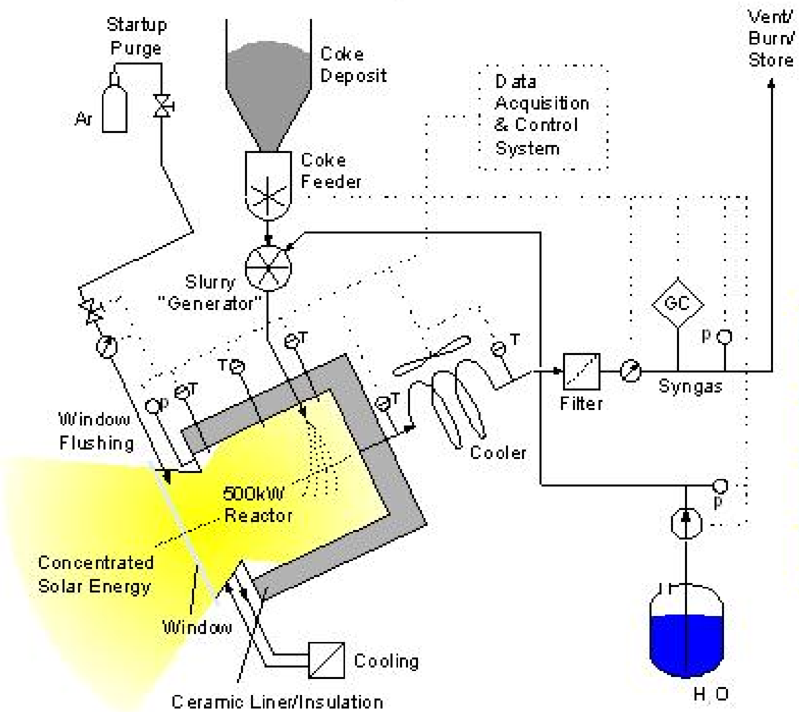
- **Development of super-heaters for water-steam receivers**

SOLAR HYDROGEN: CURRENT PROJECTS



SOLAR HYDROGEN: THE 'PDVSA' PROJECT

Phase II: Layout of 500-kW experimental



Capacity:

Scaling-up and testing

Molar ratio W/C	(n=1.0/1.5/2.0)
Coke Consumption	40 / 34 / 29 [kg/h]
Water Consumption	60 / 75 / 87 [kg/h]
Syngas Production	149/125/108 [m³/h]
Syngas Therm. Power	480/400/350 [kg/h]

R & D UNIT

ENVIRONMENTAL APPLICATIONS OF SOLAR ENERGY AND CHARACTERIZATION OF THE SOLAR RESOURCE

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Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

Plataforma Solar de Almería:
The European Solar Thermal Test Centre.
Geneve. 30 March, 2006

DETOXIFICATION OF POLLUTED WATER

PHOTONS → **REACTION**

PHOTONS → **CATALYST** → **REACTION**

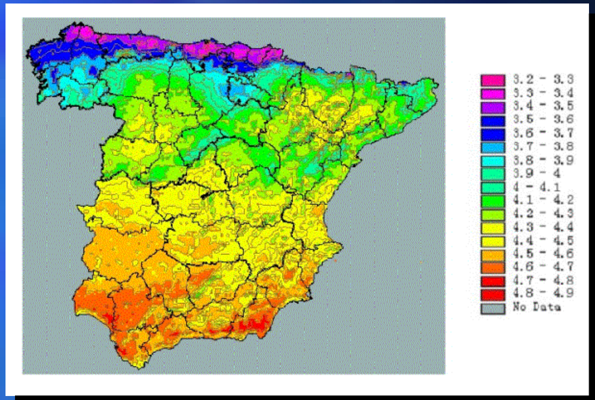
Use of the ultraviolet band of the solar spectrum, not thermal processes.

- **<u>Solar photocatalytic detoxification</u> Projects: SOLARDETOX, LAGAR, ALBAIDA, CADOX, etc.**
- **<u>Solar Disinfection</u> Projects: SOLWATER, AQUACAT…..**

SOLAR DESALINATION

- ✓ European AQUASOL project : Its purpose is coupling multi-effect distillation (MED) with a double-effect absorption heat pump and solar technology. Zero waste.
- ✓ Spanish SOLARDESAL Project : Hybrid technology based on solar energy from stationary collector and natural gas.

MEASUREMENT AND CHARACTERIZATION OF SOLAR RADIATION



Measurement of solar radiation:

- Development and management of solar radiation databases
- Methodologies focused on the determination of design parameters in solar systems
- Calibration of solar radiation specific instruments

Characterisation of the solar spectral distribution:

- Spectral-radiometer for continuous measuring of the spectral content of solar radiation components.
- Laboratory for spectral calibration

Solar radiation calculation from satellite images (spatial distribution):

- Development of statistical models to estimate the solar radiation
- Models and visualization of information by using Geographic Informatio Systems

TRAINING AND ACCESS

TWO MAIN ACTIVITIES:

- ✓ **Management of the PSA student programme (University of Almería, Leonardo da Vinci, etc.), courses and dissemination activities.**
- ✓ **European Commission Programmes concerning 'Access to Large Installations and Mobility of Researchers'.**

TYPE OF GRANT	2002	2003
UAL – Doctorate	6	7
UAL – Undergraduate	9	9
Leonardo da Vinci	5	4
Others	4	11

Number of grants at the PSA

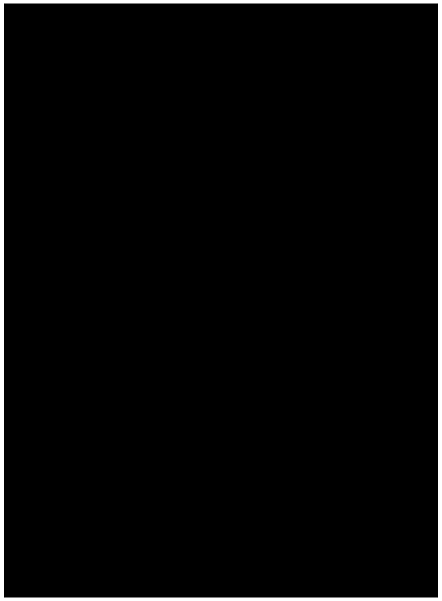
PROGRAMA 'IHP'	2002	2003
Projects	16	20
Visitors	26	53
Days of visit	438	808
Weeks of use	53	70

Access by European Research Groups to the PSA test facilities through EC programmes

A Short History

- Nine parabolic trough plants (SEGS) in commercial operation at California: 354 Mwe
- Last of them was finished in 1992.
- And after.........

354 MWe



0 MWe

Something is Moving in Spain

- **A new legal framework for renewable energies has been approved on last March.**

- **There were several commercial projects 'on standby'.**

- **Besides, the PLATAFORMA SOLAR DE ALMERÍA (PSA), stands in the breach of demonstration projects, keeping the interest alive.**

NEW FEED-IN TARIFFS FOR R.E. IN SPAIN

Royal Decree 436/2004 of March 12th

Principles:

- Contribute to sustainable development and to meet Kyoto's committtments.

- Set a stable, long-term, objective and transparent legal framework for IPPs

OPTIONS FOR SOLAR THERMAL POWER PLANTS IN SPAIN

a) TO SELL THE ELECTRICITY TO THE DISTRIBUTOR

The producer will receive:

- A percentage of the <u>Average Reference Tariff</u> (ART) defined in RD 1432/2002. Payments go down as installation is getting older.

- Supplementary payment for reactive energy.

Selling option can be revised by annual periods

b) TO SELL DIRECTLY IN THE ELECTRITY STOCK MARKET (daily, fixed-term periods or by bilateral contract)

The producer will receive:

- Market price

- Premium which is a percentage of ART

- Incentive which is a percentage of ART

Alternatives of economical regime (RD 436/2004)

a) Regulated Tariff (Art. 22.1.a):

- Selling electricity to distributor. Selling price is a percentage of ART. Tariff is unique for all market program periods.
- <u>It is compulsory to supply production predictions</u>.

Payment: % ART + Reactive (between +8% and –4%) - Deviations

Advantages:

✓ Well known Prices Scheme

✓ Less volatile premiums

Disadvantages:

✓ Deviation costs (10% ART)

✓ Less profitability than market option

Alternatives of economical regime (RD 436/2004)

b) Going to the electricity stock market:

- Operating as/through a market agent and joining the market.

Payment: Pool market price + Premium + Incentive + Reactive (between + 8% and –4%)

Advantages:

✓ No deviation cost

Disadvantages:

✓Adapt to market agent capabilities.

✓Higher risk because of variations of pool price (hydropower fluctuations, weather influence, fuel prices,...)

Royal Decree 436/2004

- **Fossil fuel backup:** Natural gas or propane, only to keep the temperature in the storage system.

  – Regulated Tariff Option: 12% Yearly Electricity Production

  This backup to be used at non-generating periods, only.

  – Market Option: 15% Yearly Electricity Production

  Backup can be used at any time.

Royal Decree 436/2004

- **Deviations (only applicable to 'tariff option')**: For 10 MW STPP, commitment to communicate the distributor electricity production forecasts 30 hours beforehand for 24 periods per day:
  - ✓ Tolerance 20%
  - ✓ Monthly Deviation Costs=10% ART (Σ Deviations over tolerances)

- **Tariffs, Premiums and Incentive Revisions (only applicable to new plants):**
  - ✓ First in 2006, afterwards each four years
  - ✓ After first 200 MW

Tariffs, premium and incentives: New R.D.

- Regulated tariff:

  ✓300 % of ART (First 25 years) – 240% (from 26th year)

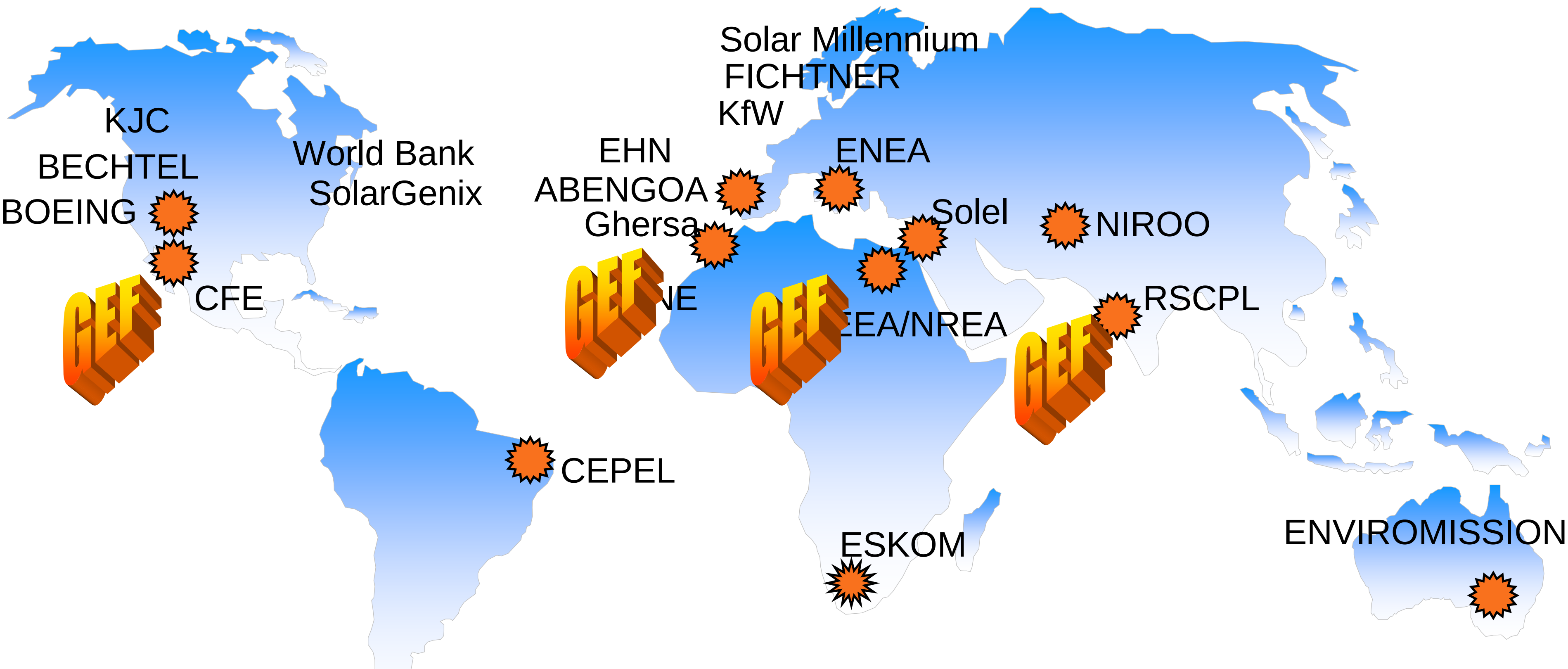
- Electricity stock market:

  ✓Premium: 250 % of ART (First 25 years) – 200% (from 26th year)

  ✓Incentive: 10% of ART

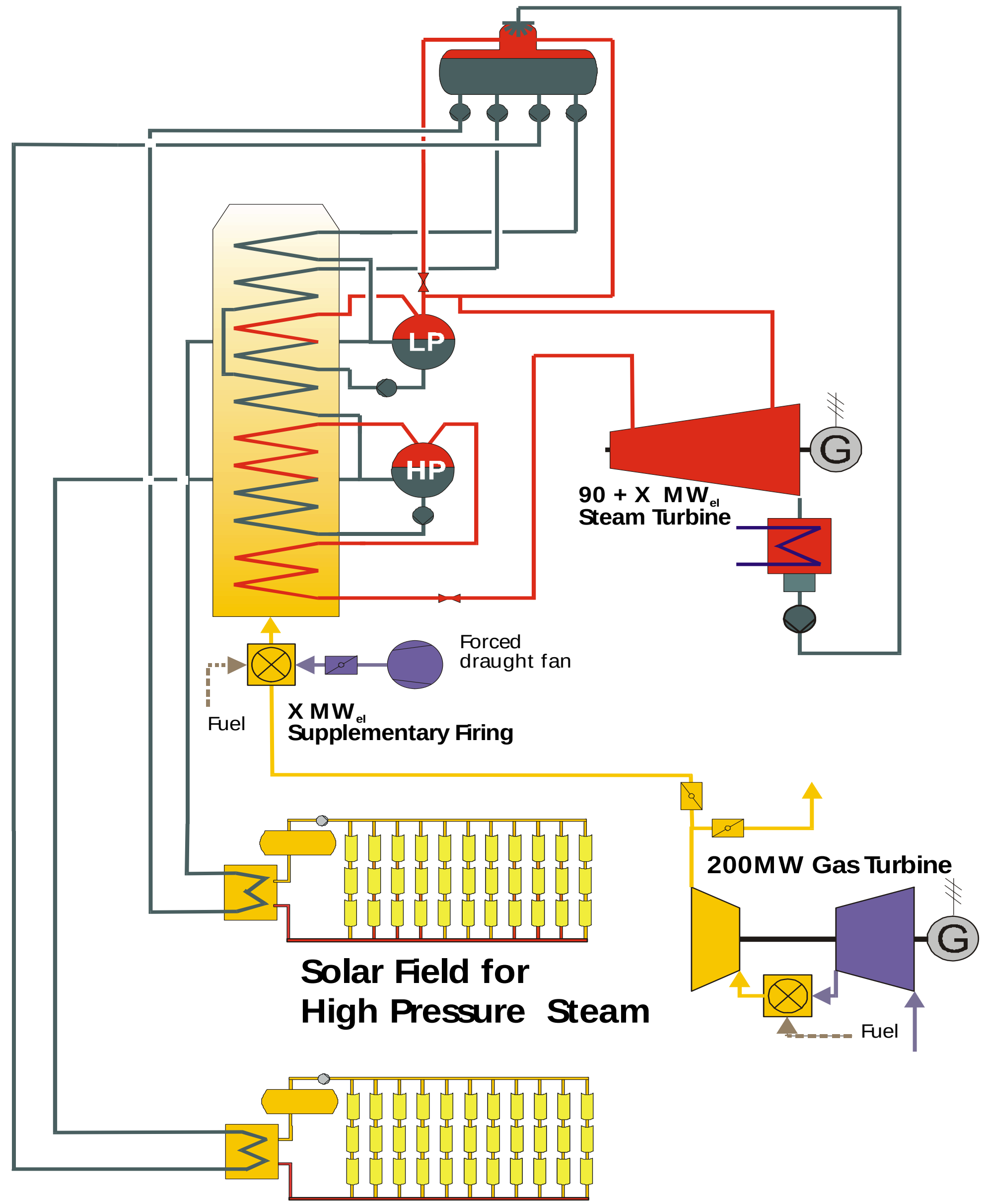
ART: 7.2072 c€/kWh for 2004)

Current Commercial Projects on the World



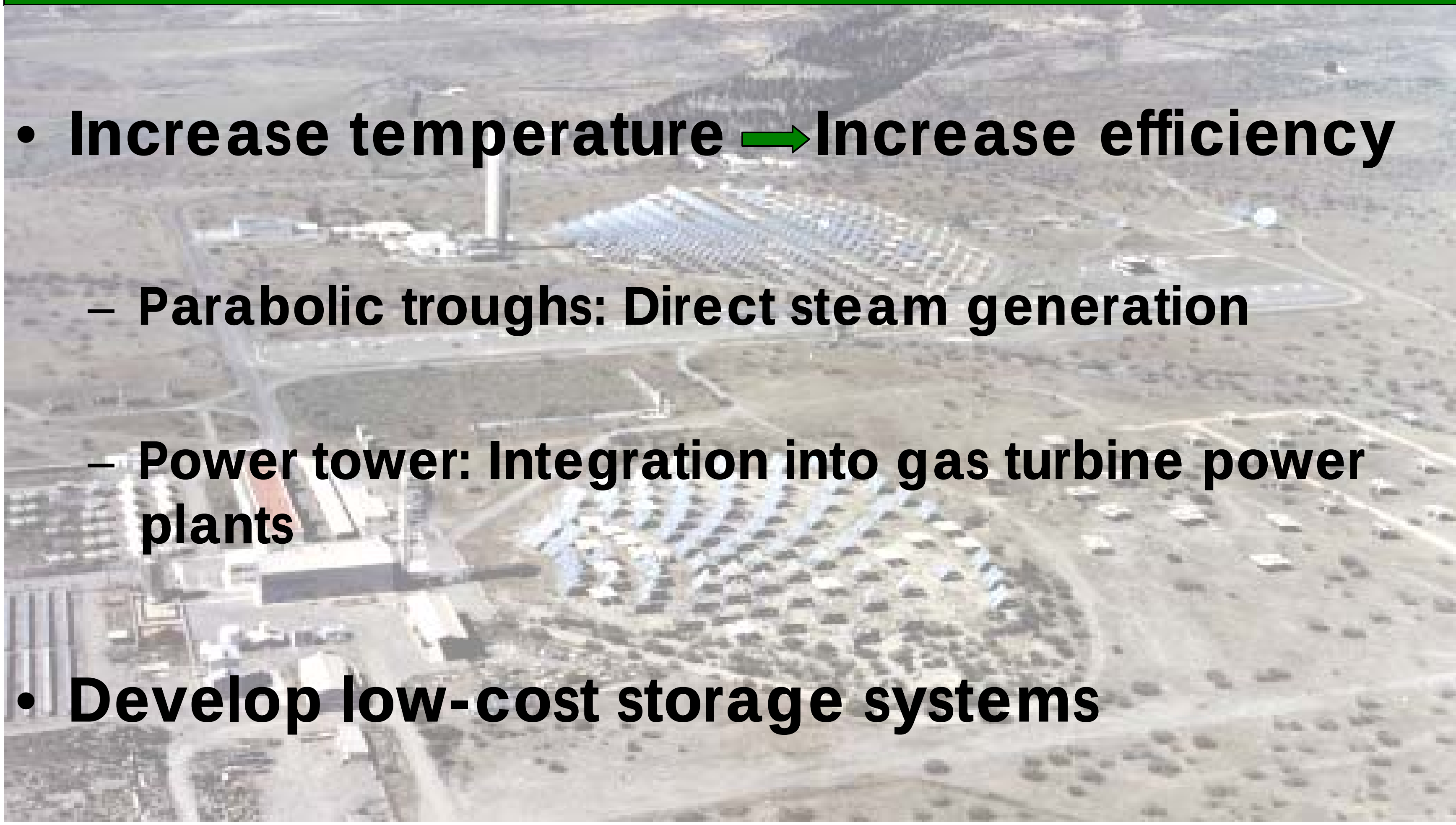
LOCATION	Cycle	Solar Technology	Solar Capacity MW	Aperture [m^2]
Egypt	Combined Cycle	Trough	35	200’000
India	Combined Cycle	Trough	35	200’000
Mexico	Combined Cycle	Investor’s Choice	>25	200’000
Australia	Combined Cycle	CFLR	35	132’000
South Africa	Steam Cycle	Tower	100	?
USA	Steam Cycle	Trough	50	300’800
Israel	Steam Cycle	Trough	100	500’000
Spain	Steam Cycle	Trough (Andasol)	50	549’360
Spain	Steam Cycle	Tower (*PS10*)	10	88’290
Spain	Steam Cycle	Tower (*Solar Tres*)	15	240’000
Italy	Steam Cycle	Trough (Molten salt)	40	451’215

International CSP Projects are seeking Support from the Global Environmental Facility (GEF) in the framework of Operational Program No.7



The ISCCS Concept

What can <u>we</u> do to decrease costs ?



- **Increase temperature → Increase efficiency**
  - **Parabolic troughs: Direct steam generation**
  - **Power tower: Integration into gas turbine power plants**
- **Develop low-cost storage systems**

Direct Steam Generation

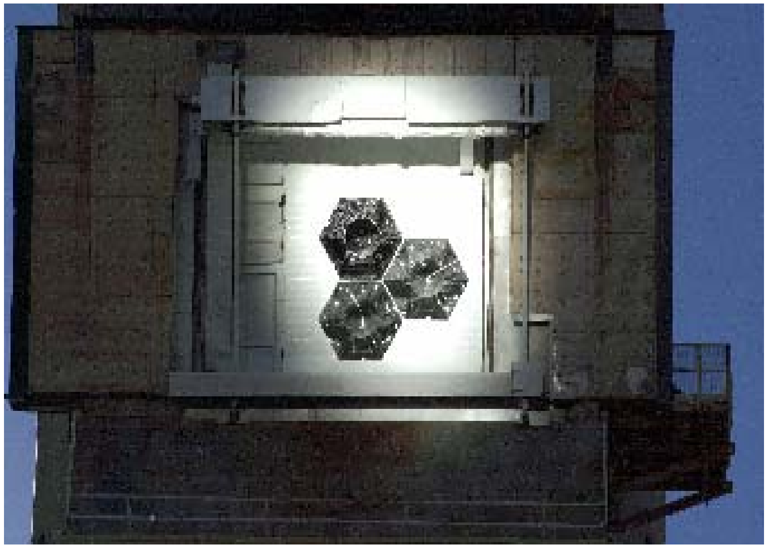
- **It's necessary to develop**:
  - **a selective absorber coating, stable up to 550ºC**
  - **a suitable storage system**
  - **a low-cost water-steam separator**

Project INDITEP at PSA

Power Tower Technology

- Pressurized-air receivers, able to feed a gas turbine.

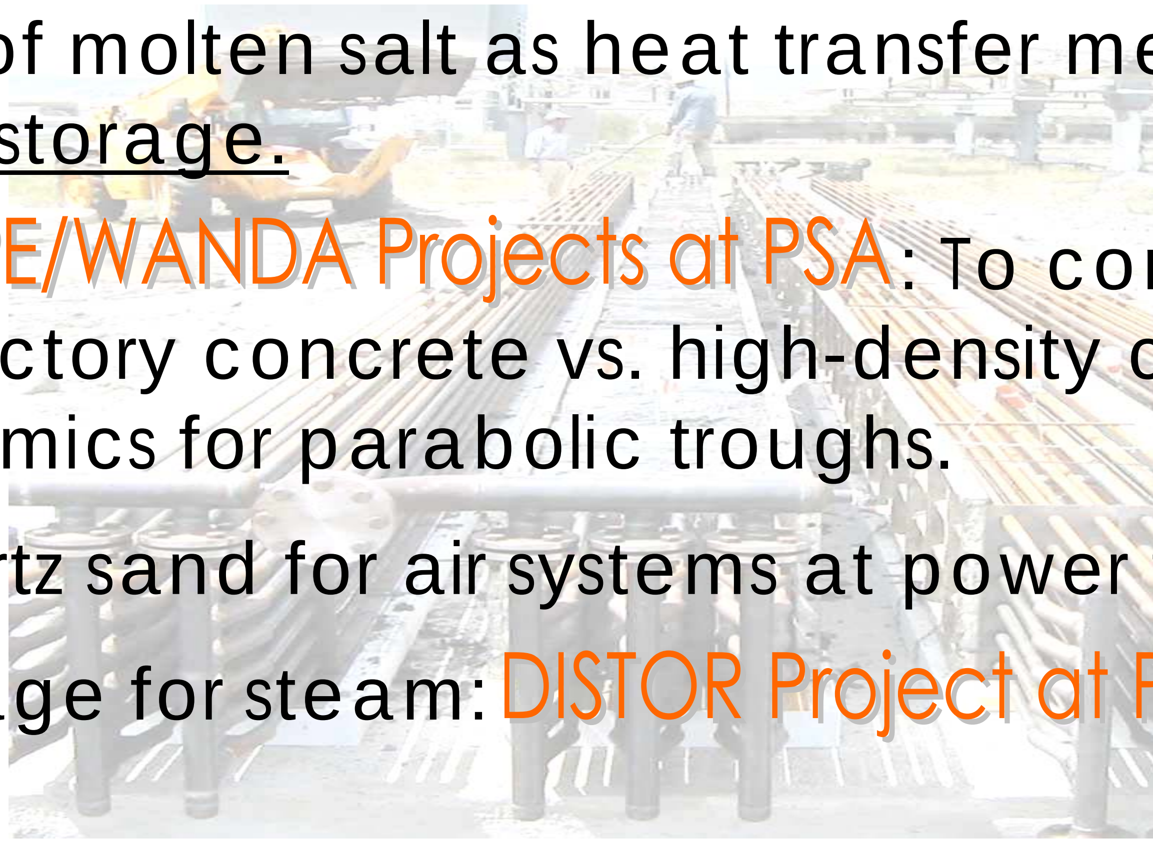
Project SOLGATE at PSA



Storage Systems

- **A set of minimum requirements:**
  - **90% efficiency**
  - **30 year life time**
  - **investment cost below 20 €/kWh of thermal capacity**

Storage Systems



- Use of molten salt as heat transfer medium and storage.
- WESPE/WANDA Projects at PSA: To compare refractory concrete vs. high-density castable ceramics for parabolic troughs.
- Quartz sand for air systems at power towers
- Storage for steam: DISTOR Project at PSA

Conclusions

- **<u>Let's be optimistic</u> !!**

Several good reasons for that:

- The new R.D. 436/04 in Spain: Earliest plants soon

- The financial support from GEF/WB

- Entry into force of Kyoto's Protocol

- Global Market Initiative (GMI), for 5.000 MW by 2015, just signed at the Bonn Conference by 6 countries.

For further information........

www.psa.es

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