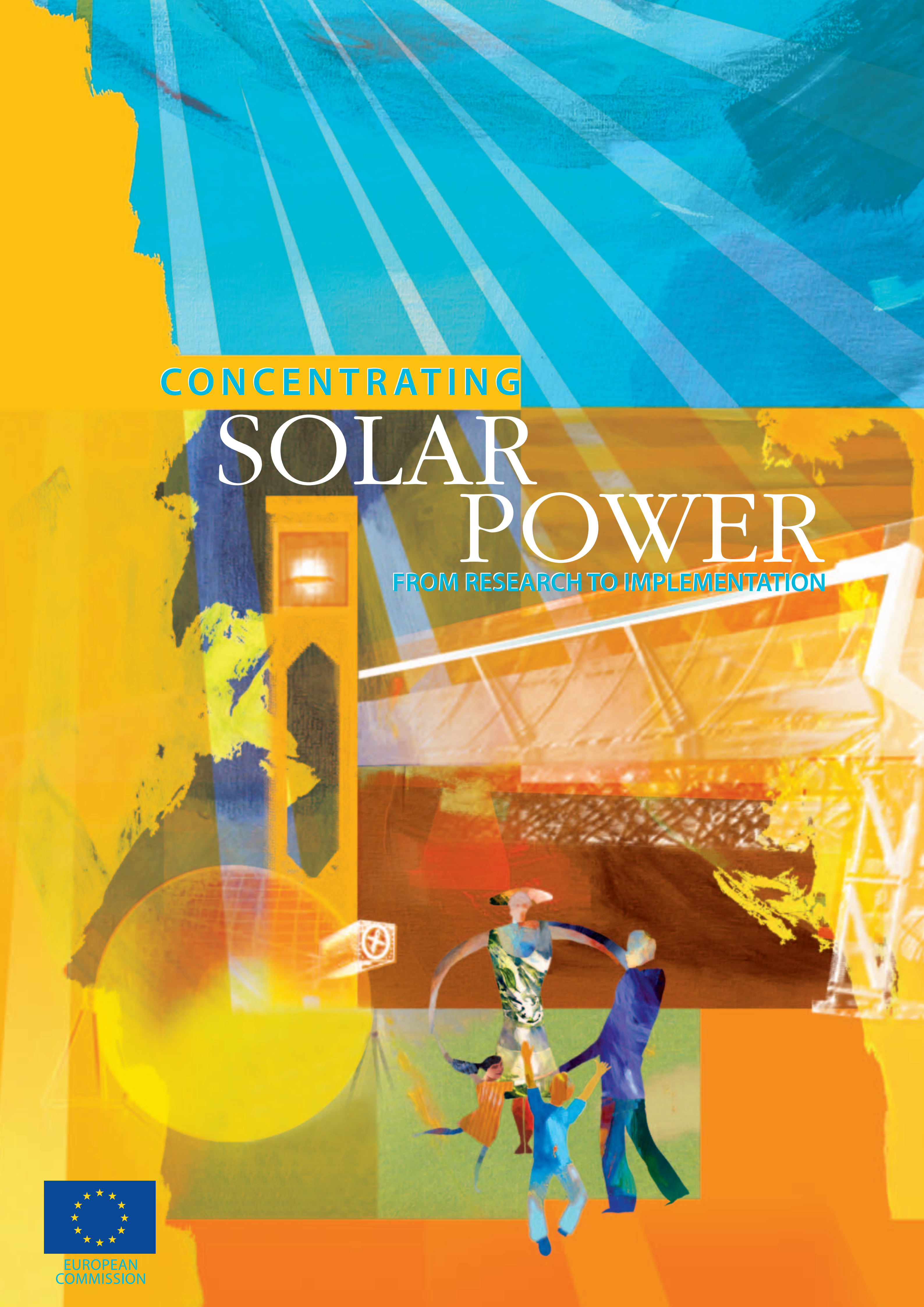
CONCENTRATING SOLAR POWER

FROM RESEARCH TO IMPLEMENTATION



EUROPEAN COMMISSION

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Directorate - General for Energy and Transport

Directorate - General for Research

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A wider exploitation of renewable energy sources is a key priority for the European Union (EU). Along with energy efficiency, the development of renewables is part of the EU's strategy to enhance its security of energy supply, boost industrial competitiveness and promote economic and social development.

Renewable energy sources are an integral part of the new energy policy for Europe. Implementation of the existing directives on green electricity and on biofuels should allow the EU to reach ambitious targets for the share of renewables.

We need to move towards greater market penetration of these energy sources over the coming decades. To do this, the European Commission, following the conclusions of the European Council of 8 March 2007, plans to set ambitious objectives under a long-term road map, while respecting market mechanisms.

A major issue for the development of renewables is the further reduction of their costs. A two-track approach is needed on this score:

- More effective and targeted support schemes, to improve the environment for private investments and move faster along the learning curves of the renewable technologies;

- More and better research, to develop and demonstrate new and innovative technological solutions.

In this context, wind is a clear EU success story and good progress has been made in biomass and photovoltaics. The potential contribution of Concentrating Solar Power plants to a more sustainable energy system has still to be exploited.

The EU has been supporting the Concentrating Solar Power sector for more than ten years. This effort has made it possible to:

- research, develop, validate, demonstrate and disseminate the performance of Concentrating Solar Power technologies;

- maintain and develop the knowledge stock (human capacity) in Concentrating Solar Power technologies in Europe in both the public and private sector;

- improve the learning curves of the different technological approaches to Concentrating Solar Power.

Research, technological development and demonstration of a new generation of renewable energy technologies has an essential role to play in meeting growing energy demand and to allow Concentrating Solar Power technologies to become another EU success story.

Alfonso GONZALEZ FINAT

Director

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Director

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CONTENTS

"Concentrating Solar Power" in Europe

Renewable energies are centre stage as the European Union develops a new energy policy fit to ward off the potentially dramatic effects of climate change and reduce the EU's dependence on imported fossil fuels.

Inspired by the European Commission's wide-ranging package of energy proposals issued in January 2007, the EU has set ambitious energy targets that place a new emphasis on renewable energies and that will bring renewables firmly into the economic and political mainstream.

The EU intends to achieve a 20% share of renewable energies in its overall energy consumption by 2020. It is also targeting a minimum 10% share of biofuels in overall EU transport petrol and diesel consumption by 2020. Concentrating Solar Power (CSP) is a clean energy that can help the EU to meet its 20% target for renewable energies and its broader energy goals.

CSP technologies could make a significant contribution to developing a more sustainable energy system. This is especially so in areas which receive a high level of solar radiation, like some regions of Southern Europe, and in EU partner countries particularly in North Africa.

Indeed, it is for such reasons that the EU has already supported research into CSP technologies for many years, and with significant results – an effort that will continue into the future.

How it works

Solar power systems use the sun's rays – solar radiation – as a high-temperature energy source to produce electricity in a thermodynamic cycle. The need for Concentrating Solar arises because solar radiation reaches the Earth's surface with a density (kW/m^2) that is adequate for heating systems but not for an efficient thermodynamic cycle for producing electricity.

This means the density has to be increased, and the incoming solar radiation concentrated by using mirrors or lenses. The first commercial plants to do this have been in operation in California in the US since the mid-1980s, with 354 MW of solar power installed.

In the meantime, a variety of technological approaches have been developed for different market segments and which are at different levels of maturity. The main concepts used in CSP technologies are parabolic troughs, solar towers, or dish/engine systems (see box), which vary according to the concentration devices, energy conversion methods, storage options and other design variables.

Solar radiation can also be used to drive chemical reactions for the production of fuels and chemicals. Additional applications, aimed at a medium- to long-term horizon, include environmentally-friendly technologies in fields such as detoxification of chemical waste and energy storage.

EU research past and present

Under the 5th and 6th EU Research Framework Programmes (FP5 and FP6), the EU contributed some € 25 million to research projects working to develop CSP technologies.

This contribution has had a multiplying effect by leveraging a large amount of additional private investment worth several hundred million euro, in a ratio of about € 10 for each euro invested by the European research programme.

EU-funded projects – which are described in detail in the course of this brochure – constitute an important basis for further action by the European Commission and EU Member States. The evaluation of their results and their potential to substitute greenhouse gas-emitting electricity production will allow for a proper assessment of the benefits of CSP technology.

Several projects – centred on medium- to long-term research and backed by about € 10 million in EU funding – have studied CSP topics like components, storage, solar-hybrid co-generation, and solar chemistry including hydrogen production.

But it is also important to show that CSP technologies are not just something confined to the science laboratory, but something efficient and cost-effective enough to be put to use on a much larger, industrial or commercial scale. This is why EU-funded research projects have been geared to producing results that enable solar power to be scaled up in its application.

And this is why the EU is backing various demonstration activities in Europe to measure the benefits and the impact of deploying such technologies. A number of demonstration projects were launched under the Framework Programmes for Research, Technological Development and Demonstration of the European Union (FPs): the European Commission is supporting three major full-scale MW-size demonstration projects to the tune of € 15 million. These projects – described in the following chapter – aim to validate the full-scale application of different technological approaches and their economic viability under market conditions.

EU research moves into the future – FP7 and the Energy Technology Plan

The EU will continue to promote research into solar power in the years ahead, reflecting the strong interest in this technology. Solar research will be promoted within the 7th Framework Programme (FP7) that will run from 2007 to 2013.

The € 50 billion FP7 has four main components:

- **Cooperation** – Collaborative research in ten priority areas: € 32,413 million
- **Ideas** – European Research Council: € 7,510 million
- **People** – Human potential: € 4,750 million
- **Capacities**: € 4,097 million

A fifth specific programme under the Euratom Framework Programme concerns nuclear research, worth € 2.7 billion over five years 2007-2011.

Within the Cooperation part of FP7, € 2.35 billion has been earmarked for energy-related research projects, where development of renewable energy sources like solar power is carried out. More specifically, the Energy Theme includes research on renewable electricity generation (technologies to increase overall conversion efficiency, cost efficiency and reliability, driving down the cost of electricity production) and renewable fuel production (fuel production systems and conversion technologies).

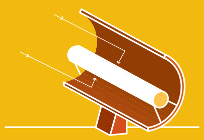
Meanwhile, with the aim of enabling the EU to be a front-runner in changing the way energy is produced, distributed and used, the European Commission will prepare the European Strategic Energy Technology Plan (SET Plan) in 2007 for endorsement by EU member states at their 2008 Spring European Council meeting.

The EU has three key objectives in the development of its energy technology:

- lowering the cost of renewable energy
- facilitating the efficient use of energy
- placing European industries in the leading position in low carbon technologies

The key aim of the proposed SET Plan is to accelerate innovation of energy technologies and push European industry to turn the threats of climate change and security of supply into opportunities to increase its competitiveness.

CSP TECHNOLOGY EXPLAINED

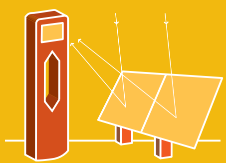


Parabolic troughs

A parabolic trough solar collector is designed to concentrate the sun's rays via parabolic curved solar reflectors onto a heat absorber element – a "receiver" – located in the optical focal line of the collector. The solar collectors track the sun continuously.

The key components of a parabolic trough power plant are mirrors, receivers and turbine technology. The receiver consists of a specially coated absorber tube which is embedded in an evacuated glass envelope. The absorbed solar radiation warms up the heat transfer fluid flowing through the absorber tube to almost 400°C. This is conducted along a heat exchanger in which steam is produced, which then generates power in the turbines.

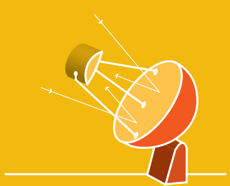
The output of the power plant is between 25 MW and 200 MW of electricity, at its peak. Thanks to storage systems, the plant can keep working at a constant load. With high performance and low electricity production costs, the outlook for parabolic trough power plants is very good.



Solar towers

Solar Central Tower systems have a single receiver placed on top of a tower surrounded by hundreds of mirrors (heliostats) which follow the apparent motion of the sun in the sky and which re-direct and focus the sunlight onto the receiver.

The key elements of a solar tower system are the heliostats – provided with a two-axis tracking system – the receiver, the steam generation system and the storage system. The number of heliostats will vary according to the particular receiver's thermal cycle and the heliostat design.



Dish/engine systems

In solar dish/engine systems, parabolic dishes capture the solar radiation and transfer it to a Stirling engine – an engine which uses external heat sources to expand and contract a fluid – placed in the focus of the parabolic dish. This approach is particularly suited for decentralised electricity generation.

DEMONSTRATION PLANTS

A number of demonstration projects were launched under the Framework Programmes for Research, Technological Development and Demonstration of the European Union (FPs): the European Commission is supporting three major full-scale MW-size demonstration projects to the tune of € 15 million. These projects – described in this chapter – aim to validate the full-scale application of different technological approaches and their economic viability under market conditions.

- PS10: An 11 MW Solar Thermal Power Plant in Southern Spain
- ANDASOL : 50 MW parabolic trough plant with thermal storage
- SOLAR TRES : 15 MW solar tower with molten salts storage

PS10: An 11 MW Solar Thermal Power Plant in Southern Spain

The PS10 solar thermal power plant at Sanlúcar la Mayor, southern Spain – just West of Seville – represents an energy milestone. Inaugurated on 30 March 2007 by the Prime Minister of the Andalucía Region, the plant is the world's first solar thermal power plant based on tower and heliostat field technology that will generate electricity in a stable and commercial way. It is also among Europe's largest electricity-producing solar facilities.

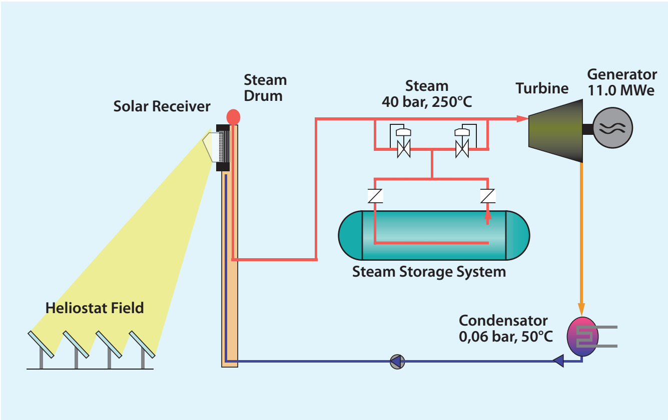
The plant – construction of which started in June 2004 – concentrates the sun's rays onto the top of a tower 115 m high using mobile mirrors that are faced towards the sun by a control system. The solar receiver on top of the tower produces saturated steam and circulates it to a conventional steam turbine that generates the electricity. The plant should generate some 23 GWh of electricity every year.

The PS10 plant is promoted by the company Abengoa (Solúcar Energía). In commercial terms, the project will benefit from the solar premium of € 0.18/kWh that is supplied by Spanish Government to solar thermal installations producing electricity.

The project makes use of existing and proven technologies – like glass-metal heliostats, a saturated steam receiver, and a water-pressurised thermal storage system, all developed by European companies.

PS10 – DESIGN FEATURES	
Location	Sanlúcar M., Spain
Nominal electrical power	11.02 MW
Tower height	100.5 m
Receiver technology	Saturated steam
Receiver geometry	Cavity 180º, 4 panels 5.40 m x 12.00 m
Heliostats	624 @ 120 m^2
Thermal storage technology	Water/steam
Thermal storage capacity	20 MWh, 50 min @ 50% rate
Steam cycle	40 bar 250ºC, 2 Pressures
Electric generation	6.3 kV, 50 Hz -> 66 kV, 50 Hz
Ground area	55 ha
Annual electricity production	23.0 GWh

Plant Description



PS10 therefore avoids technology uncertainties and gives priority to scaling-up, integration of the different subsystems, demonstration of dispatchability (capability to feed the power grid), reduction of operation and maintenance costs, and compiling information for elaboration of standards.

The project is worth some € 16.7 million, with an EU contribution of € 5 million.

How it works

The PS10 features a large solar field of 624 heliostats. Each heliostat is a mobile 120 m^2 curved reflective surface mirror. The receiver on the tower – based on a cavity concept to reduce radiation and convection losses – is designed to produce saturated steam at 40 bar-250ºC from thermal energy supplied by concentrated solar radiation flux. Steam is sent to the turbine where it expands to produce mechanical work and electricity.

The receiver is basically a forced circulation radiant boiler with low ratio of steam at the panels output, in order to ensure wet inner walls in the tubes. Special steel alloys have been used for its construction so that it can operate under significant heat fluxes and possible high temperatures.

Aerial view of PS10 tower plant

It is formed by four vertical panels of 5.40 m wide by 12 m high, each one making up an overall heat exchange surface of about 260 m^2. These panels are arranged into a semi-cylinder of 7 m radius.

During operation at full load, the receiver will receive a thermal power of about 55 MW of concentrated solar radiation with peaks of 650 kW/m^2. Flux measurements are performed by a 2D array of calorimeters. Temperature is measured by a thermocouples matrix.

For cloudy periods, the plant has a saturated water thermal storage system with a thermal capacity of 20 MWh (50 at 50% load). The system is composed of four tanks that are sequentially operated in relation to their charge status. During full load operation of the plant, part of the steam produced by the receiver is used to load the thermal storage system. When energy is needed to cover a transient period, energy from saturated water is recovered at 20 bar to run the turbine at a 50% partial load.

Information

Contract: **NNE5-1999-356**

Acronym: **PS10**

Title: **11 MW Solar Thermal Power Plant in Southern Spain**

Coordinator: **Solúcar Energía S.A., Spain**
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Partners: **1. Instalaciones Inabensa S.A., Spain**
2. Fichtner GmbH, Germany
3. CIEMAT, Spain
4. DLR, Germany

Total eligible costs: **€ 16,650,000**

European Union contribution: **€ 5,000,000**

ANDASOL: 50 MW parabolic trough plant with thermal storage

The "AndaSol" solar power plant is located in the Marquesado del Zenete – a wide valley in Andalusia, Spain – converting solar energy into electricity using a parabolic trough collector and a molten-salt thermal storage system.

Due to its altitude of 900-1,100 m, the AndaSol project has one of the best direct solar radiation resources in Spain. The 400 kV line of the Red Eléctrica de España (REE) distribution grid passes through the middle of the valley. The northern slope of the Sierra Nevada Mountains provides plentiful groundwater resources. And with the new A-92 highway and the Almería-Granada train, the project also enjoys good transport access for construction and operation.

Thanks to its thermal storage system, the AndaSol project will be able to meet demand for electricity after sunset. Without thermal storage, the solar resources in the Marquesado del Zenete would only allow about 2,000 annual equivalent full-load hours. The thermal storage system increases the annual equivalent full-load hours to 3,589. This is the key to reducing production costs, as it enables better performance of the power block and higher productivity of the operation and maintenance staff.

AndaSol is developed and promoted by the Spanish ACS Cobra Group, the majority shareholder, and the German Solar Millennium Group, the minority shareholder. The project company is called AndaSol-1 Central Termosolar Uno S.A. Construction of the first AndaSol-1 project started in June 2006 and should be completed by 2008.

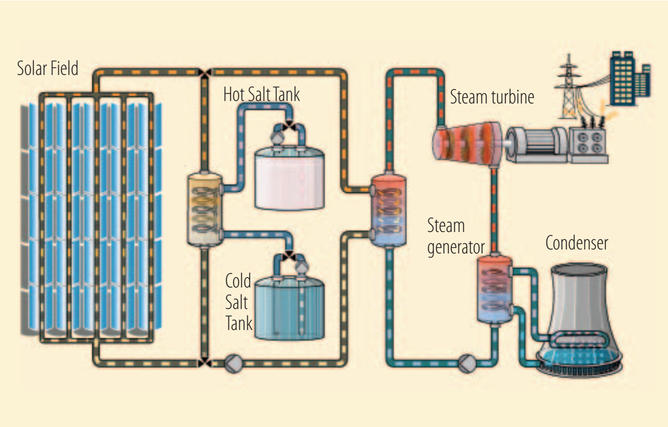
The AndaSol project is worth a total € 14.3 million, with EU backing of € 5 million.

ANDASOL – DESIGN FEATURES

Location	**Andalucía, Spain**
Nominal electrical power	**49.9 MW**
Annual equivalent full-load hours	**3,589**
Receiver technology	**Parabolic trough solar field**
Receiver geometry	**510,120 m^2**
Thermal storage technology	**Molten-salt**
Thermal storage capacity	**7.5 hr reserve**
Ground area	**200 ha**
Annual electricity production	**179 GWh**

Plant Description

Simplified AndaSol flow diagram



How it works

The fundamental principle of the AndaSol project is to convert primary solar energy into electricity using a 510,120 m² SKAL-ET parabolic trough solar field, a 7.5-hour reserve molten-salt thermal storage system and a 49.9 MW-capacity steam cycle. Thanks to the storage system, the AndaSol project can ensure plant capacity and dispatch power day and night.

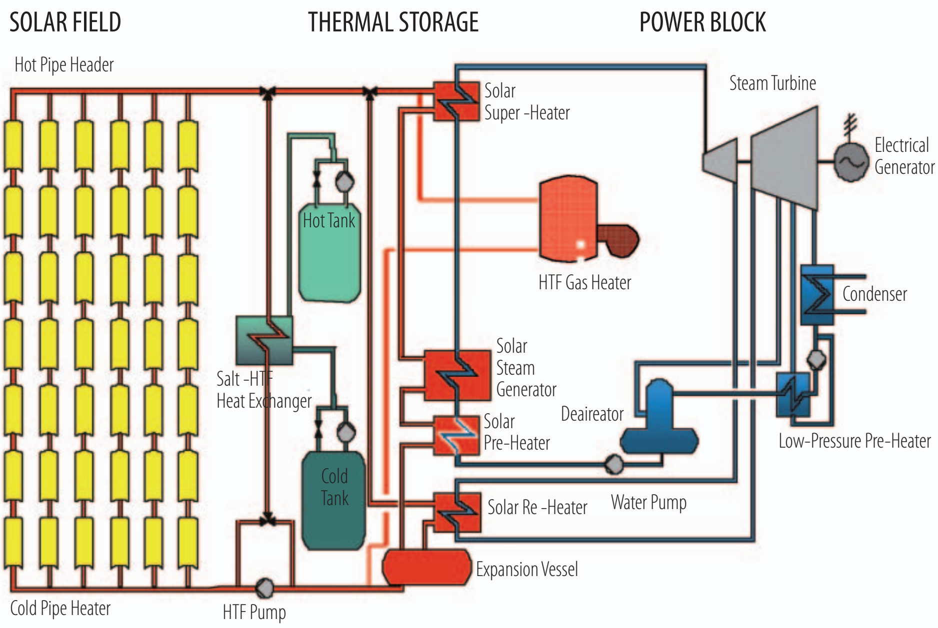
In the AndaSol plant, the parabolic trough collectors track the sun from east to west using a high-precision optical sensor, thus collecting the maximum solar radiation. A heat transfer fluid (HTF) flows through absorber tubes. This HTF is a synthetic oil, similar to the synthetic oil used in automobile motors.

Power production in the AndaSol plant varies during the day and different times of year depending on the available radiation. During the hours of sunlight, the parabolic trough collectors in the solar field concentrate the radiation on the absorber tubes, heating the HTF. The energy contained in this HTF can be pumped directly to the steam generator or it can be pumped to a thermal storage system where it is stored for later use.

The Kramer Junction solar plant in California, where the first AndaSol pilot loop was successfully tested.

Plant Description

AndaSol project solar field, storage and steam cycle operation



At midday when the sun is high in the sky, electricity can be generated and the storage system charged at the same time: for this the heat from the HTF is transferred to the thermal storage medium, a molten-salt fluid, which collects the heat while the salt goes from a cold tank to a hot tank, where it accumulates until it is completely full.

In other words, to charge storage, the salt is heated. On discharging, it is cooled down again. During this process, the salt is liquid. The cold and hot salts are kept in separate tanks, so it is called a two-tank system. With this storage, the AndaSol plant can produce solar electricity even when there is no sunshine, to dispatch the power demand at any time and ensure the rated power capacity.

As the day advances and the intensity of the solar radiation drops in the afternoon, heat is no longer sent to the storage system but employed entirely to produce electricity. After the sun sets, the solar field stops working and the storage system begins to discharge.

The heat is recovered from the hot salt tank through the thermal oil to keep up electricity production during the night. To avoid deviation from scheduled production during cloudy periods, and to avoid solidification of the HTF and storage salt when electricity generation is interrupted, the plant has auxiliary gas heaters for hybridisation.

The 624 SKAL-ET collector units that make up the AndaSol solar field are controlled from a control room by a central computer. It starts up the solar field during the day, when the weather and plant availability permit, and puts it into stow position for the night or when there are very high gusts of wind. The AndaSol projects occupy a total area of around 200 hectares.

Information

Contract: **NNE5-2001-00560**

Acronym: **AndaSol**

Title: **AndaSol 50 MW Parabolic Trough Plant with Thermal Storage**

Coordinator: **Andasol-1 Central Termosolar Uno S.A., Spain**
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Partners:
1. **Solar Millennium AG, Germany**
2. **Instalaciones Inabensa S.A., Spain**
3. **Schlaich Bergermann und Partner, Germany**
4. **EMO Orodjarna Proizvodna Druzba D.O.O., Slovenia**
5. **CIEMAT, Spain**
6. **DLR, Germany**

Total eligible costs: **€ 14,300,000**

European Union contribution: **€ 5,000,000**

SOLAR TRES : 15 MW solar tower with molten salts storage

Demonstrating the technical and economic viability of molten salt solar thermal power technologies to deliver clean, cost-competitive bulk electricity is the main aim of the SOLAR TRES project.

The project – with a total cost of € 15.3 million including an EU contribution of € 5 million – also looks to contribute to securing a prominent role for European industry and research institutions in the development and commercialisation of these promising technologies.

The site of the SOLAR TRES demonstration plant – a 15 MW solar tower with molten salts storage – has been identified in Ecija in Spain, close to Seville.

SOLAR TRES has the following objectives:

• Attaining a total installation cost of € 2,500 /kW (electrical)

• Approaching an electricity cost of € 0.04/kWh by profiting from previous lessons learned, improving efficiency, increasing availability and reducing operation costs

• Achieving sustainable renewables-based energy production, without negative environmental impact, contributing to the reduction of greenhouse gas emissions by an equivalent of 57 kton/year and supporting EU commitments on renewables

SOLAR TRES – DESIGN FEATURES

Location	Ecija, Spain
Receiver thermal power	120 MW
Turbine electrical power	17 MW
Tower height	120 m
Heliostats	2,480
Surface of heliostats	285,200 m^2
Ground area covered by heliostats	142.31 ha
Storage size	15 hr
Natural gas boiler thermal capacity	16 MW
Annual electricity production (min.)	96,400 MWh
CO_2 mitigation (best available technology)	23,000 ton/year
CO_2 mitigation (coal power plant)	85,000 ton/year

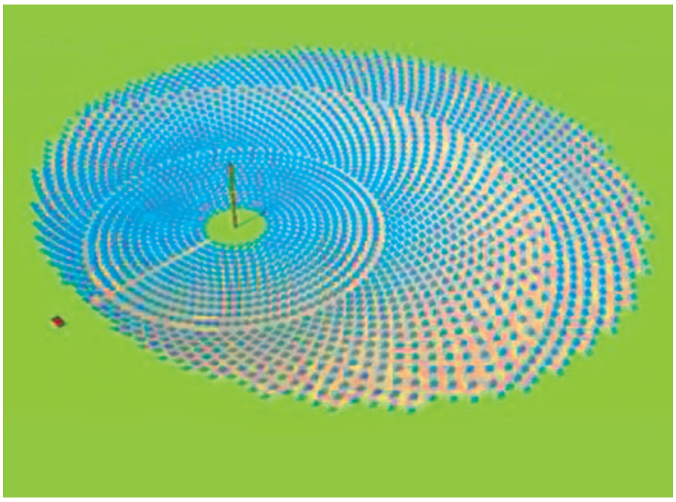
• Favouring electricity market liberalisation, competitiveness and supply reliability

• Contributing to social objectives by helping development of a depressed area, lessening regional inequalities and fulfilling cohesion policies by inducing a sizeable number of jobs

How it works

The SOLAR TRES project takes advantage of several advances in molten salts technology. These include:

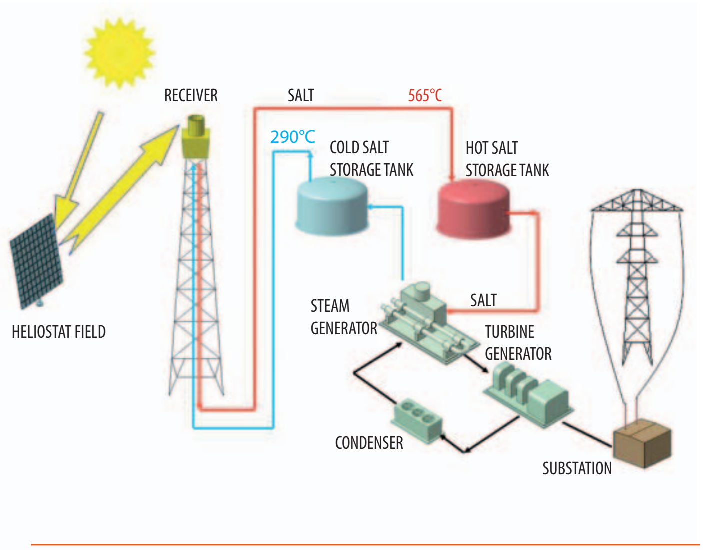
• A larger plant with a 2,480-heliostat field and 120 m^2 glass-metal heliostats – the use of a large-area heliostat in the collector field greatly reducing plant costs, mainly because fewer drive mechanisms are needed for the same mirror area



SOLAR TRES 3D view (SENSOL output)

• A 120 MW (thermal) high-thermal-efficiency cylindrical receiver system, able to work at high flux, and lower heat losses – the receiver has been designed to minimise thermal stress and to resist inter-granular stress corrosion cracking. High nickel alloy materials will be used and an innovative integral header and nozzle design to achieve high thermal efficiency, improved reliability and reduced cost

Plant Description



• An improved physical plant layout with a molten-salt flow loop that reduces the number of valves, eliminates "dead legs" and allows fail-safe draining that keeps salt from freezing

• A larger thermal storage system (15 hours, 647 MWh, 6,250 t salts) with insulated tank immersion heaters – this high-capacity liquid nitrate salt storage system is efficient and low-risk, and high-temperature liquid salt at 565ºC in stationary storage drops only 1-2ºC/day. The cold salt is stored at 45ºC above its melting point (240ºC), providing a substantial margin for design

• Advanced pump designs that will pump salt directly from the storage tanks, eliminating the need for pump sumps, and high-temperature multi-stage vertical turbine pumps to be mounted on top of the thermal storage tanks, using a long-shafted pump with salt-lubricated bearings – this pump arrangement eliminates the sump, level control valve and potential overflow of the pump sump vessels

• A 43 MW steam generator system that will have a forced-recirculation steam drum – this innovative design places components in the receiver tower structure at a height above the salt storage tanks that allows the molten-salt system to drain back into the tanks, providing a passive fail-safe design. This simplified design improves plant availability and reduces operation and maintenance costs.

The new design employed by SOLAR TRES will use a forced recirculation evaporator configuration to move molten salt through the shell side of all heat exchangers, reducing the risk of the nitrate salt freezing. The system should also feature:

• A more efficient (38% annual average), higher-pressure re-heat turbine - can be started up and stopped daily, and responds well to load changes, assuring a 30-year lifetime with good efficiency

• Improved instrumentation and control systems for the heliostat field and high-temperature nitrate salt process

• A better electric heat tracing system for protection against freezing of salt circuits, storage tanks, pumps, valves, etc.

Information

Contract: **NNE5-2001-369**

Acronym: **SOLAR TRES**

Title: **Molten Salt Solar Thermal Power 15 MW Demonstration Plant**

Coordinator: **SENER, Spain**
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Partners: **1. GHERSA, Spain**
2. COMPAGNIE DE SAINT GOBAIN, France
3. CIEMAT, Spain
4. SIEMENS, Germany

Total eligible costs: **€ 15,345,000**

European Union contribution: **€ 5,000,000**

SYSTEMS, COMPONENTS AND STORAGE

Several EU-funded research projects have tackled two key challenges for concentrated solar power plants – namely improving operability and reducing costs. As explained in this chapter, this has included research topics like:

- Using water as a heat transfer medium and direct steam generation
- Developing ceramic solar receivers
- Testing new components and manufacturing processes for solar dishes
- Taking an innovative approach to designing the parabolic through collectors including improving optical performance under wind loads
- Developing innovative storage media (phase-change materials)

DISS : Direct Solar Steam

Direct steam generation (DSG) offers a way of producing high quality steam from solar radiation and could have a market in both developed and developing countries where there is a high annual average amount of sun.

The technology is complex in terms of its control systems and operating strategies, but simple in its solar collector characteristics and materials. In fact the DSG power range – 500 kW (thermal) to more than 200 MW (thermal) – its technical set-up and cost make it well suited for industrial applications.

Such are the findings of the Direct Solar Steam project, DISS. The project focuses on testing a 300 kW (thermal) DSG test loop, using water as a heat transfer medium.

The related technical challenges concerned: studying the feasibility of stable two-phase flow operation using water; gaining information on operation and maintenance costs and procedures; testing the three basic steam-operating modes (once-through, re-circulation and injection) at three different operating pressures; and identifying further technology improvements.

A single row of solar collectors, capable of producing 300 kW (thermal), was built with water as the heat transfer fluid within a test loop to extract steam. The row was divided into water evaporation and superheated steam sections.

In the first section, the water is evaporated through nine solar collectors, whereas in the second section of three collectors, superheated steam – that is, steam at a temperature of above 400°C – is produced.

In the "once-through" mode, water goes once through both sections, while in the "re-circulation" mode a given amount of water is taken after the first section and re-injected at the beginning of the loop. In the "injection" mode, a given amount of water is taken after the first section and re-injected at different points in the water evaporation part. Re-injecting hot water into a cold water part is thought to improve the process.

Information

Contract: **JOR3-CT95-0058**

Acronym: **DISS**

Title: **Direct Solar Steam**

Coordinator: **CIEMAT, Spain**
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Partners:
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2. **Pilkington Solar International GMBH, Germany**
3. **Iberdrola Ingenieria y Consultoria, Spain**
4. **Union Electrica FENOSA, Spain**
5. **Empresa Nacional de Electricidad, Spain**
6. **Instalaciones Abengoa, Spain**
7. **Siemens AG, Germany**
8. **Zentrum für Sonnenenergie- und Wasserstoff-Forschung, Germany**

Total eligible costs: **€ 4,280,996**

European Union contribution: **€ 2,000 000**

SOLAIR : Advanced solar volumetric air receiver for commercial solar tower power plants

Ceramic receiver technology could offer a favourable new basis for commercial solar tower power plants, according to the results of the SOLAIR research project. Although ceramics offer various advantages over metallic meshes, including better resistance to high temperatures and weathering, they have been little used to date in solar receiver technology.

The € 3.3 million SOLAIR scheme, part-funded by the EU to the tune of € 1.5 million, set out to design a cheaper and more reliable and more efficient modular solar receiver, based on ceramic volumetric absorber modules using air as the heat transfer medium. A modular approach gives potential for mass production and facilitates up-scaling to larger systems.

In the first phase of the project work, the main design parameters and materials were chosen and tested. In a second phase, the modular aspect of the new receiver was developed and tested. The supporting steel structure of the absorber modules, the warm air return system and the passive control elements were all developed with a view to homogenising the receiver outlet air temperature. Further investigations on absorber material degradation were carried out in order to estimate lifespan.

As well as the design of a second-generation volumetric air receiver, the SOLAIR project saw the demonstration of a bigger 3 MW (thermal) prototype receiver system. An optimised cycle design was also produced, based on the improved capabilities of the receiver. An overall reduction of solar electricity generating costs of about 10% was projected, compared to current volumetric air receiver technology.

The industrial consortium partners involved in the project gained such confidence in the new system that they were considering up-scaling the solar receiver design to build a full solar power plant.

Information

Contract: **ERK6-CT-1999-00021**

Acronym: **SOLAIR**

Title: **Advanced solar volumetric air receiver for commercial solar tower power plants**

Duration: **54 months**

Coordinator: **Instalaciones Abengoa S.A., Spain**
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Partners: **1. Inabensa Solucar, Spain**
2. DLR, Germany
3. CIEMAT, Spain
4. Heliotech Aps, Denmark
5. CERTH/CPERI, Hellas, Greece
6. IBERESE S.A., Spain

Total eligible costs: **€ 3,312,110**

European Union contribution: **€ 1,497,092**

EURODISH: Reducing the costs of dish/Stirling systems

Solar dish technology could become more competitive for small generation applications thanks to potential cost savings identified by the EURODISH project. The € 1.7 million scheme – part-funded by the EU – holds out the prospect of costs no longer forming a barrier to the wider uptake of the technology.

The project produced a fundamental rethinking of classic dish/Stirling systems, focusing on the optical dish design, the supporting structure, the Stirling engine and the control system. The dish/Stirling design developed by EURODISH offers high performance and easier manufacturing and installation procedures.

Newly developed components proved to work smoothly compared to the former systems, while their performance almost reached the design power output. A peak power of 10 kW (electrical) was achieved during the 300-hour operation time, and a remote monitoring and control mechanism required for cost-effective servicing was developed, tested and installed.

The cost of the system was put at near the target of € 5,000/kW (electrical) for a production level of 500 units per year. System costs need to be lower than € 5,000/kW (electrical) at annual production levels of 100 to 500 units (i.e. 1 to 5 MW for initial installation in remote areas and on islands). Costs for existing dish/Stirling designs are an estimated € 11,000/kW for single prototype installations.

The EURODISH analysis also highlighted potential areas for further cost reduction for several components, thus improving the chances of achieving a cost level that would permit competitive entry into the market.

Information

Contract: **JOR3-CT98-0242**

Acronym: **EURODISH**

Title: **Cost reduction for dish/Stirling systems**

Coordinator: **Schlaich Bergermann und Partner, Germany**
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Partners: **1. Instalaciones Abengoa, Spain**
2. CIEMAT, Spain
3. DLR, Germany
4. SOLO Kleinmotoren GmbH, Germany
5. MERO GmbH & Co. KG, Germany
6. Klein & Stekl GmbH, Germany

Total eligible costs: **€ 1,665,531**

European Union contribution: **€ 750,000**

DISTOR : Energy Storage for Direct Steam Solar Power Plants

Developments in the field of energy storage are of particular importance to the maturation of solar power technologies. The advantages include the further lowering of electricity production costs, the stabilisation of grid-connected solar power plants, and the possibility of realising stand-alone solar thermal plants in remote or insular areas.

The € 3.9 million DISTOR project – with an EU contribution of € 2.2 million – focuses on the development of phase-change materials (PCM) for more efficient energy storage, under three main themes:

- Developing innovative storage media based on the micro-encapsulation of PCM in a matrix of expanded graphite
- Selecting the most efficient storage configuration for high-efficiency internal charging/discharging heat transfer
- Demonstrating the feasibility of the developed material and storage design through *in situ* testing of the storage module on a 100 kW test prototype under real field conditions.

The innovative approach to increasing storage efficiency taken by DISTOR is the micro-encapsulation of PCM in a matrix material with high porosity and superior thermal conductivity. Limiting the size of PCM clusters in the matrix, the thermal conductivity of the total composite will be controlled by the matrix of expanded graphite.

The feasibility of the micro-encapsulation concept has already been demonstrated with paraffin PCM for applications in temperatures below 100°C. For higher temperature ranges, salt materials have to be used as storage media.

Information

Contract: **SES6-CT-2004-503526**

Acronym: **DISTOR**

Title: **Energy Storage for Direct Steam Solar Power Plants**

Coordinator: **DLR, Germany**
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Partners:
1. CNRS, France
2. EPSILON Ingénierie S.A.S., France
3. DEFI Systèmes, France
4. SGL Technologies GmbH, Germany
5. FLAGSOL GmbH, Germany
6. CIEMAT, Spain
7. Fundacion Inasmet, Spain
8. Solúcar Energía, S.A., Spain
9. Sistemas de Calor S.L., Spain
10. Iberdrola Ingenieria y Consultoria, Spain
11. WIS, Israel
12. Central Laboratory of Solar Energy and New Energy Sources, Bulgarian Academy of Science, Bulgaria

Total eligible costs: **€ 3,936,650**

European Union contribution: **€ 2,228,917**

ECOSTAR : European Concentrated Solar Thermal Road-Mapping

Finding new ways of reducing the costs of solar power and making it more competitive relative to fossil fuels is the name of the game for the European Concentrated Solar Thermal Road-Mapping project ECOSTAR.

Despite the emergence of successful concentrating solar thermal power (CSP) plants in Europe, where costs can be reduced through mass production, cost innovations are still needed.

The ECOSTAR Coordination Action aims to identify the European innovation potential with the highest impact on cost reduction for CSP. It looks to focus European research activities and national research programmes of the partners involved on common goals and priorities. And it also works to foster industrial and research excellence, capable of solving multi-disciplinary problems related to CSP.

ECOSTAR identifies, evaluates, and disseminates options for innovative cost reduction in CSP technologies, mainly those suitable for bulk electricity production. Models are used to estimate normalised electricity costs. Annual calculations are performed and a roadmap document is drawn up.

The roadmap indicates the most promising directions for R&D activities that would help reduce costs and thus ease the introduction of CSP technologies into the marketplace.

Workshops and other activities disseminate the ECOSTAR findings to audiences including research experts, industry and policy-makers, and help to identify partners outside of the solar community.

The roadmap document is assessed by members of the international association of power and heat generation (VGB PowerTech), which includes many of the European players in the power sector. This independent industry assessment ensures that the directions identified are feasible from an industrial perspective.

Information

Contract: **SES6-CT-2003-502578**

Acronym: **ECOSTAR**

Title: **European Concentrated Solar Thermal Road-Mapping**

Coordinator: **DLR, Germany**
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Partners:
1. **VGB PowerTech e.V., Germany**
2. **CIEMAT, Spain**
3. **CNRS, France**
4. **WIS, Israel**
5. **ETH, Switzerland**
6. **Institute for High Temperatures, Russian Academy of Science, Russia**

Total eligible costs: **€ 335,293**

European Union contribution: **€ 223,129**

SOLAR HYBRID PLANTS

Finding efficient ways of storing energy is one option to deal with the lack of year-round sunshine, and thus the limited availability of solar resources during the whole year. Another option is to combine solar energy with fossil fuel – natural gas – or renewable fuel – biomass – in a hybrid plant. EU-funded research on hybrid solar technology has tackled projects including:

- modifying the combustion chamber of a gas turbine to allow dual use of solar heat and fossil fuel
- using a hybrid power plant concept applied to a dish/Stirling technology
- the solar upgrading of hydrocarbons by steam re-forming in solar receiver reactors
- developing an efficient solar-hybrid micro turbine

SOLGATE: Solar hybrid gas turbine electric power system

The SOLGATE project investigated the concept of combining solar energy with fossil fuel in a hybrid plant – and showed its feasibility by proving that a gas turbine could be modified to allow dual operation.

The € 3.2 million project showed that temperatures of as high as 1,000°C could be generated in a pressurised solar receiver module, using direct solar heating of pressurised air for the gas turbine. The project's analysis of different solar-hybrid gas turbine systems found that for a 16 MW (electrical) installation operating at 800°C, the investment cost would be € 1,440/kW, with an electricity generation cost of € 0.057/kWh at 16% annual solar share. With an operating temperature of 1 000°C, a solar share above 50% was found to be achievable, although the electricity generation cost would then rise to € 0.086/kWh.

In three stages, three different solar receivers were used to increase the air temperature from 250°C, which is the outlet temperature of the gas turbine, to 1,000°C. The SOLGATE project aimed to modify both the combustion chamber of the gas turbine and the operating control system, to allow dual use of solar heat and fossil fuel.

According to the approach taken by SOLGATE, the gas turbine receives hot air from the outlet of the high temperature receiver module. This hot air enters the modified gas turbine combustor – whose normal operating inlet temperature is 800°C – through a cooling bypass system. The development of a gas turbine able to operate at higher temperatures allows the use of this solar technology without changes.

The new components were integrated into a complete solar-hybrid power system and installed in the 7 MW (thermal) solar tower facility at Plataforma Solar de Almeria, Spain. A testing programme was designed to test operating conditions, performance of the components and the system as a whole, and durability and maintenance requirements.

Grid connection issues were also investigated, including the development of software for simulating component and system performance. The project assessed the conceptual layout of prototype systems, based on three industrial gas turbines ranging from 1.4 to 17 MW (electrical), using combined cycle and recuperated gas turbine configurations. It also assessed European and worldwide market potential.

Information

Contract: **ENK5-CT-2000-00333**

Acronym: **SOLGATE**

Title: **Solar hybrid gas turbine electric power system**

Coordinator: **Ormat Industry Ltd., Israel**
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Partners: **1. Instalaciones Abengoa S.A., Spain**
2. Inabensa Solucar, Spain
3. CIEMAT, Spain
4. DLR, Germany
5. Tuma Turbomach S.A., Switzerland

Total eligible costs: **€ 3,156,120**

European Union contribution: **€ 1,498,772**

HYPHIRE: Dish/Stirling hybrid system

The HYPHIRE project represented the first use of a hybrid solar/fossil fuel power plant concept applied to solar dish/Stirling engine technology. Such a plant offers the advantages of continuous efficient operation including for applications that are not connected to the grid – something which could benefit small remote communities in particular.

The hybrid system also offers environmental benefits: if biogas is used, the result is zero emissions of carbon dioxide (CO_2). The system is intended for commercialisation for decentralised power production in the Sunbelt region.

In the dish/Stirling system investigated in the HYPHIRE project, the fluid used in the Stirling engine is helium, the cold source is the ambient air and the hot source is the solar heat. A heat pipe receiver transfers any power combination from gas and solar input up to 45 kW (thermal) without temperature drop.

This second generation hybrid heat pipe receiver was developed and tested extensively both in the laboratory and *in situ*. Adaptations and improvements during the test phase resulted in a stable and reliable functioning of the control system.

The system was successfully operated in all modes, that is: solar-only, combustion-only and the parallel mode of solar and combustion over a period of 360 hours. The system also operated successfully during cloudy periods. The cost forecast for production of the first 100 systems was € 7,000/kW, decreasing to € 1,600/kW for a series of 10,000/year.

It was found that nitrogen oxide (NO_x) emissions could be contained well below 0.5 g/kg fuel, with methane equivalent hydrocarbon emissions between 0.1 and 1 g/kg fuel. One remaining task was to lower carbon monoxide emissions, which were in the range 5-10 g/kg fuel.

HYPHIRE also studied the market potential for hybridised dish/Stirling units as well as solar radiation sites in Morocco.

Information

Contract: **JOR3-CT95-0085**

Acronym: **HYPHIRE**

Title: **Dish/Stirling hybrid system**

Coordinator: **DLR, Germany**
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Partners: **1. INTERSOL, Sweden**
2. CIEMAT, Spain
3. SBP, Germany
4. IKE, Germany

Total eligible costs: **€ 1,775,003**

European Union contribution: **€ 971,894**

SOLASYS: Novel solar-assisted fuel-driven power system

Harnessing solar energy to produce synthesised gas – or syngas – that can be used by a gas turbine to produce electricity was the main aim of the SOLASYS project.

The process involves upgrading hydrocarbons by steam re-forming in solar receiver-reactors and the utilisation of the upgraded fuel in highly efficient conversion systems such as gas turbines or fuel cells. This process may be used on a small scale as a stand-alone system for off-grid markets and also in larger-scale plants. The technology has potential for solar/fossil hybrid operations as well as for solar energy storage.

In SOLASYS, the major challenge was to modify a previously developed receiver-reactor and to adjust the system so that it would work with steam and different hydrocarbon fuels.

The € 2.5 million project saw an entire power generation system completed, commissioned and tested and the design of a new volumetric receiver-reactor. The major technical innovations were the modification of the gas turbine, including a dual-fuel operation mode.

The project identified two possible approaches for the medium-term commercial application of the technology. The first option is the addition of a "solar upgraded fuel" system into existing large-scale gas turbine power plants. In this case no major modifications of the gas turbine would be necessary and the financial risk would therefore be reduced. The second option is to apply the technology of solar re-forming in a biogas plant from municipal or agricultural waste.

Investigations were also made into the use of fuel cells instead of a gas turbine, along with an economic assessment of the technology.

Information

Contract: **JOR3-CT98-0300**

Acronym: **SOLASYS**

Title: **Novel solar-assisted fuel-driven power system**

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Partners: **1. Ormat Industry, Israel**
2. WIS, Israel
3. SPE, Netherlands
4. ECN, Netherlands

Total eligible costs: **€ 2,536,077**

European Union contribution: **€ 1,568,320**

EUROTROUGH: Development of low cost European desalination and process heat collector

Ways of reducing costs and improving efficiency in solar power were identified by the EUROTROUGH project, which aimed to rethink and re-design collectors for concentrated solar thermal power plants. These collectors are used to make up the solar field of a power plant, representing almost half of the total investment cost.

The research focused on areas like extending the collector length; minimising wind-induced optical losses; reducing critical stress of mirror facets; and the demonstration of a thermal collector peak efficiency of 60% at normal incident design radiation of 850 W/m^2.

The increase of the collector length reduces the need for central collector tracking drives in the solar field. Reducing the stress on the mirror facets means less mirror breakage from winds and therefore improved performance and lower maintenance costs.

The new EUROTROUGH solar collector design showed stronger resistance to wind loads and improved operational performance compared to the traditional design, and a peak optical efficiency of 74%. At 350°C above room temperature, the global efficiency of converting solar irradiation energy into thermal energy was measured at 66%.

The economic performance of the new design was also evaluated using simulations for a 50 MW (electrical) plant. The evaluation showed that costs could be reduced significantly by reducing the number of components such as hydraulic drive systems. There was scope for cost reduction in areas such as the supporting structure and assembly procedure. And a reduction of metal parts by 15% and manpower needs by up to 22% was also shown to be possible.

As a result of the EUROTROUGH project, and the follow-up EUROTROUGH II, the industrial partners involved are now EU leaders in low-cost parabolic trough technology.

Information

Contract: **JOR3-CT98-0231**

Acronym: **EUROTROUGH**

Title: **Development of low cost European desalination and process heat collector**

Coordinator: **Instalaciones Abengoa S.A., Spain**
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Partners:
1. CIEMAT, Spain
2. DLR, Germany
3. Pilkington Solar International GMBH, Germany
4. Schlaich Bergermann und Partner, Germany
5. Fichtner GMBH & CO KG, Germany
6. Centre for Renewable Energy Sources, Greece

Total eligible costs: **€ 2,402,514**

European Union contribution: **€ 1,199,899**

SOLHYCO: Solar-Hybrid Power and Cogeneration Plants

The development and testing of a complete hybrid prototype cogeneration unit is the expected result of the SOLHYCO project. The main aim is to develop a highly efficient solar-hybrid micro-turbine (SHM) system for power and heat generation with dual solar power and fuel input.

The SOLHYCO technology is seen as well suited as a first step towards the replacement of fossil fuels by renewable fuels.

A reliable and cost-effective receiver system is being designed to reduce the generation cost. And a new combustion system is being developed to allow for the use of biofuels.

The development of the prototype SHM unit is based on a commercial 100 kW micro-turbine. The concentrated solar energy provided by a heliostat field is absorbed by an innovative solar receiver based on "profiled multi-layer (PML) tubes", providing outlet temperatures of above 800°C at reduced receiver cost.

The thermo-hydraulic properties are evaluated, the manufacturing process developed and the receiver layout adapted to the energy flow in a solar tower system. A six-month system test validates the components' performance and the system's efficiency. A formerly kerosene-driven 250 kW gas turbine is adapted to operate with biofuel.

A detailed market assessment for solar-hybrid cogeneration systems will determine some initial niche applications. Based on the results of this assessment, an exploitation plan for a first demonstration plant should be developed by the project consortium.

Information

Contract: **SES-CT-2005-019830**

Acronym: **SOLHYCO**

Title: **Solar-Hybrid Power and Cogeneration Plants**

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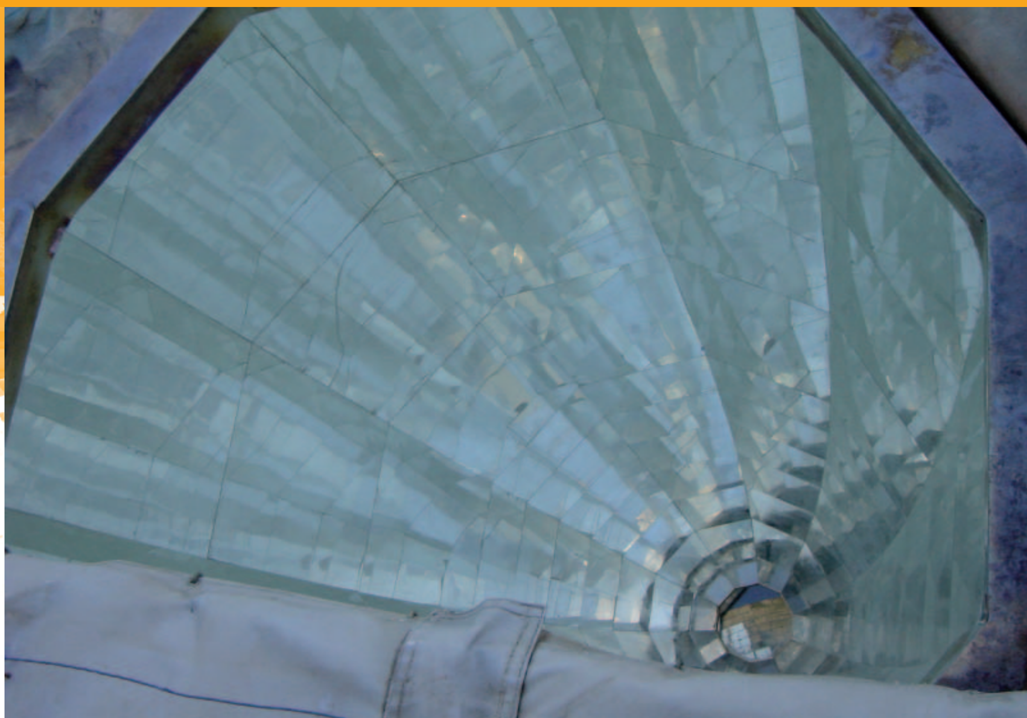
Partners: **1. Turbec R&D AB, Sweden**
2. CIEMAT, Spain
3. CEA, France
4. ORMAT Systems Ltd., Israel
5. Solúcar, Investigación y Desarrollo S.A., Spain
6. FTF GmbH, Germany
7. NEAL New Energy, Algeria
8. GEATechnika Cieplna Sp z o.o., Poland

Total eligible costs: **€ 3,088,218**

European Union contribution: **€ 1,599,988**

SOLAR CHEMISTRY



Producing electricity is not the only function of concentrated solar radiation. It can also be used directly as a heat source. EU-funded research has looked into various chemical processes relevant to this area, including:

- studying the technical feasibility of using concentrating solar thermal technology to produce zinc from zinc oxide
- exploiting solar energy for the production of hydrogen
- designing, constructing and testing a new high-temperature solar reactor to thermally decompose natural gas to obtain hydrogen-rich gas and carbon black

SOLZINC: Solar Carbothermic Production of zinc from zinc oxide

In high-temperature industrial processes, an external heat source is often used to provide the necessary energy to start and to maintain the chemical reaction. Electricity or fossil fuels are usually the source of this heat – but solar power may also have a part to play.

The SOLZINC project investigated the technical feasibility of using a 0.5 MW solar thermal chemical reactor to provide heat for producing pure zinc from zinc oxide using carbon as a reducing agent.

The purpose of this process is twofold. Firstly, metallic zinc can be produced as a commodity, with very low carbon dioxide (CO_2) emissions. Secondly, a cyclic process can be created whereby zinc is used as a "solar fuel" for electricity production in zinc-air fuel cells.

More broadly, the expected long-term benefits of the technology are numerous. They include: the mastering of solar energy storage and thermo-chemical transportation; a reduction of CO_2 emissions; savings in fossil fuel resources; an opportunity for a nearly emission-free urban transport system; and an expansion of employment opportunities in the field of renewable energy.

SOLZINC saw the design of a zinc smelting solar reactor, the optimisation of a zinc-air fuel cell for solar zinc, and the optimisation of the interface between the solar reactor and the zinc-air fuel cells. Assessments were made of the potential CO_2 mitigation and on the economic feasibility of producing zinc in such a novel way.

The key elements in the SOLZINC system are the solar reactor, the quench system for the recovery of zinc, and the zinc-air fuel cells. In a first phase, several 5-10 kW (thermal) versions of the solar reactor were built and tested in order to quantify performance variables. The experimental results were used to develop a numerical model to predict performance and to finalise the design for a large-scale reactor.

In a second phase, the larger reactor unit was built and tested and a numerical model was validated. A 10 kW (electrical) zinc-air fuel cell system was also tested.

Based on the test results from the prototype plants, a detailed economic study of the process was carried out. Numerous exploitation scenarios for a solar zinc oxide-to-zinc plant were also studied including the option to produce H_2 hydrogen from zinc by hydrolysis.

Information

Contract: **ENK6-CT-2001-00512**

Acronym: **SOLZINC**

Title: **Solar Carbothermic Production of zinc from zinc oxide**

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Partners: **1. PSI, Switzerland**
2. ETH, Switzerland
3. WIS, Israel
4. ScanArc, Sweden
5. ZOXY, Germany

Total eligible costs: **€ 3,018,632**

European Union contribution: **€ 1,284,282**

HYDROSOL: Solar Hydrogen via Water Splitting in Advanced Monolithic Reactors for Future Solar Power Plants

The use of renewable solar energy to produce hydrogen – a "clean" fuel considered to be the energy source of the future – is feasible, according to encouraging results obtained by the HYDROSOL project.

By far the most economically attractive way of producing hydrogen is the decomposition of water. However, attractive yields can only be achieved at very high temperatures, posing technological difficulties for anyone trying to harness solar energy as the driving energy for the reaction.

Catalytic materials are therefore required to lower the temperature of the reaction. The reaction takes place in two steps. In the first step the activated catalyst dissociates water and produces hydrogen. In the second step the used catalyst is regenerated.

The basic HYDROSOL idea was to combine a support structure capable of achieving high temperatures when heated by concentrated solar radiation with a suitable catalyst system so that the whole process – water splitting and catalyst regeneration – could be achieved by a single solar energy converter.

The purpose of the project was thus twofold: firstly, to develop novel catalytic materials for the water dissociation reaction at moderate temperatures (800-1,100°C), as well as the associated coating technology on supports; secondly, to develop a solar catalytic reactor suitable for incorporation into solar energy concentration systems – opening the way towards a complete hydrogen fuel production unit based on solar energy.

Catalysts were synthesised and tested for their activity with respect to water splitting. Project activities also focused on solar tests and technology assessments.

Information

Contract: **ENK6-CT-2002-00629**

Acronym: **HYDROSOL**

Title: **Solar Hydrogen via Water Splitting in Advanced Monolithic Reactors for Future Solar Power Plants**

Coordinator: **CERTH/CPERI, Hellas, Greece**
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Partners:
1. DLR, Germany
2. CIEMAT, Spain
3. Stobbe Tech Ceramics A/S, Denmark
4. Johnson Matthey Plc., United Kingdom

Total eligible costs: **€ 2,634,300**

European Union contribution: **€ 1,317,149**

HYDROSOL-II: Solar Hydrogen via Water Splitting in Advanced Monolithic Reactors for Future Solar Power Plants

The HYDROSOL-II project is working to establish the basis for mass production of solar hydrogen to help achieve the long-term target of a sustainable hydrogen economy. It is aiming to scale up the process of producing hydrogen using solar power.

HYDROSOL-II is to develop and build an optimised 100 kW (thermal) pilot plant for solar hydrogen production via a two-step thermo-chemical water-splitting process. The innovative concept uses a novel solar thermal reactor consisting of monolithic ceramic honeycombs coated with active redox pair materials.

The goal is a sustainable energy supply through zero-emission production of hydrogen by solar energy. HYDROSOL-II focuses on: enhancing the metal oxide/ceramic support system; constructing a dual absorber/receiver/reactor unit in the 100 kW (thermal) scale for solar thermo-chemical splitting of water; and the effective coupling of this reactor to a solar heliostat field and a solar tower platform for continuous solar hydrogen production within the optimised pilot plant.

The evaluation of the technical and economic potential of the process will serve to compare its costs against other hydrogen production methods. The design of a solar hydrogen mass-production plant of 1 MW is to complete the project.

The project consortium plans to exploit the project's results through spin-off companies of the researchers involved and/or joint ventures. The industrial partners involved will assess the potential for development and commercialisation of the proposed technology in the emerging fuel cell market and for novel applications of ceramic parts for solar thermal power plants.

Information

Contract: **SES6-CT-2005-020030**

Acronym: **HYDROSOL-II**

Title: **Solar Hydrogen via Water Splitting in Advanced Monolithic Reactors for Future Solar Power Plants**

Coordinator: **CERTH/CPERI, Hellas, Greece**
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Partners:
1. DLR, Germany
2. CIEMAT, Spain
3. Stobbe Tech Ceramics A/S, Denmark
4. Johnson Matthey Plc., United Kingdom

Total eligible costs: **€ 4,294,600**

European Union contribution: **€ 2,182,700**

SOLREF: Solar Steam Re-forming of Methane-Rich Gas for Synthesis Gas Production

Solar re-forming has the potential to become the most cost-effective way to drive solar concentration in large-scale power production. Developing an innovative 400 kW (thermal) solar re-former for applications such as hydrogen production and electricity generation is the main purpose of the SOLREF project.

And building on the findings of the SOLASYS project, SOLREF also focuses on the preliminary design for a 1 MW prototype plant in Southern Italy and on a full conceptual design for a commercial 50 MW (thermal) re-forming plant.

For a 50 MW (thermal) re-forming plant the cost of hydrogen is estimated to be analogous to that of hydrogen produced by conventional methods. Also, in terms of sustainable power supply, zero net carbon dioxide (CO_2) emissions can be achieved when the solar re-former operates with biogas and landfill gas as feed gases.

The SOLASYS project already validated the use of concentrated solar thermal energy for re-forming natural gas into synthesised gas, useable in a gas turbine. In the SOLREF project, various catalyst components will be investigated and a ceramic solar receiver will be prepared using different methods to single out the most efficient.

A simulation model will be developed to study the steam re-forming kinetics so as to optimise the use of the catalytic coatings in the module. The design of the new, more compact solar re-former includes a new flange containing less material, an advanced insulation configuration and an improved ceramic absorber.

Analyses and tests will be fed into the pre-design of the 1 MW (thermal) prototype plant. The conceptual design phase of the prototype plant will include a comparison between a central tower configuration and a beam-down installation. Special emphasis will be placed on the analysis of CO_2 separation and sequestration as well as CO_2 re-forming.

Importance is also attached to the dissemination of results, particularly in Southern Europe and Northern Africa. The project includes a detailed study of potential markets, infrastructure impacts, and environmental and socio-economic aspects of the exploitation of solar re-forming technology.

The market potential of this technology in a liberalised European energy market will be evaluated, and detailed cost estimates for a 50 MW (thermal) commercial plant will be provided.

Information

Contract: **SES6-CT-2004-502829**

Acronym: **SOLREF**

Title: **Solar Steam Re-forming of Methane-Rich Gas for Synthesis Gas Production**

Coordinator: **DLR, Germany**
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Partners:
1. **CERTH/CPERI, Hellas, Greece**
2. **WIS, Israel**
3. **ETH, Switzerland**
4. **Johnson Matthey Fuel Cell Ltd., United Kingdom**
5. **Hexion B.V., Netherlands**
6. **E.S.CO.Solar S.p.A., Italy**

Total eligible costs: **€ 3,451,986**

European Union contribution: **€ 2,100,000**

SOLHYCARB: Hydrogen from solar thermal energy

An unconventional but potentially cost-effective way of producing hydrogen by concentrated solar energy is being developed by the EU-funded SOLHYCARB project.

The novel process in question thermally decomposes natural gas in a high-temperature solar chemical reactor to obtain an H_2 hydrogen-rich gas and carbon black (CB), a high-value nano-material.

The project aims to design, construct, and test innovative solar reactors at different scales (1 to 10 kW and 50 kW) in the temperature range of 1 200-2 000ºC and 1 bar pressure. A methodology for scaling up the technology based on modelling and experimental validation should also be proposed.

The SOLHYCARB project develops and tests two 5-10 kW (thermal) prototypes. An analysis of the results of experiments and modelling will determine the best concept for a reactor suitable for splitting methane by solar energy, as the basis for a 50 kW pilot reactor.

The design of decentralised and centralised commercial solar chemical plants, including hybrid plants, of 50 to 100 kW and 10 to 30 MW (thermal) respectively, will conclude the project. The thermal and chemical efficiency will be determined for each solar chemical reactor.

Concerning the products, the key issues are the hydrogen content in the produced output gas and the CB quality. They are measured either on line (hydrogen content) or by industrial testing methods (CB). Modelling includes fluid dynamics of gas-solid flow, mass and heat transfer including radiation, reaction kinetics, and particle formation process.

The targeted results include methane conversion at efficiencies beyond 80%; H_2 yield in the output gas at over 75%; and CB properties equivalent to industrial products. The potential savings on carbon dioxide (CO_2) emissions compared to conventional cycles are about 14 kg CO_2 per kg H_2 produced. Energy savings of 277 MJ per kg H_2 produced are also achieved, with conventional natural gas steam re-forming and CB processing by standard processes.

The anticipated cost of H_2 for large-scale solar plants depends on the price of CB: € 14/GJ for the lowest CB grade sold at € 0.66/kg and decreasing to € 10/GJ for CB at € 0.8/kg.

Information

Contract: **SES-CT-2005-019770**

Acronym: **SOLHYCARB**

Title: **Hydrogen from solar thermal energy: high temperature solar chemical reactor for co-production of hydrogen and carbon black from natural gas cracking**

Coordinator: **CNRS, France**
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Partners:
1. **ETH, Switzerland**
2. **PSI, Switzerland**
3. **WIS, Israel**
4. **CERTH/CPERI, Hellas, Greece**
5. **DLR, Germany**
6. **TIMCAL, Belgium**
7. **Solucar Energia S.A., Spain**
8. **VEOLIA Environnement, France**
9. **N-GHY S.A., France**

Total eligible costs: **€ 3,254,600**

European Union contribution: **€ 1,997,300**

RESEARCH INFRASTRUCTURE

EU funding also supports so-called "horizontal" activities that look to strengthen the European infrastructure for solar science.

The aim is:

- to open up facilities to scientists and improve the scientific cooperation between researchers;
- to achieve scientific "critical mass" in areas where knowledge is widely dispersed; and
- to generate strong projects on a European scale to increase their competitiveness.

SOLFACE: High flux solar facilities for Europe

The SOLFACE project aims to open up a high-flux solar facility to scientists from Europe and allow them to tackle some as yet unexplored areas of research.

In the period 2004–2007, under the EU's 6th Research Framework Programme (FP6), SOLFACE proposes scientific access, free of charge, to the high-flux solar facilities at Font-Romeu-Odeillo, France: the megawatt solar furnace, 11 medium-size solar furnaces, and their associated experimental devices and diagnostic instruments.

SOLFACE offers high-quality research in two of the seven FP6 priority thematic areas, namely: "Nano-technologies and nanosciences, knowledge-based functional materials, new production process and devices" and "Sustainable development, global change and ecosystems".

Highly promising and original research is being carried out, including:

• studies of the solar photo-excitation and the solar photoluminescence of gaseous species for the accurate analysis (temperature, composition) of the gas phase at the interface with the condensed phase during high-temperature solar processes

• solar synthesis methods for producing nano-structured materials, from the understanding of the elementary growing mechanisms to the identification and mastering of the main parameters for up-scaling production

• simulation of the extreme conditions occurring during high-temperature processes and spatial applications for the study of the physical-chemical behaviour and thermo-physical properties of materials.

Other new research domains, quite unexplored at international level, will be opened to external scientists. These include the achievement of laser action in dye solutions under direct solar pumping, the study of photon-matter interaction during material processing in plasma and laser radiation processes.

Information

Contract: **RITA-CT-2003-507091**

Acronym: **SOLFACE**

Title: **High flux solar facilities for Europe**

Hosting organisation: **CNRS, France**
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Total eligible costs: **€ 345,000**

European Union contribution: **€ 345,000**

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