Development of a Low Cost European Parabolic Trough Collector

EUROTrough

Project partnership:

CIEMAT, CRES, DLR, FICHTNER Solar,
FLABEG Solar, INABENSA (coordinator), SBP

Contract: JOR3-CT98-0231

Publishable Final Report

Reference Period:
August, 1998 to January, 2001

Research funded in part by
THE EUROPEAN COMMISSION
in the framework of the
Non Nuclear Energy Programme
JOULE III

Table of contents

1 Abstract

Solar parabolic trough collectors are the key element in the current commercial application of concentrating solar thermal power plants. Although other concentrators promise higher concentration factors and higher system efficiencies, the parabolic trough will continue paving the way for concentrating solar power. Considering this importance a European consortium has developed the next generation of a parabolic trough collector based on European know-how and the long operating experience of the LUZ collector types LS-2 and LS-3 in the Californian Mojave Desert.

Within Phase I of the EUROTrough project an advanced parabolic trough collector has been developed for various applications in the 200-400°C temperature range for solar fields capable of delivering up to hundreds of MW of energy. With this, a step towards more competitive solar power generation has been achieved based on the expectations of lower cost and higher performance of the collector. Similar to other European project work on trough collectors (e.g., direct steam generation) this project aims at improved market penetration in the near-term future.

The work targeted collector development for a wide range of applications:

- Solar thermal electricity generation
- Solar thermal process heat applications
- Solar thermal sea-water desalination

The design of a new support structure for the collector, a key objective, included concept studies, wind tunnel measurements, and finite element method (FEM) analyses, resulting in a structure with a central box framework element. This torque box design will have lower weight and less deformation of the collector structure than other designs considered. Therefore it will be possible in the future to connect more collector elements on one drive, resulting in a lower total number of drives and interconnecting pipes, and thus reducing the installation cost and thermal losses. In terms of the degree of material usage further weight reduction will be possible. Other design work included the drive and control systems, mirror attachments, manufacturing and transport scenarios, and construction methods. The new design has achieved significant cost reduction for manufacturing, installation and operation, the most important goal of the EUROTrough project. A prototype collector segment has been set-up and is under testing at PSA (Plataforma Solar de Almería) for its thermal and mechanical properties in a follow-up project.

Worldwide interest in solar thermal technology is a driving force for the ongoing work on the parabolic trough collector design. The design developed in this program is available for interested license takers. Current project information can also be viewed on the website “www.eurotrough.com”.

2 EUROTrough Phase I Partners

Partner companies of Phase I of the EUROTrough project and their contact data are as follows:

PARTNER	CONTACT PERSON	ADDRESS
INABENSA (project coordinator)	Mr. Rafael Osuna	C/ Manuel Velasco Pando, 7 E-41007 Sevilla; Spain Tel: +34 95 4936217 Fax: +34 95 4936015 E-mail: rosuna@inabensa.abengoa.com
Schlaich Bergermann und Partner	Mr. Wolfgang Schiel	Hohenzollernstraße 1 D-70178 Stuttgart; Germany Tel: + 49 (711) 6 48 71-20 Fax: + 49 (711) 6 48 71 - 66 E-mail: w.schiel@sbp.de
FLABEG Solar International	Mr. Josef Langenkamp	Mühlengasse 7 D-50667 Köln; Germany Tel: +49-221-925970-0 Fax: +49-221-2581117 E-mail: josef.langenkamp@flabeg.com
CIEMAT Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas	Mr. Eduardo Zarza	P.O. Box 22 E-04200 Tabernas; Spain Tel: +34 950 387931 Fax: +34 950 365015 E-mail: Eduardo.zarza@psa.es
DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.	Dr. Eckhard Lüpfert	Apartado 39 E-04200 Tabernas/Almería; Spain Tel: +34 950 387906 Fax: +34 950 365313 E-mail: e.luepfert@dlr.de
FICHTNER Solar	Mr. Georg Brakmann	Sarweystrasse 3 D-70191 Stuttgart; Germany Tel: +49 (711) 8995535 Fax: +49 (711) 8995459 E-mail: brakmanng@fichtnersolar.com
CRES Centre for Renewable Energy Sources	Mrs. Eva Kotsaki	19th km Marathonos Avenue 19009 Pikermi; Greece Tel: +30-1-6039900 Fax: +30-1-6039905 E-Mail: kotsaki@cres.gr

3 Project Objectives and Strategic Aspects

In the EUROTrough project many of the most active high temperature solar thermal European industrial partners and research organizations in the field of solar parabolic trough technology have joined forces to initiate the development of an advanced, low cost European parabolic trough collector for solar electricity generation and process heat applications. Details on the overall objectives are:

- industrial development of a new European design of parabolic trough collector modules, incorporating the newest features in lightweight construction, drive technology, control technology and concentrator technology with a collector weight below 30kg/m²,
- development of a standard interface for different absorber types:
  - low pressure saturated steam absorber for applications below 200°C
  - low pressure mineral oil absorber for applications from 200°C to 300°C
  - low pressure synthetic oil absorber for applications from 300°C to 400°C
- achievement of a mass manufacturing, transport and assembly concept that allows the economic implementation of parabolic trough collectors for electricity generation, desalination and process heat applications ranging from a few MW up to several hundred MW,
- definition of suitable applications in the field of process heat, desalination and electricity generation,
- expanded automation of operation,
- minimization of O&M requirements,
- reduction of solar collector costs below 200 US$/m², and
- a possibility to integrate the solar heat source into co-generation processes.

The following approach has been taken to achieve the R&D objectives of this project:

- Two alternative collector structure concepts have been developed and analyzed for their cost and performance,
- One optimum design concept has been selected, for which the detailed procurement specifications and manufacturing drawings are completed,
- 280m² of a representative collector segment have been manufactured and installed at the existing solar facilities at Plataforma Solar de Almería,
- An initial testing program was conducted to qualify the prototype experimentally and to validate the performance prediction models,
- During manufacturing and erection, costs were carefully tracked to validate the cost predictions,
- Standard, modular system concepts for commercial applications have been developed, and
- Desalination and other process heat applications were identified which are feasible for the use of solar thermal energy.

For all partners, the achievement of the above stated objectives result in the following industrial benefits:

1. obtain a strong position of world-wide leadership in renewable electricity generation and co-generation systems,
2. secure a European developed and owned parabolic trough design,
3. secure European system know-how for offering parabolic trough fields based on the EUROTrough concept to World Bank/GEF projects, and
4. secure a solar concentrating technology suitable for the process heat market starting from a few MW.

4 Technical Description

4.1 Task 1: Collector Design

As mentioned before, the objective of the EUROTrough collector design task was the development of a new light weight collector structure for a solar parabolic trough power plant having a total specific weight of not more than 30 kg per m² aperture area, and thus being less expensive than existing collector structures. The optical collector performance should be equal to or even higher than the performance of the collector elements operating in various solar electric power plants in the US.

For approaching this aim the new collector structure should have the following features in comparison to existing collector elements:

- Reduction of the numbers of different collector parts for mass production, leading to less expensive manufacturing,
- Optimization by detailed FEM[1] analysis to achieve overall weight reduction,
- A more rigid collector design to reduce collector deformation due to wind loading during operation, thus increasing optical performance, and
- An optimized on-site collector assembly procedure and the associated assembling tools for achieving the required collector contour during system erection.

The following main deliverables have been achieved:

- detailed engineering specifications of all collector components of the new design,
- tender documents for a solar collector element including its support structure and drive system,
- documentation of assembling and erection procedures as far as design of required assembling and erection tools, and
- manufacturing drawings of the full size EUROTrough collector.

[1] **F**inite **E**lement **M**ethod used in structural design

The collector design phase was structured into the following work packages:

- Conceptual design of two alternative industrial collectors and their comparison with existing collector designs,
- Cost and performance analysis of the alternative industrial designs,
- Review and selection of one of the two alternative industrial collector concepts.
- Detailed design of the selected concept, elaboration of manufacturing drawings, and technical specifications including support structure, drive system, absorber, heat transfer fluid, control and instrumentation,
- Achievement of a manufacturing, transport and assembly concept with respect to future large-scale plant installations, and
- Development of a logistic, supply, transport and erection concept.

4.1.1 Conceptual Design

Early in the conceptual collector design phase, detailed FEM analyses of existing collector designs were performed. These results provided a sound basis of collector behavior under various operation conditions, e.g., elevation angle, location in the field, and wind direction. A draft EUROTrough specification list that forms the basis of the first conceptual collector design work was then derived, assisted by additional theoretical analysis of the different system components in combination with operation and maintenance experience in California at the SEGS plants, and the experience of the project partners Inabensa, FLABEG Solar, CIEMAT and DLR during manufacturing, erection and operation of the DISS-collector at the Plataforma Solar de Almeria.

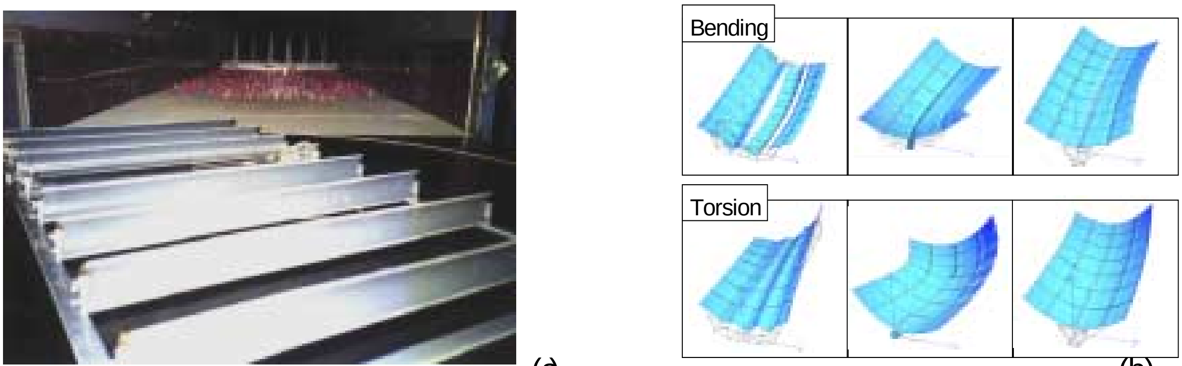
Based on this first set of technical specifications the main design parameters were derived, discussed with the partners, and approved by the consortium as the basis of the conceptual collector design phase. For example, the main parameters included the geometric boundary conditions (collector width and length), system weight and expected optical collector performance in terms of required accuracy of the components.

In addition it was found that the publicly available data on local and overall wind loads on the collector structure were not sufficient for an optimized collector design. Thus it was decided to perform a wind tunnel test for measuring the required wind forces in term of local pressure coefficient values for various wind directions, collector elevation angle and collector location in the field.

The following list summarizes the main tasks performed during the conceptual design phase:

- Acquisition of additional financial resources for the required wind tunnel tests,
- Execution of the wind tunnel tests to determine local and overall wind forces to the collector for various field positions, collector angles and wind directions,
- Conceptual design of two different new collector structures,
- Detailed FEM analysis of the designed structures,

- Determination of the structural deformation under operating conditions in terms of bending and twisting of the collector elements (see Figure 1),
- Preliminary design of the drive system,
- Consideration of manufacturing, assembly, transportation and erection aspects,
- Calculation of the expected optical performance based on the deformed collector structure,
- Analysis of wind data for potential plant sites worldwide,
- Analysis of wind safety regulations in different potential countries, and
- Determination of expected transportation and collector erection cost.



(a) (b)

a) Experimental set-up of the wind tunnel test. Cp values have been measured at different positions of the collector element, different locations in the field and various pitching angles of the SCE as well as different wind directions.

b) Calculated structural deformations of various collector design

Figure 1 Experimental set up in wind tunnel

At a final conceptual design review meeting, the preferred collector design concepts were presented to the industry consortium and discussed in detail. It was found that the torque box structure, consisting of a 12 m long torque box with 14 cantilever arms on each side for attachment of the single mirror facets, was the most promising concept to achieve the project objectives.

4.1.2 Detailed Design

Within the next collector design phase, all parts and components of the torque box design were detailed. Extensive FEM calculations have been performed for dimensioning all parts and calculating the expected stress levels for various operation and survival positions.

The main work packages were:

- Elaboration of collector specifications,
- Determination of final load and design criteria,
- Finalizing of the EUROTrough collector structure by detailed FEM analysis,

- Finalizing of the drive system design,
- Tender drawings of the collector structure for budgetary quote,
- Construction drawings of the collector support structure including absorber support,
- Construction drawings of the pylons,
- Construction drawings of the drive system,
- Reinforcement design of the foundation, and
- Finalizing of detailed engineering specifications and tender documents.

Through completion of this work package a full set of manufacturing drawings of all steel components, including bolt and part lists, were generated, as well as a detailed specification schedule for all components. Further, the design of the erection jig was finalized as well as the detailed description of manufacturing requirements and erection procedures.

The key characteristics of the EUROTrough collector concept are summarized in Table 1 below:

Layout	parabolic trough collector
Support structure	steel frame work, pre-galvanized, two variants with light weight, low torsion
Collector length	12 m per element; 100 - 150 m collector length
Drive	hydraulic drive
Max. wind speed	operation: 14 m/s; stow: 40 m/s
Tracking control	Mathematical algorithm + angular encoder checked by sun sensor
Parabola	$y = x^2/4f$ with f = 1.71 m
Aperture width	5.8 m
Reflector	28 glass facets per SCE
Absorber tube	evacuated glass envelope, UVAC® or other, application dependent
Fluid	oil, steam, application dependent
Cost	< 200 Euro/m^2

Table 1 EUROTrough characteristics

4.1.3 Cost Tracking and Performance Modeling

This section summarizes the performance and cost information gathered during the first phase of the project. Furthermore, the benefits that might be expected from the new collector design are estimated.

According to the results of the favorable deformation analysis of the collector structure, a EUROTrough collector composed of 12 solar collector elements (SCE) is expected to have the same optical accuracy and similar performance characteristics as the shorter LS-3 collector (8 SCE's long).

Detailed measurements will be performed at the prototype of the EUROTrough collector erected at the PSA to assess those improvements, and a detailed performance analysis will be made during Phase II of the project.

The cost calculations are based on the assumption that each EUROTrough collector will consist of 12 SCE's, compared to the LS-3 structure comprised of 8 SCE's per 100 m SCA.

Since the cost of the metal support structure will largely depend on its mass, the weight of the EUROTrough structure was calculated and compared to the LS-3.

Actual collector weights were calculated for both the 100m option, which was erected within Phase 1, and the extension to 150m, which will be constructed during Phase 2 of the project. Since the strong version of the EUROTrough collector will only be used for outer unshielded rows, about 95% of the solar field will consist of regular collectors, the so-called "Field Version". Based on the strong collector design concept and the reduced wind forces to be expected within the solar field, SBP calculated the weight of the regular collector structure (presented in Table 2).

EuroTrough Collector Field Version	**For 1 SCE**	**For 100m (8 SCE)**	**For 150m (12 SCE)**
Component:	[kg]	[kg]	[kg]
Glass mirrors	747	5,976	8,964
HCE	73	584	876
Subtotal:	**820**	**6,560**	**9,840**
Metal Support Structure:			
Box	597	4,776	7,164
End Plates	130	1,043	1,564
Cantilever Arms	231	1,844	2,767
HCE supports	90	720	1,080
Torque Transfer	32	254	382
Middle Pylon	-	728	1,092
Bearing on Middle Pylon	-	131	196
Drive Pylon (without Hydraulics) (incl. Bearing and Torque Transfer)	-	860	860
Subtotal:	**1,080**	**10,357**	**15,105**
LS-3 structur weight* (steel only)	1,229	12,020	17,717
Weight reduction of ET vs LS-3	**12%**	**14%**	**15%**

*) Weight of 150 m LS-3 estimated

Table 2 Weight of Regular Collector Structure

In the next step, the collector costs were evaluated in detail. Similar to the weight reduction, there are two reasons for the cost reduction: the reduced number of components (e.g., hydraulic systems, control units, sensors, etc.) and the lower cost of single components such as the metal support structure.

The total unit cost in US$/m^2 of the metal parts needed for one collector[2] decreases about 15% from the LS-3 to the EUROTrough design. This is due to the lighter structure and, with this, lower material and manufacturing costs. A cost increase of 25% is anticipated for the hydraulic drive system, as there are more SCEs installed at one drive unit which will lead to higher forces. Simplified erection and lower transport cost leading to additional savings. Overall, the expected investment cost reduction of the EUROTrough design versus the LS-3 design is on the order of 8%.

In addition to this, operation and maintenance savings are expected due to easier mirror cleaning, less complex realignment requirements, and fewer components due to the longer collector length.

[2] For a 100m long LS-3 compared to a 150m long ET collector.

4.1.4 Alternative Design Based on Metallic Sheet Reflectors

In an effort to improve the collector design via a different design approach compared to the mainstream EuroTrough concept, CIEMAT analyzed the possibility of simultaneously improving collector efficiency and reducing cost by integrating the optical and structural functions in just one component: a parabolic trough with a thin metallic sheet as the substrate of a front surface mirror (*Metallic Collector*). One of the goals in the EUROTrough project was to solve the problems associated with structural issues of such a design, i.e. optimizing the structure, taking into account that the reflector substrate (a metallic foil) acts as a structural element, and finding the best way of mounting the reflector substrate to assure a good parabolic shape.

After a preliminary theoretical study, two metallic collector designs were chosen for further work: a stretched thin metallic concept (0.2 mm thickness) and a non-stretched thick metallic concept (0.5 mm thickness). Two small prototypes (aperture 1.2 m) were built for analyzing the geometric behavior as well as mounting processes. Based on torque box structure concept, a 3D triangular structural matrix was used for the stretched prototype and a 3D square structural matrix for the non-stretched prototype. Seeking simplicity in procedures and good optical performance, the mounting processes for both concepts have been significantly improved.

4.2 Task 2: Tracking Control and Data Acquisition

The tracking system developed by CIEMAT for this project is based on a local control with an open loop concept, wherein the sun position is known by the calculus of the solar vector, and compared with the angular position of the collector. The solar vector is obtained by a mathematical algorithm and the collector position by an optical encoder. This information is handled by a local control, which sends an order to the drive system, inducing tracking.

This tracking control design evolved from the previous 'virtual' tracking controls installed in the LS-3 and DISS loops. The design activities can be gathered in three general lines:

- Local Control. Looking for a flexible and optimized design, the local control has been divided in two electronic cards: the OTE0015, in charge of control itself, i.e., reading encoder outputs, making calculations and handling orders and information; while the OTE0032 is the electronic device to assemble the EUROTrough power drive system requirements. Basically, both electronic cards have been optimized focusing on a decrease in cost as well as on a high capability of computing and processing. The PLC has been reprogrammed and the software of the central PC has been modified for consistency with the LS-3 and EUROTrough local controls
- Optical Encoder. A wide market research for absolute encoders with an SSI bus connection has been carried out. The previous absolute encoders had a parallel bus connection, limiting the separation to the local control to 5m, while for the current design, with SSI connection, it is possible to have a 100m separation. The encoder model has been chosen taking into account structure requirements (e.g., axial plug instead of radial plug, total encoder size, etc.)
- Solar Vector Calculus. Actualized mathematical algorithms have been looked for during the project. Following initial use of an algorithm based on Michalsky's, the

final implementation is based on the SunPos3.0 algorithm, developed at PSA, which assures an accuracy of 0.14 mrad for the solar vector until 2015.

On the basis of the design of this local control, a system to evaluate collector twisting for different times during the day has been developed. Initially it was planned to be installed at the Harper Lake SEGS plant in California, but this idea proved unworkable for non-technical reasons. Subsequently, it was implemented in the 11-collector row at the DISS site at PSA. An optimized version of this system will be installed in EUROTrough collector at PSA in the second phase of this project.

4.3 Task 3: Implementation of the Collector Prototype

As mentioned before, four Solar Collector Elements (SCE) of the EUROTrough I prototype were manufactured and installed for testing at the Plataforma Solar in Almería (see Figure 2).

Figure 2 EUROTrough prototype installation at the PSA

A detailed evaluation was made of the manufacturing and construction aspects of the EUROTrough collector design in comparison the SEGS LS-3 design in order to estimate differences in complexity of the operations and in the manpower requirements. Each element of the collector is treated in this way, and the results compiled in a single tabular summary. The evaluation includes the steps of manufacturing, metal treatment (galvanization), transport to the site, and site erection.

The results show that a slight manpower reduction per square meter can be observed for the EUROTrough collector (37.5 minutes/m^2) in comparison with the LS-3 collector (39.0 minutes/m^2). Nevertheless the difference could be higher if the task of assembling the mirrors could be simplified as in the LS-3 collector (e.g., with a redesign of the mirrors joints). It is important to remark that the manpower reduction for the EUROTrough collector, obtained with a simplification of the torque box instead of the space frame (about 13.9 vs. 18.7 hours per collector) is lost with the increase in the mirrors assembly task (from 7.8 hours in the LS-3 collector to 12.1 in the EUROTrough). Since the pylons of both designs are based on the same concept, no erection advantages have been identified in the tasks of erecting them nor in the task of assembling the collectors to the pylons. There are also no differences for the task of welding and assembling the HCE.

4.4 Task 4: Performance Prediction and Experimental Validation

The task "Performance Prediction of the EUROTrough Collector and its Experimental Validation" includes theoretical work on the thermodynamic and optical behavior of a EUROTrough solar collector as well as the testing of the prototype.

The main parameter to evaluate on the prototype at the end of the task is the thermal efficiency and its comparison to other existing solar collectors. For the formulation of the efficiency two different approaches are considered:

- The experimental approach considers the efficiency as a function of the collector temperature in the form of a parabolic curve, for which the 3 parameters can be determined by least-square analysis, and
- The theoretical approach is based on treating the total losses in three components: thermal losses, optical losses and geometrical losses. The theoretical model best describes the physics of the radiation and its conversion into heat. Several of the involved parameters are difficult to determine in the test stand, though some of them can be approached with simplified models.

The test program aims particularly at the determination of the overall collector efficiency as a function of the fluid temperature, the direct normal irradiation and the incident angle of the radiation to the optical axis.

At this stage in the project, testing of the prototype EUROTrough collector has been started, including the oil loop preparation and thermal pre-treatment of the thermal oil used in the test loop.

Initial tests included steady state operation of the collector at various temperature levels from ambient to 380°C. During the tests, once-a-day normal incidence of the sun's rays on the collector occurs, due to its orientation on a east-west axis. The test result raw data includes all test loop parameters, including temperatures, volume flow and pressure, as well as pumping power, cooling power and logical signals and position from the collector tracking controller.

The evaluation results will be published following completion of the data checks and analysis.

4.5 Task 5: Market Introduction and Dissemination

4.5.1 Industrial Process Heat Requirements in Mediterranean Countries

Within this task, industrial process heat requirements in Mediterranean countries were assessed, with Greece and Egypt serving as typical countries. This section summarizes the detailed investigations of industrial process heat (IHP) requirements of Egypt segregated by temperature range and suitability for solar process heat generation, based on published sources.

In Egypt, industrial process heat is mainly used in the 80 – 150 °C temperature range. There is another major use at temperatures above 300°C, largely in the metal sector. The fuel consumption segregated by temperature and sub-sectors is shown Figure 3.

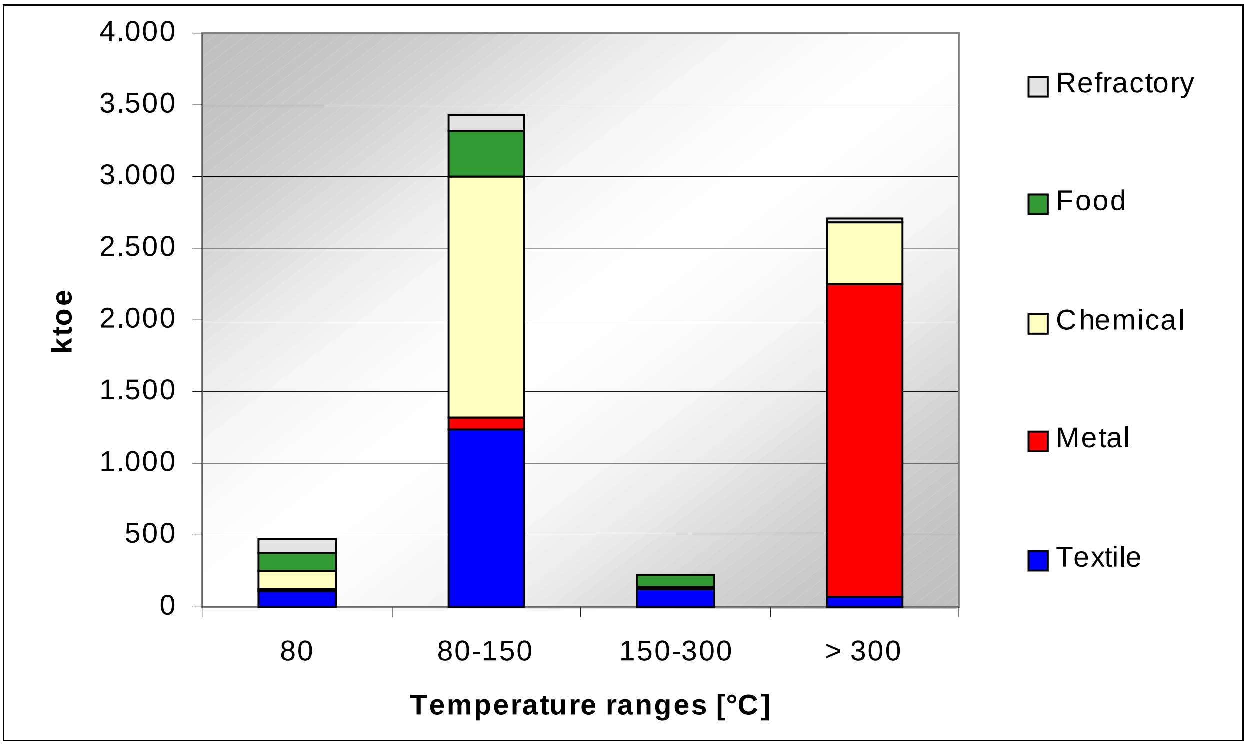


Figure 3 Industrial Process Heat Demand by different industrial sub-sectors and different temperature ranges in 1995

Experience gained with the various evacuated tube and parabolic trough collectors indicates that collector performance mainly depends on how high the operating temperature is above ambient and the intensity of the incident radiation. The thermal output of different collector options were determined for the solar conditions of Cairo and used in the analysis, which shows clearly that without concentration collector performance drops drastically for higher temperatures. For Industrial process heat application a concentrating collector like the EUROTrough is required.

The total market potential for Solar Collectors for Industrial Process Heat Application has been estimated as follows:

Basis:	year	1995	2003	2011
Primary energy consumption for IPH in 80 – 300°C temperature range	**ktoe*/a**	3 700	4 800	6 300
Potential savings by solar plants (without thermal storage)	**ktoe/a**	**550**	**720**	**950**
Total solar collector area	**million m^2**	3.8	4.9	6.3
Effect of thermal storage		The fuel savings and market potential will increase by 30 %		

* ktoe – kilo tons oil equivalent

Table 3 Market potential for solar IPH in Egypt

4.5.2 Financing Considerations for Demonstration Plant

With the state-of-the-art price of 200 €/m^2 for the specific solar field costs, a demonstration project (first of its kind) in Spain will represent a challenging task for any project developers. Even for a target price for the EUROTrough collector of 178 €/m^2,a sound demonstration project will not be realized if the financing conditions correspond to the base case assumptions without additional grants. A low interest loan with a debt ratio of at least 80% and a grant of 25-30 million € (=20% grant proportion) would be essential for a first demonstration project. Table 4 shows the base case assumptions.

Description	Assumed Value
Location	Southern Spain
Direct Normal Irradiation	2000 kWh/m^2
Capacity	50 MW_{el}
Solar Share	100%
Solar field size	383 000 m^2
Annual electricity output	96 GWh
Total plant investment cost	138 million €
Plant lifetime	25 years
Interest rate	4%
Grants	10%
Solar field cost	200 €/m^2
Solar electricity tariff (planned)	0.156 €/kWh

Table 4 Assumptions for Demonstration Plant in Spain

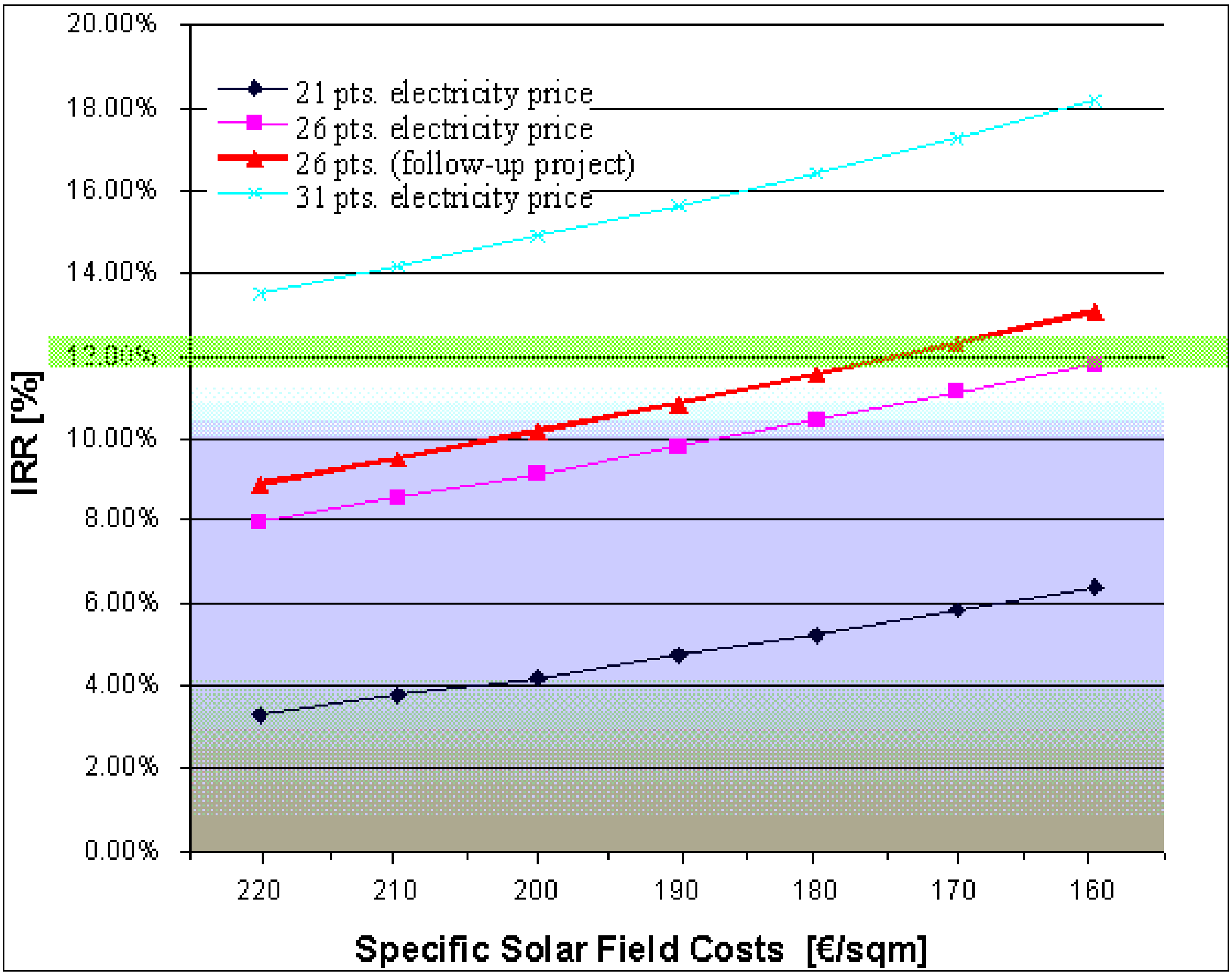


Figure 4 Internal Rate of Return (IRR) sensitivity depending on the solar collector costs and the electricity tariff

Figure 4 demonstrates that a 50MW parabolic trough power plant in southern Spain would only achieve an IRR of at least 12% either for specific solar collector costs below 170 €/m^2 at an electricity price of 26 pts, or a tariff above 30 pts/kWh at a solar field cost of 200 €/m^2.

4.5.3 Environmental Impact

A project study of environmental impacts and environmental benefits has shown detailed results on resource needs, impacts and benefits of the solar parabolic trough technology (EUROTrough). Exigencies of current European - especially Spanish - environmental regulations fit with the properties and impacts of a Solar Thermal Power Plant with trough collectors. The technology is able to fulfill exigencies of the European White Paper of 1997 and of the European directive “on the promotion of electricity from renewable energy sources in the internal electricity market” to introduce renewable energy for greenhouse gas mitigation in an efficient and environmentally and socio-economically compatible and beneficial way in Southern Europe and elsewhere in the world.

5 Results and Conclusions

The outcome of the EUROTrough project is above all the prototype of a commercial product under testing, along with associated detailed background information. This is an excellent milestone on the way towards the next solar power plants and the aim of reducing CO_2-emissions in power generation with renewables. With knowledge gained from European and other resources, this technology is in a strategic starting position for worldwide project opportunities. Thus the project consortium has achieved a leading position in concentrating solar power technology. The partners are very satisfied with the overall results and the general situation at the end of this project phase. The project objectives have been almost fully accomplished, some of them with a certain delay after extensions in the design phase.

The design of the new trough collector support structure, including conceptual studies, wind tunnel measurements, and finite element (FEM) calculations, resulted in a structure with a central box framework element. This torque box design showed lower weight and less deformation of the collector structure than the other considered design options. Therefore it will be possible in future to connect more collector elements on one drive, resulting in a reduced total number of drives and interconnecting pipes, thus lowering the thermal losses, installation and O&M cost. In terms of the degree of material usage it is expected that further weight reduction will be possible. The final design has a significant potential for cost reduction, the most important goal of the EUROTrough project. A prototype collector has been set-up and is under testing at PSA (Plataforma Solar de Almería) for its thermal and mechanical properties. Alternate sheet metal collector designs are also under consideration for future comparison to the primary reference design.

Figure 5 EUROTrough Prototype at the Plataforma Solar de Almería

A virtual tracking control concept has been designed and optimized, with an expected tracking accuracy of about 0.8 mrad. This accuracy is obtained by considering the combination of both the optical encoder accuracy (0.77mrad) and the solar vector mathematical algorithm accuracy (0.14mrad). In addition to this, a sun sensor has been installed at the EUROTrough prototype in order to check the virtual tracking system. The main features of the local control design are flexibility, low cost and high operation capability of collector field.

Regarding implementation of the new design in power plants, the main ways identified that can reduce the manufacturing costs are the reduction of the structure weight as well as the manufacturing manpower.

A thermodynamic model for parabolic trough collectors has been detailed for the EUROTrough prototype, and the test program has been prepared. Evaluation is still ongoing as a consequence of the delayed construction of the prototype collector.

Besides the obvious market for electricity production commensurate with saving CO_2 emissions, there is a sizable market for the EUROTrough collector for producing industrial process heat in the medium temperature range. Here the focus is on applications in the range of 80 – 150°C. Using Egypt as an example, this market potential has been estimated at 6.3 million m^2 of collector area that could potentially be installed over the next ten years. If these collectors are combined with low cost thermal storage then the potential will further increase by 30%.

The technology fits European environmental regulations. It is able to fulfill exigencies of the European White Paper of 1997 and of the European directive “on the promotion of electricity from renewable energy sources in the internal electricity market” to introduce renewable energy for greenhouse gas mitigation in an efficient and environmentally and socio-economically compatible and beneficial way in Southern Europe and elsewhere in the world.

Coordination of the partners has been excellent during the course of this project. A consortium agreement has been prepared and signed by all partners. It stands in order to execute and fulfill the EC Contract and defines responsibilities, ownership, exploitation and dissemination of results and further agreements. There remains a critical need to implement full loop testing of the new EUROTrough collector to prove the readiness of the design in preparation for market introduction in the context of upcoming project opportunities in Europe and worldwide.

6 Exploitation Plans and Anticipated Benefits

Minimizing the environmental impact of the cost-effective production and use of energy in Europe will help preserve the ecosystem by reducing emissions at local and global levels and by increasing the share of new and renewable energy sources in the energy system. It will also have socio-economic impacts by enhancing the capability of European industry to compete in world markets, helping to secure employment and promoting social cohesion with less favored regions.

The industrial development of a European parabolic trough technology has a strategic role for the competitiveness of the involved European solar equipment suppliers in the upcoming solar thermal projects initiated by the World Bank's Solar Initiative and the Global Environmental Facility (GEF).

It has been demonstrated in California that parabolic trough systems are among the most cost effective renewable power technologies. Over 80 years of accumulated operating experience with nine solar thermal power plants of the parabolic trough type have fed over 7 billion kWh of solar-based electricity into the Californian grid. The parabolic trough technology is now ready for more widespread application.

The joint European development of a European parabolic trough collector technology is therefore a strategic step for the European solar thermal industry to become fully capable to design, manufacture and offer the presently most mature and competitive solar thermal technology - parabolic troughs. The fulfillment of the objectives of the EUROTrough project guarantees an improvement of the competitiveness of European industry and will serve as a worldwide showcase.

The short to mid-term exploitation plans of the EUROTrough Partners are shown in the following table:

Activity	Description
Build one EUROTrough Loop	Build one demonstration loop of the EUROTrough collector consisting of 6-8 collectors of 100m length (FICHTNER, FLABEG Solar, INABENSA, SBP,DLR, CIEMAT)
Offer EUROTrough Solar Fields to GEF Projects in India, Morocco, Egypt, Mexico	Offer 200,000-300,000m² of EUROTrough Solar Fields in response to the RFP's coming 2001-2002 for the GEF supported solar thermal projects in India, Morocco, Egypt and Mexico (FICHTNER Solar, FLABEG Solar, INABENSA, SBP)
Offer EUROTrough Solar Fields to solar plant developers in Europe	Offer 200,000-400,000m² of EUROTrough Solar Fields to developers that implement parabolic trough plants in Europe in the context of RES-E directive implementation (FICHTNER Solar, FLABEG Solar, INABENSA, SBP)
Evaluate extension of the EUROTrough from 100 to 150m	Design and Prototype Testing at Plataforma Solar
Publication and promotion of the technology and the project results	Publication through international institutions (e.g., SolarPACES, EUREC, World Bank), conferences, papers, Internet pages, books, education and training

Table 5 EUROTrough Exploration Plans

Figures

Tables