SENER

Engineering and Systems Inc.

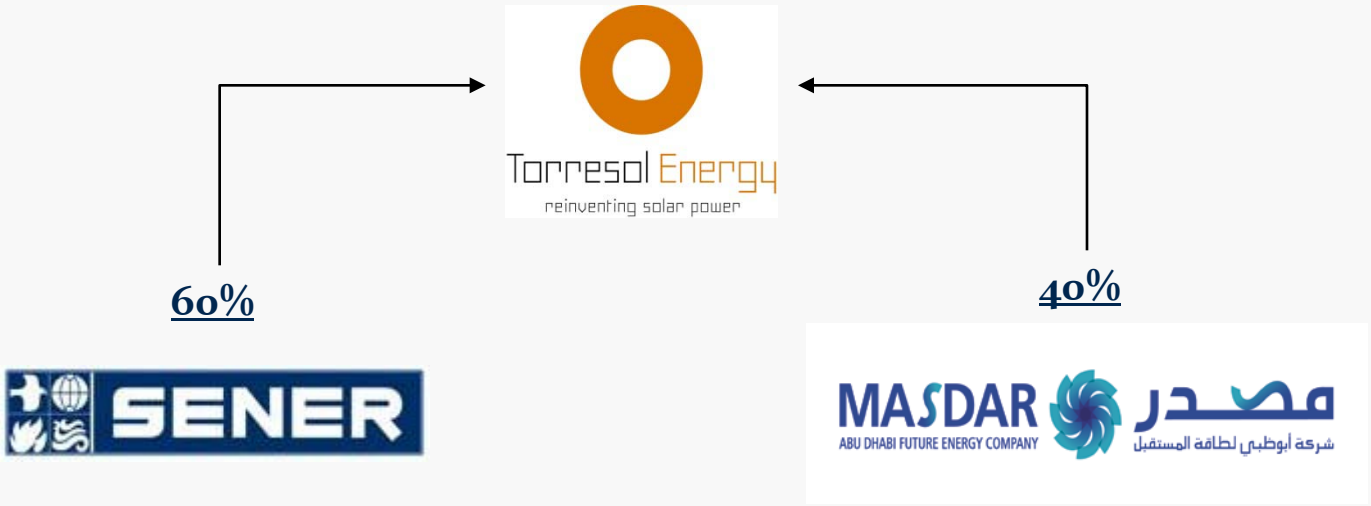
Case Study: GEMASOLAR Central Tower Plant

CSP today

San Francisco
24&25 June 2010

Table of Contents

1.-Introduction



Founded in 1956, SENER is the largest privately owned engineering company in Spain. The company is recognized for its capacity to deliver innovative and highly complex multidisciplinary projects.

Owned by the government of Abu Dhabi (UAE) through the Mubadala Development Company, Masdar is committed to developing and delivering future energy solutions.

Joint Venture Agreement signed March 12th, 2008

GEMASOLAR – Central Receiver Plant 17 Mwe.

1.-Introduction

GENERAL DATA	
Name of the Plant	GEMASOLAR
Location	Fuentes de Andalucía - Sevilla (Spain)
Owner	TORRESOL
Role of SENER	EPC JV partner and Technology Supplier + supplier of receiver and heliostats drives
Status	In construction
Start of operation	Apr. 2011
TECHNICAL DATA	
Number of heliostats	2.650
Nominal receiver capacity	120 MWt
Tower height	147 m
Thermal Storage Capacity	15 h
Turbine capacity	17 MWe
Thermal Cycle Efficiency	40%
Annual normal direct radiation	2.172 KWh/m2
OPERATION	
NG hibridation	15%
Annual equivalent hours	About 6.500 h/year
Annual Capacity Factor	About 75%

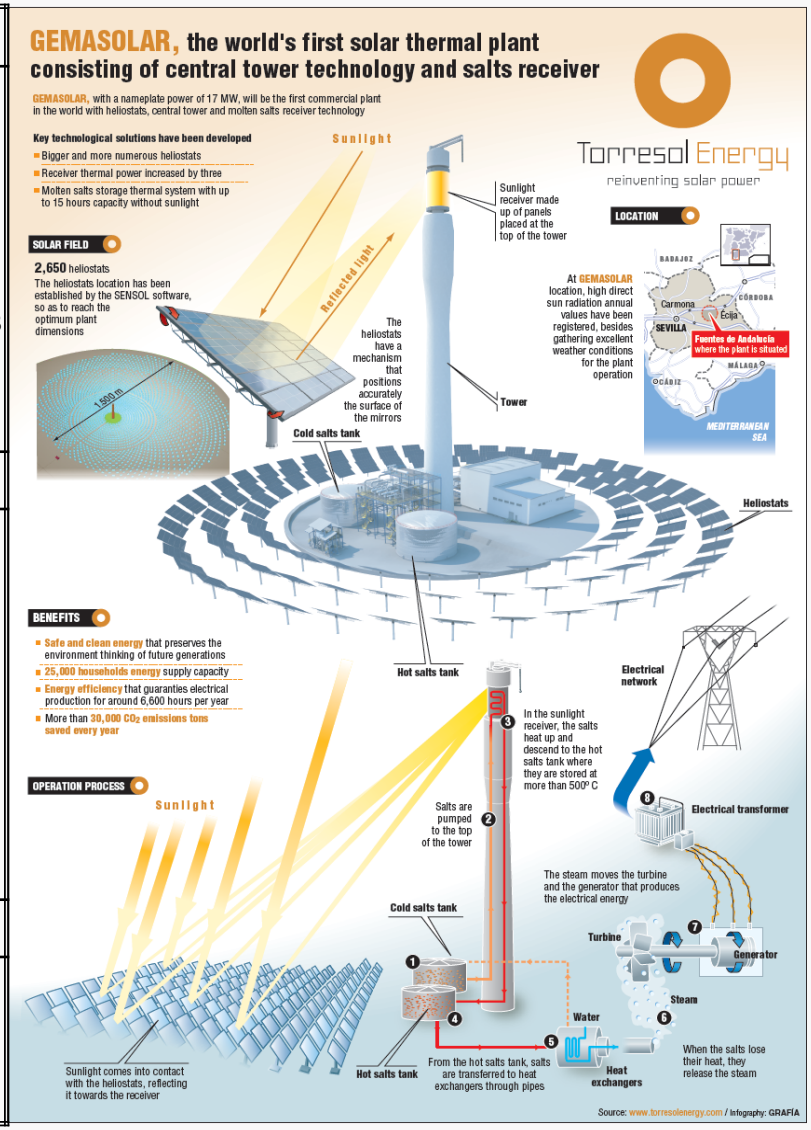


Table of Contents

2.- Main advantages of Central Tower with Molten Salts Receiver Technology

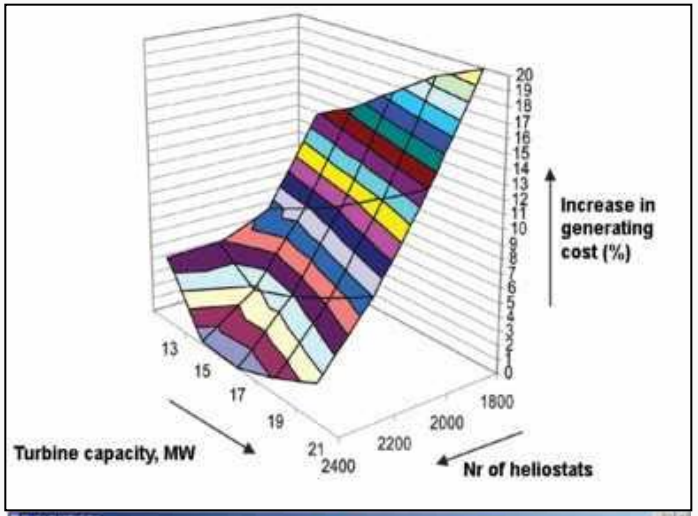
- The same HTF is used for collection, transport and storage of the thermal energy.
- The high operating temperature of the molten salt allows the operation with high steam conditions, leading to high thermal cycle efficiencies
- The high difference between the maximum and the minimum operating temperature of the molten salt in this technology, allows a significant reduction of the storage volume (the energy stored per kg of salt with the central tower technology is three times the energy stored per kg of salt with the parabolic trough technology).
- Elimination of the oil-molten salt heat exchangers
- Two axis tracking allows for better sun capture, specially in winter
- Reduced piping length and subsequent thermal losses
- Solar energy collection and electrical energy production are “independent” processes. The power block always operates at design load (except when desired by any special reason).
- Very high utilization factors (close to 75%) can be achieved with this technology with economically-efficient configurations.
- Hybridization with NG is possible, providing also an additional support to the reliability of the generation.

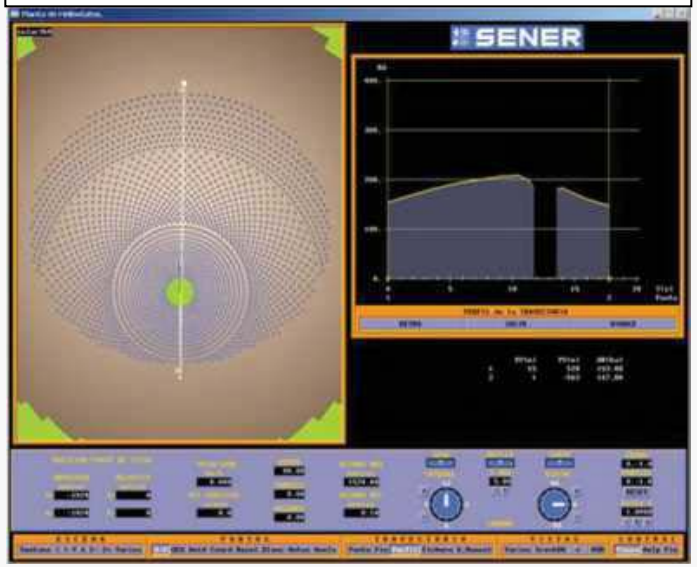
Table of Contents

3.- Gemasolar Design: Main elements

A. SENSOL

- The plant configuration and the sizing of the different components and systems has been optimized with SENSOL, CSP simulation Software developed by SENER.
- SENSOL is an extremely flexible and powerful tool to design and optimize solar plants, components and systems.
- It allows the simulation of different plant operating strategies to maximize the plant output.
- Its economical module analyzes the result of different plant configurations, looking for the minimum levelized energy cost, that is, maximizing the financial return.
- It allows also for optimization of component parameters, like heliostat structure stiffness, mechanism pointing errors, etc…
- It allows for the definition of performance guaranteed values which allow project bankability





3. Gemasolar Design: Main elements

B. MOLTEN SALT RECEIVER

- Molten salt central receiver of high thermal efficiency, able to operate at high fluxes without compromising the life (at least 25 years)
- Receiver size optimized to minimize thermal losses in the plant
- Small fluid cavities to maximize efficiency and minimize the HTF conducts volume, the costs of the receiver and the pumping power consumption
- Thin-walled conductions to improve efficiency
- Design that minimizes pressure losses in the salt circuit
- Optimized number of panels and molten salt circuit routing
- Innovative integral header and advanced header-tube nozzle (SENER patents) to improve reliability and life
- High nickel alloy material with excellent mechanical properties
- Definition of procedure and operation modes to assure the receiver life and to optimize the plant efficiency

3. Gemasolar Design: Main elements

C. TURBINE

- Guaranteed output: 17 MW
- In spite of the small size:
  - ✓ High steam conditions, comparable with any modern utility scale power station (100 bar/538 ºC/538 ºC)
  - ✓ Single reheat
  - ✓ The use of molten salt as HTF (vs. oil) allows for the generation of high temperature steam
  - ✓ Although the fuel is free, the investment costs to capture solar energy justify the interest in reaching high efficiency cycles.
  - ✓ The plant will demonstrate the commercial operation of a reheat turbine with molten salt steam generation systems.
  - ✓ The use of a 15 hrs TES significantly reduces the number of start-up/shut-down cycles.

3. Gemasolar Design: Main elements

D. HELIOSTATS

- SENER started its activity in the solar power field in 1978, with the development of one of the first heliostats operating in the World
- First heliostats installed 1980 in the CESA 1 field, at the Spanish solar research center Plataforma Solar de Almería (PSA), where they still keep performing satisfactorily
- Optimized structure to reduce the Heliostat cost maintaining the optical performances:
  - ✓ Reduced mass
  - ✓ Construction friendly
  - ✓ Reduced manufacturing costs
- New facet based on stamped steel and reduced mirror thickness (SENER patent in process)

3. Gemasolar Design: Main elements

E. DRIVE MECHANISMS

- The two axis drive is relevant plant component:
  - ✓ High pointing accuracy, high load capacity, reliability, stiffness, low maintenance, high efficiency and operation during 25-30 years
  - ✓ Large impact on energy production→ plant profitability
  - ✓ Construction friendly
  - ✓ Reduced manufacturing costs

- Apart from Gemasolar, SENER Solar Tracker has been installed in:
  - ✓ CESA I (PSA): 300 Heliostats in total, 150 operating since 1980
  - ✓ ISFOC, CENER: CPV Solar Tracker for IEC 62019:07normative
  - ✓ LASESA:720 PV Solar Trackers

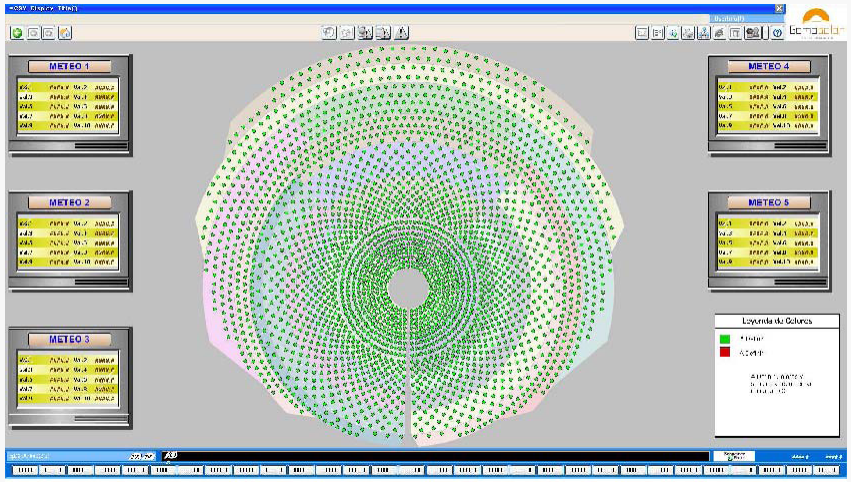
- Applicability to Heliostats, CPV and PV modules as well of Stirling

- Product developed and manufactured by SENER

3. Gemasolar Design: Main elements

F. SOLAR FIELD CONTROL SYSTEM

- Innovative 360 º field control system
- Minimization of power consumption for drive actuation
- Optimization of solar flux incidence on the receiver
- Optimization of solar field depointing, going to safe position and (of course) nominal operation mode
- Reliable weather forecast prediction and cloud management integrated in the system



3. Gemasolar Design: Main elements

G. THERMAL STORAGE SYSTEM

- Thermal storage equivalent to 15 h of turbine operation
- 75% plant capacity factor (more than 6.500 h of operation per year)
- Capability to decouple energy production from delivery
- Turbine working always at design load→ higher efficiency
- Significant reduction of the number of turbine start-up operations throughout the year
- Volume required to store energy is 1/3 that of Parabolic Trough plants with thermal storage
- Higher molten salt temperature→ higher efficiency of the thermal cycle

Table of Contents

4. Plant Construction Status

- Overall Project progress close to 70%
- Engineering and Procurement activities finalized
- Construction of the power block beyond 50%
- Slight delay in the Solar Field due to heavy rain in Southern Spain this year. Can be recovered now with additional shifts
- Receiver panels on top of the tower. Work on this unit to be finalized by mid- July
- Plant operation still planned for April 2011

4. Plant Construction Status

Receiver panels lifting operation

2 first panels erection

4. Plant Construction Status

Structure buiding for deaerator and feedwater preheaters

Detail of progress of steam turbine mechanical erection

Gas fired salt heater erection

Table of Contents

5. Next Steps

- Significant R&D effort both to optimize concepts already in operation as well as to investigate new promising solutions:
  - ✓ Central Tower with Molten Salt :
    - Development of 240 MWth and 360 MWth receivers
    - Plant optimization with Sensol for these concepts (scale factor leads already to LEC reduction)
    - Next generation of higher thermal power receivers with improved solar field design (new concepts for Heliostats: structure, drives and facets plus improved solar field control system)
    - High fidelity accurate simulation: improved performances prediction
  - ✓ Other developments:
    - Single tank molten salt thermal storage
    - Solid thermal storage for higher temperatures (DOE support)
    - Innovative system for heliostat mirror cleaning
    - Etc.
- Comercial effort to deploy the next generation of towers in different countries throughout the world

The way to see the future