International Energy Agency (IEA)

Solar Power and Chemical Energy Systems

SolarPACES

Annual Report 2006

Edited by M. Geyer

in cooperation with

M. Mehos, A. Meier, R. Meyer, C. Richter, W. Weiss

Deutsches Zentrum für Luft- und Raumfahrt e.V.

Cover picture:
Nevada Solar One
(Photo courtesy of Acciona Solar Power)

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April, 2007

DLR

Deutsches Zentrum für Luft- und Raumfahrt e.V.
Köln/Germany

Further information on the IEA-SolarPACES Program can be obtained from the Secretary, from the Operating Agents or from the SolarPACES web site on the Internet http://www.SolarPACES.org.

The opinions and conclusions expressed in this report are those of the authors and not of DLR.

Editors

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Tom Mancini
Chairman, SolarPACES
Executive Committee

Foreword

Hello All,

The year 2006 has been all that was promised for CSP and much more. The 13th International CSP Symposium in Spain was a fantastic success with many presentations, a visit to PS 10, and attendance exceeding 300 persons. (I personally shared an "appropriate beverage" with at least half of the conference attendees.) The 10 MW_e Solucar power tower Planta Solar (PS10) located near Sevilla, Spain started operation in the fall; Solargenix, a subsidiary of Acciona, is scheduled to bring a 64 MW trough plant on line in Nevada, USA in April of this year; and two Andasol trough plants, under development by ACS Cobra and Solar Millenium, are under construction in the plains northeast of Granada, Spain.

Solar Requests for new projects around the world are at an all-time high and a number of projects have closed or started operation. New Energy Algeria (NEAL) has accepted a proposal from Solucar (Abengoa) to build the solar field for a 150 MW hybrid solar/gas power plant at Hassi R'mel. The Egyptian project at Kuraymat is scheduled to close soon.

With the development of so many projects around the world, we are finding this to be not only an exciting time for CSP but also a very challenging one. Technology transfer from R&D laboratories is happening at an ever increasing rate. In some cases, staff are leaving R&D positions to join development companies. We wish them all well and look forward to working with them as projects continue to develop and enter construction and validation phases. The migration of staff places pressure on all of us to develop new researchers and staff who will help us carry the momentum that has been building and has brought us to where we are today. This is an exciting challenge for all of us and, I am sure, one that we are all happy to assume.

Best Regards,

Thomas R. Mancini

SolarPACES Chair

Table of Contents

List of Acronyms

AEE............. Austrian Ministry of Transport, Innovation and Technology
AERONET.... Aerosol Robotic Network
ANL .... Argonne National Laboratory (USA)
AOP .... advanced oxidation process
APS............. Arizona Public Service Co. (USA)
ASME .... American Society of Mechanical Engineers (USA)
ASES .... American Solar Energy Society
AUS .... Australia

B .... Belgium
BFE .... Swiss Federal Office of Energy (CH)
BMU .... Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (D)
BSRN .... Baseline Solar Radiance Network

CB .... carbon black
CC .... combined cycle
CCD........... Charge-coupled device
CDM .... clean development mechanism
CEA............ Commissariat à l'Energie Atomique (F)
CERT........... Committee on Energy Research and Technology (IEA)
CESI............ Centro Elettrotecnico Sperimentale Italiano
CFD............ computational fluid dynamics
CFE............. Comisión Federal de Electricidad (MEX)
CH.............. Switzerland
CHP............ combined heat and power
CIEMAT....... Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (E)
CLFR........... compact linear fresnel reflector
CNRS........... Centre National de la Recherche Scientifique (F)
CPC .... compound parabolic collector
CR5 Counter Rotating Ring Receiver Reactor Recuperator
CSIC........... Higher Council for Scientific Research (E)
CSIR .... Council for Scientific and Industrial Research
CSIRO .... Commonwealth Scientific and Research Organisation (AUS)
CSP .... concentrated solar power
CST............. concentrating solar technologies
CU.............. University of Colorado at Boulder

D.................. Germany
DG RDT....... Directorate General Research Development and Technology (EC)
DG TREN..... Directorate General Transport and Energy (EC)
DISS .... Direct Solar Steam

DLR	Deutsches Zentrum für Luft- und Raumfahrt e.V. (D)
DLR ISIS.......	*Irradiance at the Surface derived from ISCCP cloud data*
DNI	direct normal irradiance
DOE.............	Department of Energy (USA)
DSG	direct steam generation
E..................	Spain
EAWAG......	Swiss Federal Institute of Aquatic Science and Technology
EC...............	European Commission
ECMWF	European Centre for Medium-Range Weather Forecasts
EGY	Egypt
ENEA	Agency for New Technology, Energy and the Environment (I)
ENSMP........	Ecole des Mines de Paris (F)
EPC.............	engineering, procurement, construction
EPFL	Ecole Polytec. Federale de Lausanne (CH)
ESTIA...........	European Solar Thermal Industry Association
ET	emission trading
ETH..............	Institute of Energy Technology (CH)
EU	European Union
ExCo...........	Executive Committee (SolarPACES)
F	France
5th or 6th FP	5th or 6th Framework Programme (EC DG RDT)
FEM.............	Finite element method
GA	General Atomics (USA)
GEBA	Global Energy Balance Archive
GEF.............	Global Environmental Facility
GEO	Group on Earth Observations
GEOSS........	Global Earth Observation System of Systems
GEWEX.......	Global Energy and Water Cycle Experiment
GHI	global horizontal irradiance
GISS	Goddard Institute for Space Science (NASA)
GMI	Global Market Initiative
GR	Greece
GSFC	Goddard Space Flight Center (NASA)
ha	hectare
HHV	higher heating value
HIA..............	Hydrogen Implementing Agreement (IEA)
HTF..............	heat transfer fluid
I...................	Italy
IA	Implementing Agreement (IEA)
ICP..............	Instituto de Catálisis y Petroleoquímica (E)
ICROSS.......	International Community for the Relief of Starvation and Suffering (Kenya)
ICV	Instituto de Cerámica y Vidrio (E)
IEA	International Energy Agency
IIE	Instituto de Investigaciones Eléctricas (MEX)

IL..................	Israel
INCO...........	International Cooperation Programme (EC)
INETI	Instituto Nacional de Engenharia, Tecnologia e Inovação (P)
IPHE	International Partnership for the Hydrogen Economy
ISCCS..........	integrated solar combined cycle system
ISCCP	International Satellite Cloud Climatology Project
ISE................	Institute for Solar Energy Systems
ISES..............	International Solar Energy Society
ITES	
ITW	Institut für Thermodynamik und Wärmetechnik (Univ. Stuttgart) (D)
IWSD	Institute of Water and Sanitation Development (Zimbabwe)
JIA...............	joint implementation actions
JRC	Joint Research Centre (EC)
KfW..............	Kreditanstalt für Wiederaufbau (D)
KJC	Kramer Junction Company
LFR...............	linear Fresnel reflector
LHV..............	lower heating value
LSPMS	Laboratoire Structures, Propriétés et Modélisation des Solides (F)
MAR............	Morocco
MaReCos...	Maximum Reflector Collectors
MEX.............	Mexico
MFR.............	mixed flow reactor
MODIS	Moderate Resolution Imaging Spectroradiometer
MPP.............	Model Power Plant
MSIR............	Multi-angle Imaging SpectroRadiometer
MTTS............	Medium Temperature Test Stand
N..................	Norway
NASA LaRC	National Aeronautical and Space Administration Langley Research Center (USA)
NC...............	National Coordinator (Task 2)
NCAR..........	National Center for Atmospheric Research (USA)
NCEP	National Centers for Environmental Prediction
NEAL	New Energy Algeria
NL................	Netherlands
NOAA.........	National Oceanic and Atmospheric Administration (USA)
NREA...........	National Renewable Energy Agency (EGY)
NREL............	National Renewable Energies Laboratory (USA)
NSO.............	Nevada Solar One (USA)
O&M...........	Operation and Maintenance
OA	Operating Agent (SolarPACES)
ONE	Office National de l'Electricite (MAR)
P	Portugal
PCM............	phase change materials

PDVSA........ Petróleos de Venezuela
PFR.............. plug flow reactor
PGM .... platinum group metals
PHS .... priority hazardous substances
POP .... persistent organic pollutants
PoW............ Plan of Work
PNNL .... Pacific Northwest National Laboratory (USA)
PROMES ..... Laboratoire Procédés, Matériaux et Energie Solaire, CNRS (F)
PS................ priority substances
PSA .... Plataforma Solar de Almería (E)
PSE.............. Projektgesellschaft Solare Energiesysteme GmbH,
PSI............... Paul Scherrer Institute (CH)
PV .... Photovoltaic
PVD .... physical vapor deposition
PVDSA........ Petróleos de Venezuela, S.A.
PVGIS .... Photovoltaic Geographical Information System
PVPS .... Photovoltaic Power Systems Agreement (IEA)

RCSI............ Royal College of Surgeons in Ireland (IR)
REWP .... Renewable Energy Working Party
RFA .... Radiative Flux Assessment (GEWEX)

S.................. Sweden
SBP.............. Schlaich Bergermann und Partner (D)
SCE............. Southern California Edison
SEGS .... Solar Electric Generating Systems
SEIA .... Solar Energy Industries Association (USA)
SES .... Stirling Energy Systems, Inc.
SHC .... Solar Heating and Cooling Implementing Agreement (IEA)
SHIP .... Solar Heat for Industrial Processes
SI .... Sulfur Iodine cycle
SNL.............. Sandia National Laboratories (USA)
SODIS .... Solar Water Disinfection
SolarPACES Solar Power and Chemical Energy Systems
SSE .... Surface Meteorology and Solar Energy (NASA) (USA)
START.......... Solar Thermal Analysis, Review and Training
STMS solar thermal methane splitting
STP .... solar thermal power
SUNY........... State Univ. of New York
SWERA........ Solar and Wind Energy Resource Assessment

TCA............. total cost assessment
TCE .... trichloroethylene
TEM............. transmission electron microscope
TES .... thermal energy storage
TOC .... total organic carbon

UC .... University of Colorado (USA)
UK .... United Kingdom
UNED.......... National Univ. Distance Education (E)
UNEP........... United Nations Environment Program
UNIGE......... Univ. Geneva (CH)

UNLV .... Univ. Nevada Las Vegas (USA)
UNSW .... Univ. New South Wales (Aus)
USA .... United States of America
USACH .... Univ. Santiago de Chile
USYD .... Univ. Sydney (Aus)

VOCS .... volatile organic chemicals

WDS .... Wavelength dispersive spectrometry
WGA .... Western Governors Association (USA)
WH .... Westinghouse cycle
WIS .... Weizman Institute of Science (IL)
WMO .... World Meteorological Organization
WRF .... Weather Research and Forecast model (NASA)
WSSD .... World Summit on Sustainable Development

XPS .... X-ray photoelectron spectroscopy
XRD .... x-ray diffraction

YSZ............... yttria stabilized zirconia

ZA .... Republic of South Africa
ZSW .... Zentrum für Sonnenenergie und Wasserstoff-Forschung (D)

Part 1: Report of the SolarPACES Executive Committee for 2006

by
Michael Geyer
IEA SolarPACES
Executive Secretary

1 Report of the SolarPACES Executive Committee for 2006

Part 1 of this Report, which gives an overview of results and achievements of the SolarPACES Implementing Agreement in 2006, is submitted to the IEA by the SolarPACES Executive Committee as stipulated in Article 3(f) of the Implementing Agreement.

Part 2 presents the activities of the IEA SolarPACES Implementing Agreement for the period of January 2002 through December 2006 and identifies the proposed strategy for SolarPACES for the following 5-year period for January 2007 through December 2011.

The more detailed, technically substantial, non-proprietary information on the progress of SolarPACES projects and their results are given by the four SolarPACES Operating Agents in Parts 3, 4, 5, 6 and 7 of this report.

As in previous years, it is also the aim of the Annual Report for the year 2006 to inform member country institutions and partners inside and outside the IEA on progress in developing Concentrating Solar Technologies (CST) for near and long-term competitive markets. In this sense, this report exceeds the formal IEA reporting requirements.

1.1 Objectives, Strategy and Scope

The objectives of the IEA SolarPACES Strategic Plan expanded the role of the Implementing Agreement from one that focused on technology development to one addressing the full range of activities necessary to overcome barriers to large-scale adoption of concentrating solar technology. The primary objectives of the Strategic Plan are to:

1. Support TECHNOLOGY development,
2. Support MARKET development, and
3. Expand AWARENESS of the technology.

In the Strategic Plan, SolarPACES has chosen to expand its outreach and market development related activities in recognition of the impact that increased utilization of concentrating solar power (CSP) systems will have on global climate change; the increased interest by developing countries in SolarPACES; the changing needs of the CSP industry; the revision of the REWP's strategy; and accelerated means of communication through the internet.

Specific examples of expanded outreach and market development are:

- In 2002, SolarPACES joined forces with UNEP, the Global Environmental Facility (GEF) and the Solar Thermal Industry Associations of Europe and the U.S.A. to develop the Concentrated Solar Power (CSP) Global Market Initiative (GMI) to facilitate building 5,000 MW of CSP power plants worldwide over the next ten years. This initiative represents the world's largest coordinated action in history for the deployment of solar electricity.
- In 2004, the SolarPACES GMI proposal was included in the International Action Program (IAP) of the International Conference for Renewable Energies, held 1-4 June 2004, in Bonn, Germany.
- Reaching out to other IEA Implementing Agreements, SolarPACES has extended its collaboration to the PVPS and SHC implementing agreements on the crosscutting issues of solar resource assessment and the application of CSP technologies for industrial processes.
- Recently, SolarPACES responded to an invitation to participate in the IEA Office for Energy Technology and R&D Gleneagles program of work for the proposed Climate Change, Clean Energy and Sustainable Development Initiative. Of the G8 Plus Five countries, five are active participants in SolarPACES (France, Germany, the United States, Mexico, and South Africa), two countries are in the process of joining (Italy and Brazil), and two other countries have participated in the past (Great Britain and Russia).

The IEA SolarPACES Vision, Mission and Strategy are described in the IEA SolarPACES Strategic Plan. The IEA SolarPACES

IEA SolarPACES *VISION*	Make a significant contribution with concentrating solar power (CSP) technologies to the delivery of clean, sustainable energy services in the world's sun belt.
IEA SolarPACES *MISSION*	Facilitate, coordinate and maintain concentrating solar technology research, development and demonstration through international cooperation and information exchange, leading to the deployment and commercialization of sustainable, reliable, efficient and cost-competitive concentrating solar power technologies.
IEA SolarPACES *STRATEGY*	Assist the participating countries in expanding the use of economical, reliable and efficient concentrating solar technologies in a manner linked to and consistent with the REWP strategy and goals.

vision and mission statements focus on overcoming the technical, non-technical, institutional, and financial barriers to the deployment of CSP technologies.

Technology development is at the core of the work of SolarPACES. Member countries work together on activities aimed at solving the wide range of technical problems associated with commercialization of concentrating solar technology, including large-scale system tests and the development of advanced technologies, components, instrumentation, and systems analysis techniques. In addition to technology development, market development and building of awareness of the potential of solar thermal are key elements of the SolarPACES program.

The scope of IEA SolarPACES is cooperative research, development, demonstration and exchange of information and technical personnel, for solar power and chemical energy systems. The scope of subjects undertaken is shown in Figure 1.1, by the solar concentrating and conversion process.

IEA SolarPACES collaboration extends from concept development in the different solar thermal disciplines, to laboratory research, prototype development, pilot scale demonstrations and final product qualification.

A few examples illustrate the range of the work of SolarPACES. Cooperative development and testing of key solar components, including advanced concentrators and receivers, has helped reduce the costs and improve the reliability of concentrating solar technology. System tests of pilot-scale plants, such as the 10-MW Solar Two power tower in the United States

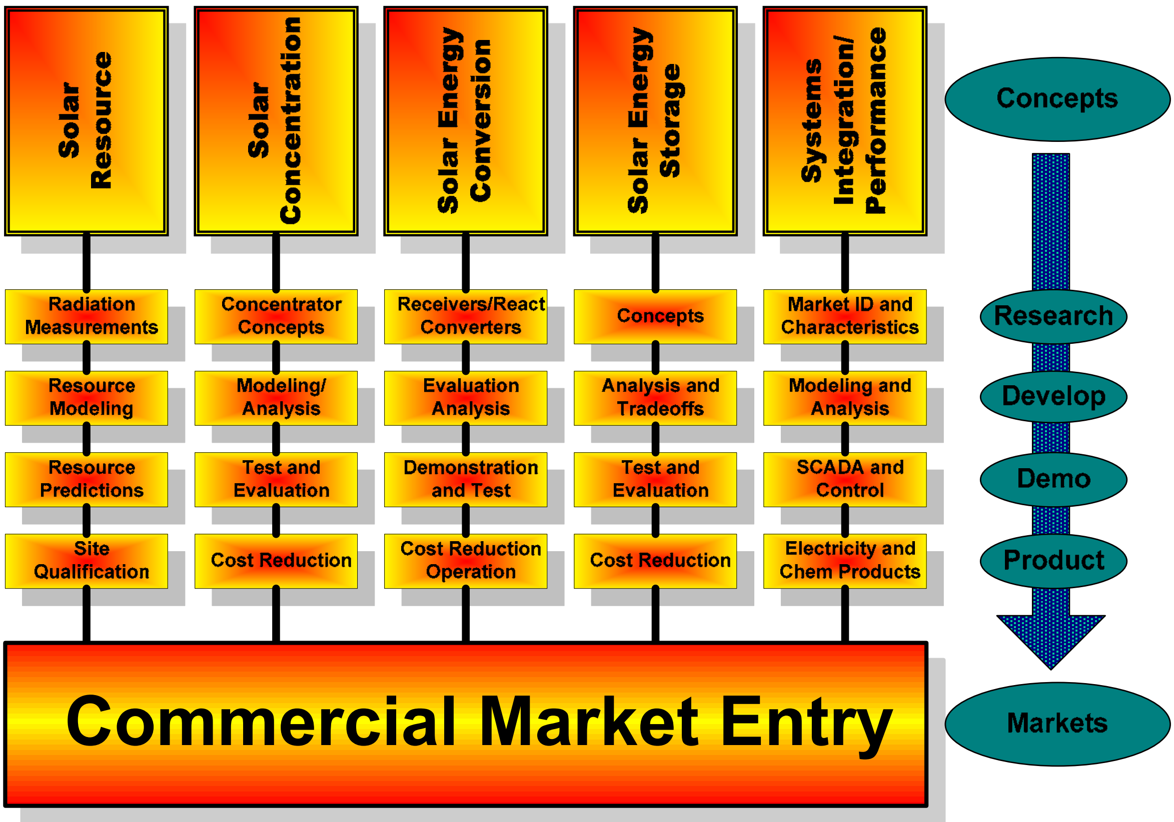

Figure 1.1. Scope of CSP research, development and demonstration work

and the DISS trough system in Spain have demonstrated the performance and reliability data needed to predict commercial plant performance. Similarly, cooperative action on systems operation and maintenance has led to reduced costs at the commercial Kramer Junction parabolic trough plants in the United States, and will help ensure cost-competitiveness at future concentrating solar power plants. The SolarPACES "START" (Solar Thermal Analysis, Review and Training) team missions have assisted in the introduction of concentrating solar power in developing Sunbelt countries. By sending an international team of experts, independent technical advice has been made available to interested countries including Egypt, Jordan, Brazil, Mexico and Algeria. START missions to Algeria, Egypt, and Mexico have already contributed to the first phase of planning concentrating solar power plants in these countries. In solar chemistry research, where the commercialization goals are more long-term, SolarPACES has succeeded in building and promoting international interest, defining research priorities, and facilitating cooperative international research.

1.2 Participation of Countries, R&D Institutions, Utilities and Industry

As of December 2006, 12 countries or organizations, designated by their governments, participate in IEA SolarPACES Table 1.1:

Table 1.1. SolarPACES Contracting Parties as of December, 2006

Country	Represented by	Govt.	R&D Institute	Industry	Electric Utility	ExCo Member
Algeria	NEAL		X			Tewfik Hasni
Australia	Consortium				X	To be nominated
Egypt	NREA	X				Samir M. Hassan
European Union	DG-RTD DG-TREN	X				Domenico Rossetti Pietro Menna
France	CNRS		X			Alain Ferriére
Germany	DLR		X			Robert Pitz-Paal
Israel	WIS		X			Michael Epstein
Mexico	IIE		X			Jorge Huacuz Villamar
South Africa	ESKOM				X	Louis van Heerden
Spain	CIEMAT		X			Diego Martínez Plaza
Switzerland	PSI		X			Pierre Renaud
United States of America	CSP Industry			X		Dale Rogers Robert Liden Gilbert Cohen

The SolarPACES Implementing Agreement has attracted the ***Non-IEA Member countries***, Algeria, Egypt, Israel, Mexico, and South Africa, which possess excellent solar resources for the application of solar concentrating technologies. Task Participation is shown in Table 1.2 below.

Table 1.2. Task Participation

SolarPACES Task	ALG	AUS	EC	EGY	F	D	IL	MEX	RSA	E	CH	USA
I. CSP Systems	x	x	x	x	x	x	x	x	x	x		(X)
II. Solar Chemistry		x	x		x	x	x			x	(X)	x
III Technology and Advanced Applications	x	x	x		x	(X)	x	x	x	x	x	x
IV SHIP Solar Heat for Industrial Processes				x		(X)		x		x		
V Solar Resource Knowledge Management	x			x		x		x		x		(X)

Cooperation with industry is a key element in the SolarPACES activities. Over a fourth of the contracting governments designated industrial or utility partners as SolarPACES participants - i.e., Algeria (project developer), Australia (utility association), Mexico (utility), South Africa (utility) and US (industry). Those countries that have nominated industry or utilities as the contracting party are represented in the ExCo by representative companies and utilities. Furthermore, the ExCo has invited special guests from industry, utilities, financial institutions and regulatory bodies to most of its meetings. Details are given in the SolarPACES Annual Reports. This has been intensified by introducing a special "Host Country Day" in the ExCo meeting agenda, where energy policy makers, utilities and industry are invited to report and discuss the host country's CSP project perspectives.

Industry and utility partners are actively participating in the Tasks and their technical meetings and seminars, as reported in detail in the SolarPACES Annual Reports. Since the announcement of renewable electricity incentive programs in the European Union, industry and utility participation in the task meetings has increased sharply. At the last task meetings, over a dozen private firms were represented. At the biennial Symposia, about a third of the 150-200 participants come from industry and utilities. Industry actively participates in SolarPACES Tasks and other activities as partners. Task I, which focuses on CSP systems and is most closely related to market and near-term demonstration projects, is the most prominent example. Industry is responsible for over 50% of the information sharing projects.

The CSP Global Market Initiative has been jointly developed with the European Solar Thermal Industry Association (ESTIA) and the Solar Energy Industry Association (SEIA) of the United States.

The nature of the CSP technologies with their large concentrator fields, receivers and storage systems implies intensive collaboration with industry in all stages of development, from initial conceptual engineering, to prototype development, and to large-scale demonstration. The CSP cost reduction strategy builds on progress in R&D and mass manufacturing by industry. Potential for increased participation:

- Greece, which announced a CSP feed-in tariff in 2006
- Italy, where a 110 Million Euro research, RD&D program on CSP was launched in 2000.

- Morocco, where ONE, the national utility, is currently bidding for a combined cycle plant with integrated CSP in Ain Beni Mathar
- Portugal, where a new CSP feed-in law is under preparation

Other countries with high solar insolation and power needs include Jordan and Chile.

With the approval of the new IEA Framework for International Energy Technology Cooperation, which admits industrial sponsors to Implementing Agreements, further industrial participation is expected.

1.3 The SolarPACES Work Program

SolarPACES member (contracting party) activities are carried out through cooperative research, technological development and demonstration, and exchange of information and technical personnel. As the nature of electric power technologies would imply, the parties involved comprise governments, public research institutions, industrial suppliers, electric utilities, and international financing entities. They all cooperate by means of information exchange, formal and informal initiation of joint or national activities – task-shared as well as cost-shared – and also by sharing the costs of mutually agreed-upon activities. In the period under review, the work within IEA SolarPACES was structured in the five main Tasks with a number of Subtasks shown in Figure 1.2.

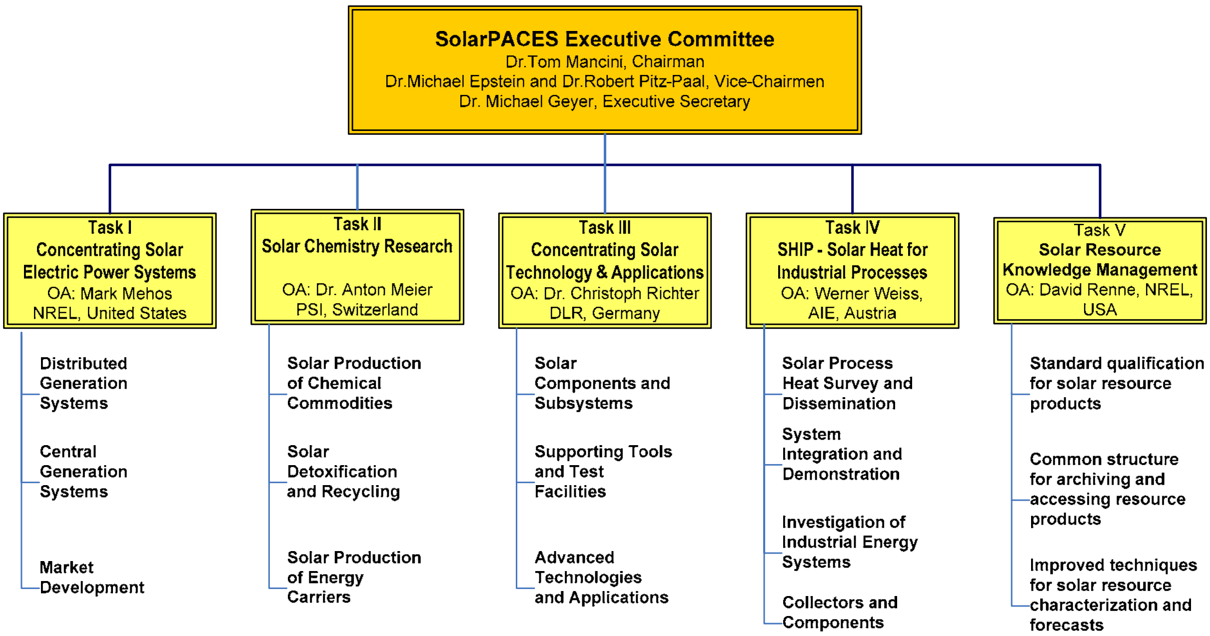

Figure 1.2. Organization of Work within the SolarPACES Task Structure

The collaboration that was earlier focused on Research, Development and Demonstration is now increasingly also emphasizing large-scale worldwide deployment. The new Task V on "Solar Resource Knowledge Management" in 2005 supports solar thermal power plant planning around the world.

1.4 Task I: Concentrating Solar Power Systems

Task I addresses the design, testing, demonstration, evaluation, and application of concentrating solar power (also known as solar thermal power) systems, including parabolic troughs, power towers, and dish/engine systems. The focus of our efforts is on the ultimate application of complete systems and the needs associated with getting them to the marketplace. The component and research efforts of Task III will logically feed Task I as new components are merged into systems, while the results of Task I will help provide direction on new component needs that could be addressed through Task III.

Organization and Structure: The Task Operating Agent, currently Sandia National Laboratories, is responsible for organization and operation of the Task, including reporting. Activities are divided into sectors, as designated by the OA and approved by the ExCo. A Sector Leader appointed by the OA coordinates each sector. Sector Leaders have responsibility for coordination of activities within their Sector. Current Sectors are:

I.1. ***Central Generation Systems***, including activities primarily associated with large-scale parabolic trough and power tower systems.

I.2. ***Distributed Generation Systems***, including activities associated with dish/engine and other systems capable of providing power on a distributed basis.

I.3. ***CSP Market Development***, addressing financial, environmental, regulatory, and marketing issues.

Task activities are cost-shared, task-shared (either through SolarPACES or between SolarPACES participants), and/or information-shared. Cost-sharing and task-sharing activities involve cooperative efforts between two or more participants where either costs of activities or responsibilities for activities, respectively, are mutually agreed upon and shared by the Participants. Information sharing is used for the exchange and discussion of results of projects carried out independently by Participants, but of interest to all.

1.5 Task II: Solar Chemistry Research

Task II (Solar Chemistry Research) encompasses activities that deal with solar-driven thermochemical and photochemical processes for:

- Production of energy carriers: conversion of solar energy into chemical fuels that can be stored long-term and transported long-range. During this term, special focus is on solar thermal hydrogen production.
- Processing of chemical commodities: use of solar energy for processing energy-intensive, high-temperature materials.
- Detoxification and recycling of waste materials: solar energy treatment of polluted air, water, and soil, and for recycling waste materials.

Organization and Structure: The Task II Operating Agent, currently PSI, Switzerland, is responsible for organization, operation, and reporting. International solar chemical research, development and demonstration efforts are coordinated in cost, task and/or information-sharing activities by National Coordinators, making use of an efficient network, for the rapid exchange of technical and scientific information. The Task II Annual Meeting provides a forum for presenting and discussing major technological achievements. The Task II Program of Work provides an up-to-date description of the national and international projects. When appropriate, Task II conducts a status review on novel technologies for assessing their technical and economical feasibility. Task II is continuously striving to stimulate public awareness of the potential contribution of solar chemistry to clean, sustainable energy services. Activities are classified into three sectors:

II.1 ***Solar production of chemical energy carriers***: solar hydrogen, solar reforming of natural gas; solar reduction of metal oxides; solar conversion of carbonaceous materials; solar cracking of hydrocarbons; solar chemical heat pipes.

II.2 ***Solar processing of chemical commodities***: solar production of metals, hydrogen, synthesis gas, carbon filaments, fullerenes, lime, cement, and other fine and bulk chemicals.

II.3 ***Solar detoxification and recycling of waste materials***: solar detoxification of contaminated water, soil, and air; solar recycling of hazardous waste and of secondary raw materials.

1.6 Task III: Concentrating Solar Technology and Applications

The objectives of this task deal with the advancement of technical and economic feasibility of the emerging concentrating solar technologies and their validation with suitable tools by proper theoretical analyses and simulation codes, as well as by experiments using special arrangements and adapted facilities. For this purpose, procedures and techniques are defined design, evaluation and optimized use of the components and subsystems, which concentrate, receive, transfer, store and apply solar thermal energy. In essence, the goals are to investigate innovative multi-discipline advances needed for the further development of concentrating solar systems. This also concerns, among others, process heat applications, solar concentration for materials development, and introduction of hybrid solar/fossil power plant concepts.

Task III is an ongoing effort covering R&D-oriented activities with clearly defined technical objectives, time schedule and expected results.

For structuring purposes, each of these activities is assigned to one of the following sectors:

III.1 Solar Specific Technology Components and Subsystems
III.2 Supporting Tools and Test Facilities
III.3 Advanced Technologies and Applications

1.7 Task IV: Solar Heat for Industrial Processes

This task is an IEA Solar Heating and Cooling and IEA Solar-PACES collaborative research project bringing together experts and industries from residential solar heating and high temperature solar power. Industry accounts for approximately 30% of the energy consumption in the OECD countries. The major share of the energy that is needed in trade and industry for production and heating production halls is below 250°C. To be able to make use of the huge potential for solar heat in the industry and to open a new market sector for the solar thermal industry, solar thermal systems must be suitably integrated in industrial processes. Further development of solar thermal components is especially critical to meet the requirements. Applications, systems and technologies, which are included in the scope of this task, are:

- All industrial processes requiring heat up to approx. 250°C
- Space heating of production halls or other industrial bays is addressed, but not space heating of dwellings and
- Solar thermal systems using air, water, low pressure steam or oil as a heat carrier, i.e., not limited to a any one heat transfer medium in the solar loop.

All types of solar thermal collectors for an operating temperature of up to 250°C are addressed: uncovered collectors, flat-plate collectors, improved flat-plate collectors, e.g., hermetically sealed collectors filled with inert gas, evacuated tube collectors with and without reflectors, CPC collectors, MaReCos (Maximum Reflector Collectors), parabolic trough collectors.

To accomplish the task goals, the participants carry out research and development in the framework of the following four sectors:

IV.1 Solar Process Heat Survey and Dissemination of Task Results (Lead Country: Spain)
IV.2 Investigation of Industrial Energy Systems (Lead Country: Austria)
IV.3 Collectors and Components (Lead Country: Germany)
IV.4 System Integration and Demonstration (Lead Country: Germany)

1.8 Task V: Solar Resource Knowledge Management

The purpose of Task V is to develop and provide better information and services on solar irradiance. This concerns standardization of products, better data reliability and availability, and improved spatial and temporal coverage, with customized solar resource products, including solar radiation forecasting. Achieving these goals will reduce the cost of planning and deploying solar energy systems, improve solar system efficiency with more accurate and complete information on the solar resource, and increase the value of the solar power produced by solar systems.

Task V assembles specialists in remote sensing and meteorological modeling from seven countries. To make use of synergies the task-sharing activities in this branch are organized as a Collaborative Task together with the IEA Solar Heating and Cooling Program (SHC) and IEA Photovoltaic Power Systems. Collaboration with SolarPACES requires special emphasis on direct irradiance. This radiation component is essential for concentrating solar devices, but harder to derive and is more spatially and temporally variable.

Organization and Structure: The Task on Solar Resources is coordinated by the SHC Operating Agent Dave Renné of NREL, USA. In SolarPACES the Task is represented by Richard Meyer of DLR, Germany. Activities are structured in three sectors:

V.1 ***Standardization and benchmarking*** of solar resource products (Lead country: Germany)

V.2 ***Common structure for archiving and accessing*** resource products (Lead country: France)

V.3 ***Improved techniques for solar resource characterization*** and forecasting (Lead country: Germany).

1.9 Coordination with Other Bodies

SolarPACES is the only agreement and international program working on Concentrating Solar Power technologies. The SolarPACES ExCo represents delegates from national CST (concentrating solar technology) programs with a composite budget of 40-50 Million USD per year and is the only international, multilateral umbrella for CST cooperation.

In Europe and in the US, industry with an interest in CST has associated in their respective industry associations—ESTIA (European Solar Thermal Industry Association) and SEIA (Solar Energy Industry Association of the USA). SolarPACES is cooperating closely with these associations and has regularly invited their representatives to its ExCo Meetings.

SolarPACES joined forces with ESTIA and Greenpeace, to develop a market deployment scenario for CSP 2002-2025, which shows that near to 40GW of CSP plants may generate some 100TWh clean solar power annually by 2025.

Neighbouring technologies are the general solar utilization technologies and the power generation technologies. In this field, SolarPACES is cooperating closely with the International Solar Energy Society (ISES) and its national associations by contributing regularly to their conferences and journals. SolarPACES is also contributing regularly to the international power industry conferences like PowerGen and others.

Special acknowledgement is owed to the European Union and its support of transnational CSP projects within Europe, like INDITEP, DISTOR, EuroTrough, EuroDish, SolAir, SolGate, SOLASYS, SOLREF, SOLZINC, AndaSol, PS10 and SolarTres. The information on these projects has been shared with the non-European SolarPACES partners.

SolarPACES also gave special support to the Solar Initiative of the World Bank by in-kind contributions of the contracting member institutions to the project identification studies in Brazil, Egypt, and Mexico, and to the World Bank's Cost Reduction Study.

Proactive cooperation with the IEA Renewable Energy Unit has continued together with other renewable implementing agreements, by participating in the Exhibition at the IEA Ministerial Meeting in April 2002, contributing to the Renewable Energy Working Party, preparing an exhibit for the Renewables 2004 Conference in Bonn, developing the IEA RD&D priorities and participating in the REWP seminars.

Proactive cooperation has been established with the Solar Heating and Cooling (SHC) Implementing Agreement by the implementation of a joint task on Solar Heat for Industrial Processes (SHIP) and another joint task on "Solar Resource Knowledge Management" has been implemented together with the SHC and PVPS Implementing Agreements.

1.10 Information Dissemination

The key SolarPACES event for information dissemination is the biennial International Symposium on Concentrating Solar Power and Chemical Energy Systems, the international forum where scientists, engineers, users and students learn about the latest advances in concentrating solar technology.

At the 11th SolarPACES International Symposium on Concentrated Solar Power and Chemical Systems, held September 4-6, 2002 in Zurich, some 230 participants from 24 countries gathered in Switzerland, where the highlight was the Keynote presentation by Nobel laureate Prof. Carlo Rubbia. The Symposium Proceedings include 92 peer-reviewed papers. About a third of the 150-200 participants at the biannual Symposium came from industry and utilities.

Some 200 participants from 20 countries gathered at the 12th SolarPACES International Symposium on Concentrated Solar Power and Chemical Systems, held October 6-8, 2004 in Oaxaca, Mexico. The 12th SolarPACES Symposium was cosponsored by Mexico's Energy Secretariat, Secretariat of the Environment

Figure 1.3. Participants in the 13th SolarPACES International Symposium held June 20-23, 2006 in Seville

Figure 1.5. Participants of the 13th SolarPACES International Symposium visiting the construction site of PS10

and Natural Resources, the Instituto de Investigaciones Eléctricas (México), the State Government of Oaxaca (México) and SolarPACES.

Over 500 participants from 30 countries came to the 13th SolarPACES International Symposium on Concentrated Solar Power held this year from June 20th to 23rd in Seville, Spain. Participants had the opportunity to visit the first commercial power tower, the 10 MW PS10 plant located near Seville and the construction site of the 50-MW AndaSol-1 plant, the first commercial parabolic-trough plant with multi-hour storage, near Granada.

Publishing joint SolarPACES information material on CST and sharing all national CST publications through SolarPACES-wide distribution lists has become another important means for information sharing***.*** The ***SolarPACES Annual Report 2005*** was published and distributed to 500-1000 interested experts worldwide, giving detailed literature reference and contact addresses to encourage further cooperation.

A ***SolarPACES web page*** has been implemented to provide information over the Worldwide Web at **www.solarpaces.org** . It has had over 200,000 visitors since January 1, 2002.

Figure 1.4. Participants of the 70th SolarPACES Executive Committee Meeting hold on June 19th in Seville, Spain

Figure 1.6. SolarPACES Home Page www.solarpaces.org

1.11 Scale of Activities in 2006

The calendar of SolarPACES-related activities in 2006 was as follows:

February

14th – 16th	Participation in the 2006 Parabolic Trough Technology Workshop, hosted by NREL in Incline Village, Nevada

March

29 – 31st	Task IV, 6th Experts Meeting, Rome, Italy
31st	Task IV workshop on “Solar Thermal for Heat Production in Industries” at the University of Rome “La Sapienza”.

April

06th – 07th	Participation of the SolarPACES Executive Secretary in the IEA REWP Meeting in Paris, France

May

16th – 17th	Participation in the ADST2006 Second International Conference and Exhibition Desalination Technologies And Water Reuse in Sharm el Sheikh, Egypt

June

12th-14th	Participation in the MENAREC3 Conference in Cairo, Egypt
19th	70th SolarPACES ExCo Meeting in Seville, Spain
20th – 23rd	13th SolarPACES International Symposium on Concentrated Solar Power and Chemical Systems in Seville, Spain
24th	Tasks I, II, III meetings in Seville, Spain in conjunction with the 13th SolarPACES Symposium I Seville, Spain
27th	Participation in the CSP Seminar hosted by the European Commission in Brussels, Belgium

July

7-8th	Task V 2nd Experts Meeting in Denver, Colorado (USA)

October

11th – 13th	7th Task IV Experts Meeting, Lisbon, Portugal
16th	Participation of the SolarPACES Executive Secretary in the IEA CERT Meeting in Paris, France
13th	Task IV Industry workshop at the INETI in Lisboa (Portugal)
18th	SolarPACES Plenary Presentation by the Executive Secretary at the Solar Power 2006 Conference in San Jose, USA

November

15th – 16th	71st SolarPACES ExCo Meeting in Brussels, Belgium
17th	Host Country Day hosted by the European Commission in Brussels

Part 2: SolarPACES End of Term Report 2002-2006 and Strategic Plan 2007-2011

Michael Geyer, Executive Secretary
Thomas Mancini, Chairman
Robert Pitz-Paal, Vice Chairman
Michael Epstein, Vice Chairman
Mark Mehos, Operating Agent Task I
Anton Meier, Operating Agent Task II
Christoph Richter, Operating Agent Task III
Klaus Hennecke, Contact Task IV
Richard Meyer, Contact Task V

2 SolarPACES End of Term Report 2002-2006 and Strategic Plan 2007-2011

2.1 Introduction

At the Fiftieth Meeting of the Renewable Energy Working Party (REWP), held on October 4-6, 2006 in Ontario, Canada, SolarPACES Chair T. Mancini, presented the SolarPACES End of Term Report 2002-2006.

At its meeting on October 16-17, 2006, the IEA Committee on Energy Research and Technology (CERT) agreed to extend the term of the Implementing Agreement for the Establishment of a Project on Solar Power and Chemical Energy Systems (SolarPACES) for a period of five years, i.e., until December 31, 2011.

This part 2 summarizes the activities of the IEA SolarPACES Implementing Agreement for the period of January 2002 through December 2006 and identifies the proposed strategy for SolarPACES for the following 5-year period for January 2007 through December 2011.

2.2 Achievements, Benefits and Issues

Technology Development

In task and information-shared cooperation, it is difficult to quantify the added value of the SolarPACES Implementing Agreement to national CST projects. It is mostly the networking and catalyzing effects of the joint meetings, workshops and symposia that provide a basis for communication and a forum for initiating new projects, coordinating methodologies and objectives, and sharing results. The overall benefit to the member countries (and their respective CST programs) from these joint activities is to eliminate the potential for each country to "reinvent the wheel".

As the only international CSP forum, SolarPACES was the catalyst and birthplace for most of the European R&D projects supported by the 5th and 6th Framework Programs of the European Commission, to which special acknowledgement is due for its support of transnational CSP demonstration and R&D projects in Europe. The 5th and 6th Framework Programs have contributed a total of 15 million Euros to the three CSP demonstration projects, AndaSol-1, PS10 and Solar Tres, and approximately 20 million Euros to CSP R&D projects such as EuroTrough, EuroDish, Inditep, SolAir, SolGate, SOLASYS, SOLREF, SOLZINC, HYDROSOL, DISTOR, Solhyco, SOLHYCARB, etc. (see http://europa.eu.int/comm/research/energy/nn/nn_rt_cs5_en.html). Information on these projects has been shared with non-European SolarPACES members. They have set the technological basis for future CSP cost reduction. Essential outcomes are the replacement of the thermal oil in parabolic troughs by water/steam, development of thermal heat storage systems for water/steam, the integration of solar high temperature heat into a gas turbine and hydrogen production by water splitting in thermochemical cycles. SolarPACES has been the joint forum and platform for all CSP related applications, for which there is no other forum or research association in Europe. Similar international framework programs covering the participation of partners from the US and Australia would be desirable. At the last ExCo meeting in Paris in April 2004, discussions were held with the EU about how the 6th Framework Program now facilitates participation of non-European partners.

CSP Global Market Initiative – A Deployment Success Story

Some of the most notable results of the Johannesburg 2002 World Summit on Sustainable Development (WSSD) are the alliances that were developed at the margin of the official negotiation process - in particular the so-called "Type II Partnerships". Driven by emerging market opportunities rather than formal international agreements, these public/private teams are pioneering new ways of advancing the sustainability agenda. A remarkable example is the CSP Partnership, which was launched in Berlin in June 2002 and accepted as a WSSD Type II initiative in September 2002. More than 50 key actors interested in emerging CSP markets were assembled under the leadership of the United Nations Environment Program, IEA SolarPACES, and the German Government.

The CSP Partnership is an effort to facilitate CSP uptake in markets that offer the most favorable conditions. Ten investment opportunities were identified as the initial targets.

At the 65th SolarPACES Executive Committee Meeting, which took place in Johannesburg from September 30th to October 1st, 2003, the ExCo mandated the Executive Secretary to offer the full support of the IEA SolarPACES Implementing Agreement as an international cooperation platform for the CSP Global Market Initiative at its Palm Springs Conference.

At the invitation of the then-Governor Gray Davis of California, approximately 100 people from 14 countries and 4 international organizations gathered in Palm Springs, California, from October 21-23, 2003, to finalize and launch the Concentrating Solar Power (CSP) Global Market Initiative (GMI). The International Executive Conference on Expanding the Market for CSP was sponsored by the United States Department of Energy (DOE), the German Development Bank (KfW), the California Energy Commission, the Global Environment Facility (GEF), the United Nations Environment Program (UNEP), the German Federal Ministry for the Environment (BMU) and IEA SolarPACES. The conference was further supported by members of the CSP industry who hosted the conference events, including the conference reception and dinner.

This Executive Conference was the second of two conferences focusing on the international CSP market by removing barriers to deployment and accelerating its expansion. The first conference, sponsored by the BMU, KfW and GEF, was held in Berlin in June 2002, and focused on identifying and overcoming barriers to current CSP projects. Following the Berlin conference, two working groups focusing on different regions of the world, were formed and collaborated to formulate an integrated strategic plan for global expansion of the CSP market. At the Palm Springs conference, the draft Global Market Initiative created by the working groups was reviewed and revised into a more formal draft that was endorsed by the participants on Day 3.

The IEA SolarPACES Implementing Agreement was mandated to act as a coordinating Secretariat for the GMI to prepare GMI participation in the Renewables 2004 Conference in Bonn, Germany 1-4 June 2004, and received financial support for this from the German Ministry for Environment. At this conference, a plenary report on the CSP GMI was given by Fred Morse, as documented in the CSP GMI Brochure.

A text for ministerial GMI endorsement was negotiated with the governments of Algeria, Egypt, Germany, Israel, Italy, Jordan, Morocco, Spain and the state of Nevada (USA) during various trips on this mission by the SolarPACES Executive Secre-

Figure 2.1. GMI Endorsement Press Event with the Egyptian Minister for Energy, Hassan Younis, the Jordanian Minister for Energy, Azmi Khreisat, the Moroccan Minister for Energy, Mohamed Boutaleb, the German Minister for Environment, Jürgen Trittin, and the SolarPACES Executive Secretary, Michael Geyer.

tary with the support of the SolarPACES ExCo members. Ministerial endorsements for the GMI were finally obtained from the governments of Algeria, Egypt, Germany, Israel, Italy, Jordan, Morocco, Spain, Yemen and the states of Nevada and New Mexico (USA).

A text for the GMI Action Proposal was edited in close cooperation with the GMI Interim Management team and included in the Actions and Commitments of Governments in the International Action Program endorsed by the country delegations of the Renewables 2004 Conference in Bonn.

A follow-up concept for the GMI was prepared and adjusted by the GMI Interim Management Team along with participants. This follow-up concept conceives of the GMI as a new Task within the SolarPACES Implementing Agreement.

Networking

In almost 25 years of SSPS and its successor, SolarPACES, cooperation, a strong and efficient network has been set up by two generations of CSP experts from research, industry and utilities, who regularly meet at the biennial international CSP symposia and in subgroups at the Task meetings and workshops.

There is no other academic network in the field of concentrating solar technologies, nor other international CSP research or trade associations. The industrial CSP associations ESTIA (European Solar Thermal Industry Association) and SEIA (Solar Energy Industry Association in the US) are geographically limited and represent only a very small fraction of the worldwide CSP community.

Policy Relevance

The work of SolarPACES has already added explicit CSP value to the policy goals of three members:

As **Algeria** takes its place within the IEA Solar/PACES program, the country's emerging interest in CSP technology could lead to exciting developments in the future, including solar exports to Europe. The trigger, which has provided the framework for new investment opportunities, is liberalization of the Algerian power market, as the result of a law passed in February 2002. Two major objectives to be achieved by 2010 are to build a number of power plants with a total capacity of 2,000 MW and, secondly, to construct two power export cables (Algeria-Spain and Algeria-Italy) with an export capacity of 1,200 MW. Meanwhile, both the Algerian government and the private sector are aware of Europe's commitment to renewable energy sources, in particular the European Union's goal of 12% renewable energy by 2010.

In **Egypt**, the parliament has approved a national long-term power extension plan, which explicitly includes concentrating solar power plants. Two pre-feasibility studies were conducted based on parabolic trough and central tower technologies, followed by a SolarPACES START mission. It was agreed to implement the first solar thermal power plant as a 150 MW Integrated Solar Combined Cycle (ISCC) with a 30 MW parabolic trough solar field. The GEF granted the project consultancy services and expressed its willingness to cover the incremental cost. In

June 2003, NREA and the World Bank agreed to the change as a government project. The private sector would participate in the O&M with a five-year limited contract. A general Procurement Notice was published in February 2004. The new prequalification and bid documents were prepared in 2004, while NREA secured the required co-financing. The contracts for the Solar Island and Combined Cycle Island are expected to be awarded by the middle of 2006 and the plant is due to begin operation by the end of 2008.

The **Israeli** Ministry of National Infrastructure, which is also responsible for the energy sector, decided in 2001 to make CSP technology a strategic element in the Israel electricity market in the period ending in 2005 with an initial 100-MW_e unit. There is an option to increase the CSP share to 500 MW_e at a later stage, when the operation of the first unit has been successful.

In the **United States**, the "1000 MW CSP Initiative", a part of the GMI, has become intimately involved with the regional Western Governor's Association (WGA) 30 GW Clean Energy Initiative. The CSP industry, R&D laboratories, and project developers are working with others to identify barriers to deployment and the CSP potential in the southwestern states of New Mexico, Nevada, Arizona, and California. This effort will culminate with a Task Force report to the WGA with policy recommendations to make CSP part of the larger Clean Energy Initiative. Deployment in the U. S. includes a 1-MW trough-Organic-Rankine Cycle power plant commissioned by Arizona Public Service earlier this spring, a 64-MW trough electric power plant in Nevada that held a ground breaking in February, and 800 MW of dish Stirling systems for which power purchase agreements were issued last year by two California utilities.

More Efficient Use of R&D Resources

From the beginning of the SSPS Implementing Agreement, the CSP community has tried to reduce the total cost of technology development by distributing and sharing responsibilities for the various CSP subsystems (concentrator, receiver, storage). This SolarPACES cooperation has continued successfully.

Typical examples of this type of cooperation are the CSP projects on component development and testing at the Plataforma Solar in Almeria, Spain, and similar component development activities at the Weizmann Institute in Israel. In European Commission co-funding projects, the partners concentrate on different subsystems, engineering services, or scientific tasks for the transnational project with the result that all participants have full access to the results and the technology. In some of these projects, SolarPACES members from outside Europe (like Algeria and Israel) could be involved through the SolarPACES organization. The results are disseminated through SolarPACES channels, thus avoiding the duplication of work at other research laboratories. In addition, the development of systems, components and standardized methodologies and tools provide a significant added value for all SolarPACES members. Some specific examples of these are the development of complex CSP simulation tools, the exchange of unique flux measurement devices, joint calibration campaigns for flux measuring devices, the use of each other's CSP test facilities for component testing, joint development of standardized evaluation procedures, and shared solar resource data.

SolarPACES has helped many of the participants to strengthen their national R&D capabilities through personnel exchanges, training, and access to information, technology and equipment. The birthplace for this exchange was the former IEA SSPS Implementing Agreement, which served as the genesis for the Plataforma Solar de Almeria, where many of the leading CSP experts received their first CSP hands-on education. Based on this experience, the successor SolarPACES work programs have always placed a high priority on personnel exchange, training and student programs. New SolarPACES members from non-IEA countries (like Algeria, Egypt, Mexico, and Brazil) have joined SolarPACES, among other reasons, for the opportunity to send their CSP pioneers to CSP test facilities of other SolarPACES members.

With upcoming project development opportunities, CSP industry interest is in the area of more precise resource data. This is being tackled by a new SolarPACES task on resource assessment in cooperation with other implementing agreements. The focus of this activity is to jointly develop the methodology and databases for finding direct normal solar radiation from high spatial and temporal resolution satellite images.

In a similar sense, the interest in high-temperature collectors for solar industrial process heat applications was brought to our attention by the Solar Heating & Cooling Implementing Agreement. This is being taken up by another new cooperative SolarPACES task on this subject to which its members bring their experience on concentrating solar collectors, performance, cost and operation and maintenance issues.

2.3 Achievements of SolarPACES Tasks 2002-2006

The results and achievements of the SolarPACES Tasks have been reported in detail in the SolarPACES Annual Reports from 2002 to 2005, which have been submitted to IEA and REWP annually, as well as in this report.

2.3.1 Task I on Concentrating Solar Power Systems. 2002-2006 Achievements

The major Task I achievements for the term of this agreement have largely been associated with large-scale system testing and collaboration with solar project developers. For the first time in an EOT Report, we are pleased to report the actual startup of construction of next-generation CSP power plants in Spain and the U. S. This marks the start of a new phase of CSP global interaction focusing on project development, startup of new CSP plants, and evaluation of plant performance and operating parameters for plants throughout the world. SolarPACES will serve as THE resource for international experts and coordination of information on CSP systems deployed around the world as we continue to work on the R&D of next-generation components and technologies.

Major activities conducted/coordinated through the auspices of the SolarPACES Implementing Agreement are reported below. This is not a complete listing but includes only major international Task I activities.

Commercial Project Development. Because of successful system testing and project development in SolarPACES countries and supported by policy recommendations to local, state and national governments by SolarPACES members and working groups, we can now report the start of construction of large CSP projects in Spain and the United States. As a direct result of SolarPACES activities through the Global Market Initiative, the political/economic conditions have aligned with the state of the technology developed in SolarPACES countries to make full-scale, commercial projects possible.

In **Spain**, the 11.0-MW-rated PS10 plant being developed by Sanlúcar Solar, S.A., is nearing completion and expected to begin commissioning in the summer of 2006. The project utilizes proven technologies that have evolved out of the R&D efforts of SolarPACES member organizations including glass-metal heliostats and a solar-steam receiver. Solúcar is promoting three more plants, PS20, AZ20 and AZ50, in the same area where PS10 is under construction.

In the **United States**, SolarGenix, Inc. has completed construction of a 1-MW Organic Rankine Cycle trough plant in Arizona. The plant solar collector designs are based on designs that have also evolved out of R&D in SolarPACES countries. SolarGenix has also started construction of a 64-MW trough plant in the state of Nevada.

Other commercial projects currently under development in **Spain** include:

- Solar Tres, a molten salt power plant (based on Solar Two technologies), being developed by a consortium led by Sener;
- Two 50-MW_e trough solar power plants, AndaSol-1 and 2, jointly promoted by ACS Cobra and the Solar Millennium group in the region of Andalusia, with a SKAL ET solar collector field and six hours of molten-salt thermal storage;
- Spanish utility companies, Iberdrola and Hidrocantabrico-Genesa, have started to promote over a dozen 50-MW parabolic trough plants in Southern Spain;

Stirling Energy Systems of Phoenix, Arizona, USA, has announced two power purchase agreements with California utilities, Southern California Edison and San Diego Gas and Electric, for 500 and 300 MW, respectively.

Development of four GEF-supported hybrid parabolic-trough (or perhaps power tower) plants (each roughly 30 MW solar capacity) by member countries is underway in India, Egypt, Morocco, and Mexico. All of these projects are being planned by industrial consortia as commercial CSP projects in response to the favorable market conditions that have been or are being established around the world.

As described below, SolarPACES members continue to develop next-generation technologies backing these efforts and to work on marketing to create favorable policies for continued project development.

Major CSP system testing and demonstration. Large-scale testing by SolarPACES member countries working in international consortia participating in and sharing information through Task I, include the following activities.

- EuroTrough (Skal-ET) is a parabolic-trough collector designed for electricity generation in large solar thermal power plants. Prototype design, assembly and testing at the PSA facilities were completed at the end of 2002. As a scale-up step for upcoming EuroTrough market introduction in large power plants, seven collectors were installed at the existing Solar Electricity Generating System V (SEGS-V) in California and have contributed to power production since April 2003.
- Advanced Dish Development System (ADDS/U.S.) and EuroDish (SBP/Germany) collaborated in system demonstrations and operation. In the process, operation of a Solo engine with hydrogen working fluids and system controls developed for the systems was demonstrated and documented. The Sandia ADDS/WGAssociates 9-kW Advanced Dish Development System demonstrated stand-alone, off-grid, dish/Stirling operation. Each of these systems has helped improve the reliability, performance, and cost of the dish/Stirling generation technology. Many of these components, concepts and approaches are currently being used in the dish Stirling system being developed by Stirling Energy Systems.
- A major information/task sharing activity is the trough workshop, held annually by SolarPACES participants working on trough development. It is a major success story in how performance information and problem identification can be addressed on an international scale. Areas of collaboration include trough receiver performance and development issues; solar concentrator performance; and exploration of dry cooling for trough power plants.

Each of these major activities successfully demonstrated performance of new advanced CSP systems designed to improve the performance and economic competitiveness of CSP technologies for large-scale power plants.

START Missions and market support. START (Solar Thermal Analysis, Review, and Training) Missions were developed in Task I to provide information and expert assistance to potential CSP market countries. As described in the EOT report for that term, Task I held successful START Missions in Jordan, Egypt, Brazil, and Mexico, which led to increased interest in CSP in those countries. During the current term, a START Mission was held in Algeria. IEA/SolarPACES representatives and observers from Germany and the US were hosted by New Energy Algeria (NEAL) in Algiers. The purpose of the START mission was to brief NEAL and the invited experts from the Algerian Ministry for Energy and Mines, the Algerian power sector and interested industry on the current technical and economic status of solar thermal technologies and discuss the next steps in building Algeria's first large solar thermal power plant. START mission members advised the government on appropriate incentives for promoting the development of CSP technology in Algeria. As a result, the Government of Algeria pledged to develop a framework for the export of solar thermal electricity from North Africa to the European Union, which it has done.

Task I has also been instrumental in expanding SolarPACES non-technical efforts to address CSP market barriers and opportunities through various forms of technical assistance, information dissemination, systems analysis, resource assessment, and policy support. The most recent example of this is the Global Market Initiative, which is becoming a SolarPACES activity.

2.3.2 Task II on Solar Chemistry Research. 2002-2006 Achievements

The main Task II activities have been solar thermochemical production of hydrogen, solar calcination to produce lime and cement, and solar detoxification for the production of potable water.

Solar thermochemical hydrogen production is in an earlier stage of development than the generation of electricity using solar energy, but they make use of the same solar concentrating technologies. Significant "success stories" originate from three of the most advanced processes currently being scaled up to a solar power of several 100 kW_{th}:

- Solar reforming of natural gas (400 kW_{th})
- Solar steam-gasification of petcoke (500 kW_{th})
- Solar carbothermic production of Zinc (300 kW_{th})

Solar photochemical detoxification of polluted water makes use of solar CPC collectors:

- The world's first commercial solar detoxification plant is operating in Spain.

Solar Reforming of Natural Gas – Solar process heat is used for driving the endothermic reforming of natural gas (NG) into synthesis gas (syngas), which can be further processed into methanol and Fischer-Tropsch type chemicals, or can be directly used to fuel high-efficiency gas turbines and fuel cells.

- In the EC-supported SOLASYS project, the technical feasibility of solar steam reforming was successfully demonstrated at the WIS solar tower facility. During testing, the volumetric solar reformer was operated in the 100-220 kW_{th} power range to produce synthesis gas from LPG. A cost study shows that hydrogen can be produced for less than 0.05€/kWh_{LHV} of hydrogen.
- Further advances are expected from the development of an innovative 400-kW_{th} solar reformer for both hydrogen production and electricity generation. This cost-effective solar reformer is currently being developed in the framework of the EC-funded SOLREF project.

Solar Steam-Gasification of Petroleum Coke (Petcoke) –Solar steam-gasification of petcoke, in which petcoke is used exclusively as the chemical source for H_2 production and concentrated solar power is used exclusively as the energy source of process heat, offers a viable route for fossil fuel decarbonization and creates a transition path towards solar hydrogen. The advantages of supplying solar process heat are four-fold: 1) the calorific value of the feedstock is upgraded; 2) the product gas is not contaminated by the byproducts of combustion; 3) the need for a pure oxygen source is eliminated; and 4) discharge of pollutants into the environment is avoided. The purpose of the SYNPET project, partially funded by the oil industry (PDVSA, Venezuela), is to develop and demonstrate the solar chemical reactor technology for steam-gasification of petroleum coke. A 5-kW_{th} prototype reactor tested in a high-flux solar furnace in the 1300-1800 K range yielded up to 87% petcoke conversion in a single pass of 1 second residence time. The solar-to-chemical energy conversion efficiency is 20% when the sensible heat is recovered for steam generation and pre-heating. Reactor scale-up to a solar power of 500 kW_{th} and testing with slurry feeding at the Plataforma Solar de Almería is in progress.

Solar Carbothermic Production of Zinc – Solar-made zinc is can be used as a renewable fuel for Zn-air batteries and fuel cells, and can also be reacted with water to form high-purity hydrogen. In either case, the chemical product from these power generation processes is ZnO, which in turn is solar-reduced to Zn. The carbothermic reduction of ZnO, represented by $ZnO + C \rightarrow Zn(g) + CO$, proceeds endothermically ($\Delta H°_{1500K}$ = 350 kJ/mol) at above 1200 K. The use of concentrated solar energy as the source of high-temperature process heat reduces CO_2 emissions by a factor of 5, *vis-à-vis* the conventional fossil-fuel-driven electrolytic or Imperial Smelting processes. Obviously, if biomass (e.g. charcoal) is used as the reducing agent, it becomes a zero-net CO_2 process. The cyclic process from solar energy to electricity via solar-processed Zn/air fuel cells was investigated within the EC funded R&D project SOLZINC. The 300-kW_{th} pilot solar chemical plant was installed at the WIS "beam down" solar tower concentrating facility. Testing in the 1300–1500 K range yielded up to 50 kg/h of 95%-pure Zn with energy conversion efficiency (ratio of the reaction enthalpy change to the solar power input) of about 30%.

Solar Hydrogen by Thermochemical Water-Splitting Cycles – Solar-driven thermochemical processes offer the potential for large-scale energy-efficient hydrogen production. In the framework of the IPHE (International Partnership for the Hydrogen Economy), several institutions from SolarPACES member countries (CIEMAT, CNRS, DLR, ETH/PSI, NREL, CU, WIS) have initiated a joint solar thermochemical water-splitting project. The most promising thermochemical cycles for hydrogen production will be identified, and one or two cycles will be short-listed for demonstration. Lower-cost solar concentrating technology will be developed, as well as solar receiver and thermochemical reactor technology to demonstrate a fully integrated thermochemical process on-sun. Recent activities on thermochemical water-splitting cycles include production of solar hydrogen via the Zn/ZnO water-splitting thermochemical cycle, the EC funded project HYDROSOL, demonstrating solar hydrogen production by a two-step water-splitting cycle based on mixed iron oxides using a lab-scale monolithic honeycomb reactor, and the EC-funded HYTHEC project, which aims at assessing the potential of future hydrogen production by the Sulfur-Iodine (SI) and the Westinghouse (WH) thermochemical cycles, which both have the H_2SO_4 decomposition reaction in common.

Solar Hydrogen by Thermal Decarbonization of Fossil Fuels – The decarbonization of fossil fuels, i.e., the removal of carbon from fossil fuels prior to their use for power generation, encompasses endothermic reactions such as reforming (SOLASYS, SOLREF), gasification (SYNPET), and solar thermal decomposition (SOLHYCARB). These solar hybrid chemical processes conserve fossil fuels, reduce CO_2 emissions, and create transition paths to solar hydrogen. Recently, laboratory-scale solar reactors for methane cracking in the 1-10 kW_{th} power range have been experimentally investigated: A 10-kW_{th} fluid-wall aerosol flow reactor heated to temperatures in excess of 2000 K by concentrated sunlight converted approximately 90% of methane to hydrogen; a 5-kW_{th} reactor prototype featuring a vortex methane flow confined to a cavity-receiver and laden with carbon particles was tested; and a 1-kW_{th} cylindrical graphite nozzle reactor achieving 99% maximum CH_4 conversion in a 1500-1900 K temperature range in a vertical solar furnace.

Solar Lime and Cement – A scaleable solar multi-tube rotary kiln was developed for the endothermic calcination reaction $CaCO_3 \rightarrow CaO + CO_2$ at above 1300 K. The technical feasibility of this process has been demonstrated in a high-flux solar furnace with indirect heating of a 10-kW_{th} reactor prototype producing high-purity lime of any desired reactivity and with calcination exceeding 98% for quicklime production rates up to 4 kg/h. The use of concentrated solar energy in place of fossil fuels as the source of process heat in a state-of-the-art lime plant can potentially reduce CO_2 emissions by 20% and in a conventional cement plant by 40%. Furthermore, an economic assessment has shown that the cost of solar lime produced in an industrial 20-25 MW_{th} solar calcination plant is about 2-3 times the current selling price of conventional lime. The results suggest that an industrial solar lime reactor technology can be developed.

Solar Detoxification of Water – Various prototype solar photochemical reactors were designed, constructed, and tested in a comparative assessment of technologies for solar detoxification of contaminated water.

- The world's first commercial solar detoxification plant has been operating since June 2004. Solar photocatalytic treatment of wastewater from recycling of plastic pesticide containers used in greenhouse agriculture in the province of Almería (Spain) is fully automatic and maintenance requirements are minimal.
- Within the EC-funded CADOX project, a commercial closed-loop hybrid technology was developed based on integration of Advanced Oxidation Processes (AOPs) and biological processes for the remediation of industrial wastewater contaminated with organic pollutants. A demonstration plant for the assessment of the technical and economical feasibility of the technology was under construction in Spain at the end of 2005.
- The purpose of the EU-funded SOLWATER and AQUACAT projects is the development of a cost-effective solar photocatalytic technology for water decontamination in rural areas of developing countries. Two completely autonomous prototype CPC solar reactors were constructed and tested

for the degradation of trace organic contaminants and the disinfection of bacteria such as *E.Coli* in water. All pollutants treated were completely destroyed and mineralized with similar efficiencies in both types of solar reactors.

SolarPACES Task II serves as an excellent venue for catalyzing cooperation among member countries for the development of joint projects and exchange of information in this very specialized area of solar energy research.

2.3.3 Task III on Concentrating Solar Technology and Applications. 2002-2006 Achievements

Against the background of a significant increase in worldwide public interest in CSP technologies for clean electricity generation and the creation of a regulatory framework and initiatives supporting CSP market introduction, the development of CSP components and tools has undergone considerable progress in 2002 – 2006 in numerous R&D projects, frequently led by industry and including substantial industrial resources, to significantly lower costs and increase plant output. To name only one of several new design approaches for parabolic-troughs, the Eurotrough collector, completed and extensively tested on a pilot scale at the PSA, was integrated as a complete loop in the SEGS V solar field and is now a basis for solar field cost estimates in many upcoming CSP projects. Direct steam generation as an option for the next generation of parabolic-trough plants has been further demonstrated, and components such as steam separators have been adapted and tested in several thousand hours of operation.

Significant progress has been made in receiver technology for central receiver systems, where ceramic modules for open volumetric receiver systems, as well as closed pressurized receiver modules for integration in the gas turbine cycle of CC plants have been developed and extensively tested, achieving working fluid temperatures (pressurized air) of nearly 1000°C. New heliostat designs were developed and tested and an autonomous heliostat has been demonstrated.

Several dish/Stirling system components and mounting procedures have been improved and now multi-unit demonstration projects are under preparation to prepare further mass-production and market introduction.

Apart from these achievements regarding the main CSP technologies for power generation, significant progress was made in priority Task III activities from 2002 to 2006:

- Tools and methods for quality assurance of concentrator systems. Procedures based on optical and thermal measurements have been developed and demonstrated at different sites to precisely qualify the performance of parabolic trough concentrators and find sources of assembly errors. Development of high-speed measurement methods for on-site control during construction is ongoing. In this context, a working group for development of standards for component testing (to be referred to in tender documents and component specifications) has been set up as a collaborative SolarPACES activity and several papers have been published. Within these activities, trough collector performance is also compared to provide independent information on the performance of various solar collectors available in the market.

- Long-term stability testing of solar components, mainly evacuated receiver tubes, and specifically, the new SCHOTT receiver tube, in the lab and under plant operating conditions to guarantee performance over design lifetime, further improve performance, and address such issues as hydrogen diffusion from thermal oil into the vacuum.
- Storage concepts: A pilot-scale sensible-heat thermal energy storage (TES) system for parabolic trough plants, using concrete as the storage material, has been constructed and successfully tested. This was followed by design and testing of a pre-commercial module with thermal oil as the HTF. As storage for future DSG plants, a latent heat storage system based on Phase-Change Materials (PCM) has been developed and will be tested on a pilot scale at the PSA during 2006/2007.
- Combined heat and power systems for industrial process heat applications. Numerous projects of different sizes for application of process heat for CHP and cooling applications have come up. These activities are now pursued in Task IV as a collaborative activity with Task 33 of the Solar Heat and Power IA.
- Autonomous operating control of solar power systems. An autonomous heliostat has been built and is currently operating at the PSA.
- Evaluation standards for plant performance to enable objective comparison and provide future plant investors with an appropriate procedure. The studies focused on the performance of combined cycle power plants with integrated parabolic troughs providing solar steam to the bottoming cycle.

2.3.4 Task IV on Solar Heat for Industrial Processes. 2002-2006 Achievements

Task IV (solar heat for industrial processes) is a collaborative task with the IEA Solar Heating And Cooling Program. Due to the complementary background and expertise of the participants in the SHC and SolarPACES programs, significant synergies are expected from this collaboration. The work program was defined in 2002 and 2003, and after ExCo-decisions in both programs, the task duration was set as 1 November 2003 until 31 October 2007. For ease of cooperative management, the task is under the guidance of the Solar Heating And Cooling Program and Werner Weiss from the AEE INTEC is the operating agent on behalf of the Austrian Ministry for Transport, Innovation and Technology.

Potential studies in different European countries have highlighted the huge potential for industrial solar process heat. A final summary report is under preparation and will be available in 2006.

For dissemination of task results, two annual newsletters have been issued in five languages, and distributed by e-mail. Three industry workshops were held in conjunction with expert meetings, to assemble participants from solar research and industry, potential users, and decision-makers from industry and politics. Two further meetings are scheduled for 2006.

A matrix of indicators was developed as a decision support tool for solar experts working with industry to assist them in identifying suitable solar applications. Several case studies in different industry sectors were carried out to identify promising applications.

Information about suitable collectors now available on the market or under development has been collected and summarized in a report approved by the SHC executive committee and is now publicly available for download on the task web site. This includes an overview of concentrating and non-concentrating collector technologies.

In order to prepare the extension of the European collector testing standard EN12975 to include concentrating collectors, exemplary testing of a parabolic trough was carried out by DLR and ITW.

First demonstration projects were performed with funding from outside the task and are now available for monitoring. In Spain, a flat plate collector field with a nominal capacity of 357 kW thermal was installed at the CONTANK transport container cleaning facility. About 22% of the company's heat demand is expected to be satisfied by the solar system. The total investment was about 270.000€. In Austria, a solar heating system for a production hall has been implemented, and a warehouse with a solar supported heating system is under construction.

2.3.5 Task V on Solar Resource Knowledge Management. 2002-2006 Achievements

Efficient use of concentrating solar systems requires detailed knowledge on the availability of the 'fuel', basically direct normal solar irradiance, which is the fraction of sunlight which can be concentrated and used by CSP technologies. Direct irradiance is much more spatially and temporally variable than global hemispherical irradiance and uncertainty is greater, so good knowledge of solar resources for CSP must therefore include high temporal and spatial resolution.

Other solar techniques like tracking or concentrating PV as well as evacuated tubular collectors may also be modeled better if the direct radiation component is known. So it is important for the new IEA Solar Heating and Cooling Program, SolarPACES and IEA PVPS collaborative Task on solar resources to focus on direct normal irradiance.

The new Task V (equivalent to IEA-SHC Task 36) on "Solar Resource Knowledge Management" started in July 2005. Therefore, work in most activities has just begun. The first actions concern surveys on user requirements and more detailed preparation of work to be achieved in the course of the Task, which is planned to last 5 years. First results have been achieved in short-term forecasting and long-term variability of global and direct irradiance.

Solar thermal power plant planners require about 1% accuracy in long-term averages. This is difficult to achieve even with premium quality measurements and daily maintenance. But new satellites like the Meteosat Second Generation provide much improved spectral channel capabilities for better cloud detection and retrieval of their optical properties. They allow increasing temporal resolution down to 15 min, which also offers better options for now-casting. This means that the solar radiation field can be extrapolated from cloud motion vectors approximately 3 hours in advance. First now-casting results show good prediction capabilities. 30-hour forecasting of solar yields is of higher priority, as the Spanish Royal Decree offers a higher feed-in-tariff when the next day's yield is correctly predicted.

Great improvement is also expected from acquisition or derivation of better satellite aerosol data, e.g., aerosol optical depth which can be highly variable. So far, most procedures have applied only rough aerosol information or summarized all non-cloud atmospheric influences in a turbidity factor. Using improved aerosol data will significantly improve results for broadband solar irradiance. But the main advantage will be for spectral solar radiation, which might be important for certain solar-chemical reactions.

Long-term analysis of solar resources over several decades is already under way. 20% fluctuation is common, especially for direct irradiance. An increase in solar irradiance was observed in many regions of the world In the 1990s. This counter-balances a phenomenon widely known as "global dimming", which has been observed in global hemispherical irradiance measurements at several sites around the world, especially from 1960 – 1990. Causes for these changes are still not very clear, but they may significantly influence solar yields and amortization. Further work is required for more homogeneous long-term satellite-derived data bases.

2.4 SolarPACES Strategic Plan for 2007 to 2011

If solar technology is to achieve sustained market penetration, large projects (up to 100 MW) must be developed. Without large projects, economies of scale and mass-production techniques (essential to lowering the cost) cannot be achieved.

CSP was identified by the EU, as well as by the World Bank and the Global Environmental Facility, as an excellent option for providing a significant fraction of renewable bulk electricity that constitutes an essential part of the package of measures needed to comply with the Kyoto Protocol. What appeals to these organizations is that the energy payback time of a CSP plant is less than 1.5 years and that the power plant produces orders of magnitude less carbon dioxide per gigawatt-hour on a life-cycle basis than competing fossil-fired plants.

Under the EU's 5th and 6th Framework Programs, several approaches to restarting the commercial success of CSP technology in Europe have begun (e.g., the ANDASOL, PS10, and SOLAR TRES projects). All of these projects have been delayed due to non-technical barriers, resulting in essential additional cost to the industry involved, which reduces the likelihood of replication projects and endangers the overall success of CSP market implementation. With the recent publication of Royal Decree 436/2004 in March 2004, the Spanish government removed the economic barriers and equalized the conditions for large scale solar thermal and photovoltaic plants.

To overcome these non-technical barriers, SolarPACES will join forces with its national member governments, the IEA Renewable Energy Unit, the various Solar Thermal Industry Associations (ESTIA, SEIA), the development banks (i.e., World Bank, KfW, etc.), and the UNEP and GEF networks to identify and remove such barriers by the following means:

- **Monitor the progress** of commercial CSP projects, like those in Spain, Egypt, India, Mexico and Morocco.
- **Elaborate on the generic characteristics** of CSP grid integration (like special issues of capacity penalties, plant dispatching, and synchronization of CSP generation and customer load).
- **Develop methodologies for CSP certification** for Green Labels, Emission Trading (ET), Clean Development Mechanism (CDM), and Joint Implementation (JI).

2.4.1 Task I on Concentrating Solar Power Systems. 2007 – 2011 Objectives

In 2007-2011, the next generation of commercial CSP projects will be implemented in Algeria, Australia, Egypt, Mexico, Morocco, Spain, South Africa, the United States and other countries interested in CSP. The most short-term include PS10, AndaSol and Nevada Solar One.

While the Task I "Concentrating Solar Power Systems" cannot directly initiate projects of this magnitude, the expertise of the SolarPACES community, available through Task I, has and will continue to actively promote and support industry development of these plants and support research and technology demonstration.

- **Experience Exchange, Expert Knowledge Base and Project Networking**. SolarPACES Task 1 will provide the forum for exchanging experience, lessons learnt during project implementation, start-up and first operation among the various international project teams by arranging workshop and plant visits.
- **Monitoring and Performance Assessment Services**. On request of plant owners and operators, SolarPACES Task I offers its expertise, analytical tools and measurement capabilities for their needs in performance evaluation.
- **Guidelines for Independent Performance Certification**. Task I members will cooperate in writing guidelines and methods for independent performance certification.
- **Capacity Building and Training**: Task I will identify training needs and opportunities at the various projects and facilitate communication between interested candidates and interested project teams.

- **Outreach and Dissemination**. Report on success stories and best practices to those outside of the CSP community.

2.4.2 Task II on Solar Chemistry Research. 2007-2011 Objectives

The primary objective of Task II "Solar Chemistry Research" is to develop and optimize thermochemical processes using concentrated solar radiation as the energy source and to demonstrate technical and economic industrial-scale feasibility. During the next term, efforts will be focused on the production of fuels and chemicals for the power, transportation and chemical sectors of the world energy economy.

Task II Work Plan Overview – Task II is organized in four sectors or sub tasks. The main activities during the next term are listed below.

Solar Chemical Technology Survey and Future Prospects – Solar chemical technology assessment by experts from SolarPACES member countries (and perhaps others if needed) and preparation of a roadmap, in collaboration with system analysis specialists, to address the following topics: Solar chemical process status reviews, potential collaboration with other renewable and/or fossil and/or nuclear processes, secondary solar concentrating components, and chemical kinetics of processes under direct solar irradiation.

Solar Production of Chemical Energy Carriers – Large-scale demonstration (>1 MW power) of industrial thermochemical hydrogen production from water using concentrated solar energy in different thermochemical cycles.

- Identify the most promising thermochemical cycles for hydrogen production and short-list one or two cycles for demonstration.
- Develop lower cost solar concentrating, receiver and thermochemical reactor technologies to demonstrate a fully integrated thermochemical process on-sun.
- Test a MW-scale demonstration plant for the solar carbothermic reduction of ZnO and optimize the truly renewable process (CO_2-neutral when biomass is the reducing agent) for Zn production, electricity generation and hydrogen production.
- >1 MW demonstration of the solar reforming technology for syngas production for fuelling a combined-cycle system (with industrial partnership).
- Develop the solar reactor technology for the industrial production of hydrogen by steam-gasification of carbonaceous materials.

Solar Processing of Chemical Commodities – Solar high-temperature processing and production of energy-intensive materials such as lime and cement, metals and ceramics, carbon nanotubes, and fine, bulk chemicals.

Solar Detoxification and Recycling of Waste Materials – Support the deployment of solar plants for the treatment of hazardous effluents and waste materials for detoxification of contaminated water, soil and air, and recycling of hazardous waste materials. Task II provides the forum for technology transfer and a focus on advanced research for the development of processes and technologies.

Information exchange and dissemination – Task II will continue international collaboration and technical and scientific information exchange through the SolarPACES global network. It will organize and hold annual Task meetings and workshops for presenting and discussing major technological achievements, disseminate information through scientific publications, web sites, annual reports, and active participation in international conferences.

In particular, Task II will intensify collaboration in the area of hydrogen research with other organizations, such as IPHE (International Partnership for the Hydrogen Economy) and IEA-HIA (IEA Hydrogen Implementing Agreement), to leverage technical expertise, benefit from synergism, and avoid duplication of efforts.

2.4.3 Task III on Concentrating Solar Technology and Applications. 2007-2011 Objectives

In the context of activities which have grown out of commercial CSP projects, further development and improvement of CSP plant components is an obvious challenge for *Task III on Concentrating Solar Technology and Applications*. The findings of studies like Ecostar on the impact of different technological R&D efforts on the final cost reduction of CSP plants should be borne in mind and refined to efficiently allocate R&D funds.

The development of supporting tools becomes an even more important issue. Further development of storage technology remains an important goal to maximize the advantage of CSP plants and offer firm capacity and operability with increasing solar shares, as well as to offset the growing cost of fossil fuels in hybrid operation.

Addressing issues like water availability (cooling, mirror cleaning) and environmental concerns accompanying CSP plant implementation has become an important activity and a task for identifying options for low or no water consumption.

While our industrial partners competitively pursue project development and R&D on component development, the following activities appear to be appropriate for collaboration in support efforts and advancement of the technology:

- Guidelines for component performance measurements, which can help component suppliers and plant operators to qualify and validate their specifications.
- Prioritization of R&D leading to high-impact cost reduction. The findings of studies like ECOSTAR on the impact of technology R&D on the final cost reduction of CSP plants will be further refined. In addition, SolarPACES Task III will act as a catalyst to set up international R&D projects, for best use of funds to follow the roadmap laid out.
- Reliability Evaluation of solar components and systems. Task III will develop methods and procedures to predict lifetime

performance of solar plant components and systems. This also includes the use of proven methods for long-term stability testing (e.g., accelerated aging).

- Internationally standardized tools and methods for quality assurance of concentrator systems, to assure the optical quality of concentrators during installation and operation, including fast measuring systems for concentrator quality control and component performance characterization. Harmonization of simulation tools to be able to offer reliable product and performance data to investors.
- Comparison and evaluation of storage concepts. Define a methodology to compare and assess storage concepts and collect system design and operating data during testing in various locations
- Power plant optimization for arid regions. SolarPACES Task III will assess efficient solar thermal power plant operating options at sites with low water availability based on experience with dry cooling in conventional power plant operation.

2.4.4 Task IV on Solar Heat for Industrial Processes. 2007-2011 Objectives

The current Task IV on Solar Heat for Industrial Processes work plan covers the period to October 31, 2007. To allow time for further demonstration plants, and monitoring and evaluation of their operation, an extension of the task period should be considered.

In the survey and dissemination task, the summary of plants now using solar process heat will be updated and a PowerPoint road show for dissemination will be prepared. Further industry workshops will be held, and the annual newsletter will be sent out.

Additional industries (e.g., food, textile, electroplating) will be analyzed and included in the matrix of indicators. The methodology for a systematic energy audit will be worked out and tested in further case studies. The aim is to reduce the engineering effort for identification and analysis of suitable process heat applications in industry.

A round robin collector tests for knowledge exchange and benchmarking of mid-temperature collectors will be carried out at different research centers. Additionally, suitable materials for mid-temperature collectors, and the stagnation behavior of large collector fields will be studied.

Design guidelines for the integration of solar thermal heat in industrial processes will be compiled on the task web site. This information will be used in further case studies to identify suitable applications for future pilot projects.

Design guidelines for space heating of production halls will be developed based on the results of installations monitored during the first half term.

2.4.5 Task V on Solar Resource Knowledge Management. 2007-2011 Objectives

SolarPACES Task V on Solar Resource Knowledge Management is organized as a collaborative IEA Task coordinated by the Solar Heating and Cooling Implementing Agreement, where it was assigned as IEA-SHC Task 36. To make use of synergies in this field the Task collaborates with the other solar energy Implementing Agreements, SolarPACES and PVPS. The IEA-SHC ExCo agreed on the Task's Work and Information Plan, which describes the many activities in the field of solar resources for the five year period from July 1, 2005 to 30 June 30, 2010.

The overall goal of the Task is to facilitate the application of all solar energy techniques by providing better information on world solar resources. The main objectives are the following:

- Standardize solar resource products to insure worldwide inter-comparability and acceptance. One goal is for non-experts to be able to easily recognize the value and uncertainties of solar irradiance data depending on the methods used. Especially for huge investments such as those required for CSP, high-level solar resource satellite products must be acknowledged as "bankable information".
- Develop a common structure for archiving, processing and accessing solar resource information. This should help the user get a faster overview of available data sources, enable faster access, and further speed up the planning process by supplying data in standardized file formats.
- Improve solar resource characterization techniques and develop methods to provide solar radiation forecasts for various time-scales. As new satellites become available offering more accurate data with higher temporal and spatial resolution existing methods must be optimized, and often entirely new approaches are necessary to better derive the true state of the atmosphere from space. Forecasting of solar yields is a new field for which new methods must be developed, validated and applied. This field is of the highest interest for Spain, where the feed-in law offers higher prices if yields are successfully predicted one day ahead. An open question for research in this area is how regional climate change can influence the productivity of solar plants.

These objectives will be met by Task-sharing activities. Several new solar resource product services are expected to be set up in the course of the Task, which should be linked to a common web site. The Task will produce several reports, white papers and peer-reviewed publications describing the new findings, standards and recommendations. Finally, the Task participants will issue a 'Handbook on Solar Resources' documenting the latest state-of-the-art for derive solar irradiance from satellite measurements and atmospheric models.

2.4.6 Task VI on the Global Market Initiative. 2007-2011 Objectives

The objective of the proposed Task VI on the Global Market Initiative is to implement the GMI program. The Task will concentrate on:

- Identifying and promoting policies and regulations that would facilitate the building of CSP plants in the countries participating in the GMI, with initial emphasis on countries in Region I and Region II.
- Identifying and promoting financing mechanisms such as investment tax credits, production tax credits, and bankable Clean Development Mechanisms and Joint Implementation Actions.
- Facilitating project development
- Providing a forum exchanging lessons learned among CSP project developers and other key stakeholders.

Part 3: Status Report
Task I:
Solar Thermal Electric Systems

Operating Agent:
Mark S. Mehos
National Renewable Energy Laboratory

3 Task I: Solar Thermal Electric Systems

3.1 Nature of Work & Objectives

Task I addresses the design, testing, demonstration, evaluation, and application of concentrating solar power systems, also known as solar thermal electric systems. This includes parabolic troughs, linear Fresnel collectors, power towers and dish/engine systems. Through technology development and market barrier removal, the focus of SolarPACES Task I is enabling the entry of CSP systems into the commercial market place. The component development and research efforts of Task III (see Part 5 of this report) logically feed Task I as new components become parts of new systems. In return, the results of this Task I provide direction to Task III on new component needs.

3.2 Organization and structure:

The Task I Operating Agent is responsible for organization and reporting of Task I activities. These are separated into sub sectors, as designated by the Operating Agent and approved by the Executive Committee. Each sector is coordinated by a Sector Leader who is appointed by the Operating Agent and is responsible for coordinating activities within his Sector. Current Sectors are:

I.1 **Central Generation Systems**: includes technology activities primarily associated with large-scale parabolic trough, linear Fresnel and power tower systems. This sector is currently led by Mark Mehos of the National Renewable Energy laboratory in the USA.

I.2 **Distributed Generation Systems:** includes technological activities associated with dish/engine, and other systems capable of providing power on a distributed basis like mini-towers and modular schemes for troughs and Fresnel collectors. The Australian CSIRO currently leads this sector.

I.3 **CSP Market Development:** includes activities addressing financial, regulatory, environmental, marketing, dissemination and other largely non-technical issues. Task 1.3 focuses on identifying, tracking, and facilitating entry into emerging markets by the worldwide Concentrating Solar Power industry. Sandia National Laboratories, USA, leads this sector.

Task activities are cost-shared, task-shared (either through SolarPACES or between SolarPACES participants), and/or information-shared. Cost-sharing and task-sharing activities involve cooperative efforts involving two or more participants where either the cost of the activities or responsibilities are mutually agreed and shared. Information sharing is used for the exchange and discussion of results of projects carried out independently by Participants, but whose results are of interest to all.

Creation of a Task activity is based on the request of one or more of the participants and must be approved by the OA. Each activity has a lead individual designated by the Participants involved in the activity. The lead individual is responsible for coordinating the SolarPACES involvement, as well as regular reporting to the Task I OA.

Deliverables: The OA is responsible for general Task I reporting, including preparation of input to the IEA/SolarPACES Annual Report, and for maintaining a Program of Work describing ongoing and anticipated activities. Participants are responsible for detailed reporting on their respective activities. General reports (not containing proprietary information) are available to all Task participants, although the Participants in an activity may, at their option, limit the distribution of proprietary information. The activity lead is responsible for providing information to the OA for general reporting requirements. The OA is responsible for organizing one to two Task meetings per year to discuss activity status and progress.

One Task I meeting was held in 2006 in Seville, Spain in conjunction with the 13th SolarPACES symposium [3.01].

3.3 Status of the Technology

Concentrating solar power today is basically represented by four technologies: parabolic troughs, linear Fresnel reflectors, power towers and dish/engine systems. Of these technologies, only parabolic troughs have been deployed in commercial plants. Nine SEGS plants totaling 354 MW, originally built and operated by LUZ in California in the 1980s and 1990s, are continuing to operate today with performance of most of the plants improving over time. At the end of 2005 SolarGenix completed construction of a 1 MW parabolic trough plant for Arizona Public Service, the first new commercial CSP plant to begin operation in more than 15 years. Three additional CSP plants are currently under construction, PS10 and Andasol One in Spain, and Nevada Solar One in the U.S. PS10, a 10 MW saturated steam central receiver plant, and Nevada Solar One, a 64 MW parabolic trough plant, are expected to begin generating power in 2007. Andasol One, a 50 MW parabolic trough plant with 6 hours of thermal storage, is expected begin operating in 2008. Numerous other projects, described later in this report, are expected to begin construction in 2007. Many other projects are under various stages of development, primarily in Spain, northern Africa, and the southwest U. S.

Concentrating solar power offers the lowest cost option for solar energy today, with expected production costs of less than 20¢/kWh for early commercial plants with lower costs expected where additional incentives for CSP systems are available (e.g.

the existing U.S. Federal 30% Investment Tax Credit). As the cost of electricity from conventional generation technologies continues to rise, off-takers are becoming increasingly interested in CSP as a viable alternative to other renewable technology options. Concerns over global warming and the increasing likelihood of a global carbon constrained energy market, has further increased this interest.

The Chapter dealing with solar thermal power plants by Becker et al. in "*The future for Renewable Energy 2: Prospects and Directions*" edited by the EUREC Agency in 2002 (See reference [3.05]), provides a thorough, up-to-date summary of the status of the technology, a look at the road to the future, market inroads, and goals for RD&D, as seen from the standpoint of selected experts of the SolarPACES community. Chapter 6 of Volume 16 of the American Solar Energy Society (ASES) Advances in Solar Energy, written by Price and Kearney [3.06] provides a comprehensive discussion of the current status and future cost reductions related to parabolic trough technology.

Parabolic troughs are today considered to be a fully mature technology, ready for deployment. Early costs for solar-only plants are expected to be in the range of $0.17-0.20/kWh in sunny locations where no incentives are offered to reduce costs. In recent years, the five plants at the Kramer Junction site (SEGS III to VII) achieved a 30% reduction in operation and maintenance costs, record annual plant efficiency of 14%, and a daily solar-to-electric efficiency near 20%, as well as peak efficiencies up to 21.5%. Annual and design point efficiencies for the current generation of parabolic trough plants under construction in the U.S. and Spain are expected to be even higher based on the current generation of heat collection elements being furnished to the plants by both Solel and Schott. Several commercial trough projects are being pursued in Spain, the first one under construction is the 50-MW Andasol project that will use EUROTrough collectors and will have a 6-hour molten-salt heat storage system. Construction of the Andasol project near Granada began in 2006, with commissioning planned for 2008.

In the United States two commercial parabolic trough power plant projects are underway. The first is a 1-MW organic-rankine-cycle plant built by SolarGenix for Arizona Public Service. An organic Rankine cycle operates at lower temperature and efficiency than a steam-Rankine cycle and, potentially, will require lower operating and maintenance staffing. Construction was completed in December of 2005 and the plant startup started in January of 2006. SolarGenix is also nearing completion of a 64-MW trough project (conventional hot oil with a Rankine cycle power block) in Boulder City, Nevada (near Las Vegas) with operation scheduled for Spring of 2007.

Several options for hybrid solar/fossil plants exist. The integrated solar combined-cycle system (ISCCS) using trough technology has received much attention the past few years. Its advantage is lower solar electricity cost and risk in the near term, but this design's small annual solar fraction of about 10% is a concern to some [3.28]. New Energy Algeria (NEAL) selected Abener to build the first such project at Hassi-R'mel. The project will consist of a 150-MW ISCCS with 30 MW solar capacity. Similar project are under consideration in Egypt, Mexico, Morocco, and India.

Advanced technologies like Direct Steam Generation (DISS) are under development at the Plataforma Solar de Almería where research continues to compare direct steam, using a combination of sensible heat storage and latent heat storage, with oil based heat transfer fluids. Research on higher temperature heat transfer fluids and lower cost storage systems [3.17] are also being pursued.

Linear Fresnel systems are conceptually simple, using inexpensive, compact optics, and are being designed to produce saturated steam at 150-360 C with less than 1 Ha/MW land use. This technology may be suited for integration into combined cycle recovery boilers; i.e., to replace the bled extracted steam in regenerative Rankine power cycles or for saturated steam turbines. The most extensive testing experience at a prototype-scale is underway at the Liddell power station in Australia with very compact designs using multi-tower aiming of mirror facets. The first large proof-of-concept facility will be a commercial project started by the Solar Heat & Power Company, now Ausra, to integrate 36 MW of solar into an existing coal-fired power plant. In this hybrid plant, the 132,500-m^2 reflector field will supply 270°C heat to replace bled steam in the regenerative feed water heaters of the Rankine power cycle. Late in 2006, a 300-m-long array (5 MW_{th} delivery) was installed at the site. This is the first of three such arrays planned for this project stage. Connection to the Liddell plant is expected in 2007.

Power towers technology, a.k.a. central receiver technology, have completed the proof-of-concept stage of development and, although less mature than parabolic trough technology, are on the verge of commercialization. The most extensive operating experience has been accumulated by several European pilot projects at the Plataforma Solar de Almería in Spain, and the 10-MW Solar One and Solar Two facilities in California. After continuous technology improvement, CRS technology is predicted to reach efficiencies of 23% at design point and 20% annual performance.

Construction of PS10, the first commercial power tower, was completed by Solucar at its project site outside of Sevilla, Spain. The tower system uses a saturated steam receiver, producing 40 bar/250°C saturated steam to power a 10-MW saturated steam turbine. For cloud transients, the plant incorporates a thermal-oil storage system with a 20-MWh thermal capacity (1/2 hour at 70% load).

A likely more cost effective alternative to the saturated steam system developed for PS10 is the molten salt tower. This approach offers the potential for very low-cost storage that permits dispatch of solar electricity to meet peak demand periods and a high capacity factor (~70%). A molten-salt power tower three times larger than Solar Two is being designed by Sener for southern Spain. This plant is projected to achieve energy costs similar to trough technology, but with higher investment risk. Larger increases in plant size are projected to reduce energy costs significantly, achieving costs below that of advanced trough technology. Solar Tres, a 17--MW molten-salt tower under development by Sener, is projected to start construction late in 2007. Another 100-MW molten-salt plant is also under consideration in South Africa.

The use of volumetric air receivers for efficient integration into gas turbine cycles has been promoted in Europe and Israel using either open or closed loops, intermediate storage, and hybridization approaches in the SOLGATE, SOLAIR and Consolar pilot projects, but a commercial project is not yet underway.

Dish/engine systems are modular units typically between 5 and 25 kW unit size. Stirling engines have been used most frequently, although other power converters like Brayton turbines and concentrated PV arrays have been considered for integration with dish concentrators. The high solar concentration and operating temperatures of dish/Stirling systems has enabled them to achieve world-record solar-to-electric conversion efficiencies of 30%. However, due to their level of development, energy costs are about twice as high as those of parabolic troughs [3.05]. Dish/engine system development is ongoing in Europe and the USA. Reliability improvement is a main thrust of ongoing work, where the deployment and testing of multiple systems enables more rapid progress. Dish/Stirling systems have traditionally targeted high-value remote power markets, but industry is increasingly interested in pursuing the larger, grid-connected markets.

In Europe, Schlaich Bergermann und Partner have extensively tested several 10-kW systems, based on a structural dish and the Solo 161 kinematic Stirling engine at the Plataforma Solar de Almería. Follow-up activities based on the EuroDish design are being pursued by a European Consortium of SBP, Inabensa, CIEMAT, DLR and others. EuroDish prototype demonstration units are currently being operated in Spain, France, Germany, Italy and India. The EnviroDish project aims to transfer the former Eurodish system into small series production and deploy systems around the world.

In the USA, Stirling Energy Systems (SES) is developing a 25-kW dish/Stirling system for utility-scale markets. Six SES dish/Stirling systems are currently being operated as a mini power plant at Sandia National Laboratories' National Solar Thermal Test Facility in Albuquerque, NM, USA. SES has two power purchase agreements to install 800 MW of these 25 kW units in California, USA.

3.4 Program of Work in 2006

As summarized in Table 3.1 , Task I activities are organized by Sector. The focus of our efforts is on the testing of integrated CSP systems and support of commercial deployment projects. Activities listed in the table below (with contact person) are currently part of our Program of Work. In the sharing column, "I" refers to information sharing; "M" to task sharing by member countries; "T" to task sharing through SolarPACES; and "C" to cost sharing.

Table 3.1 Summarized Task I activities organized by Sector

Sectors and Activities	Contact	Sharing			
		I	M	T	C
Sector 1. Central Generation Systems	**Mark Mehos, NREL**				
Nevada Solar One	Cohen	x			
Solar Tres	Martín	x			
AndaSol I and AndaSol II Power Plant Projects	Gomez/Formica	x			
PS10	Osuna	x			
Integrated Solar Combined Cycle in Algeria	Osuna	x			
Kuryamat Integrated Solar Combined Cycle	Rashed	x			
El Nasr Project	Mohsen	x			
DIVA	Eck	x			
ITES	Laing	x			
EuroDish and Other CSP Prospects in Italy	Brignoli	x			
Sector 2. Distributed Generation Systems	**Wes Stein, CSIRO**				
SES Dish/Stirling Systems	Andraka	x			
Liddelll CLFR Col Saver Project	Mills	x			
1000 MW CSP Initiative in the Southwest U. S.	Mehos/Mancini	X			
Sector 3. CSP Market Development	**Sandia**				
1000 MW CSP Initiative in the Southwest U. S.	Mancini/Mehos	x			
CSP Global Market Initiative	Geyer			x	x
Database of Project and Market Opportunities	Geyer			x	x

3.5 Participation and National Contributions

Task I is open to all IEA/SolarPACES member. Participation requires active involvement in an appropriate activity as described by the scope of Task I. Currently, all SolarPACES member countries except Switzerland participate in Task I.

3.6 Cooperation with Industry

Industry involvement is key to the system-level nature of Task I activities. Involvement can take forms ranging from a self-funded project lead to contractor status. Current participants are listed alphabetically by country in Table 3.2 below.

Table 3.2 Current participants listed alphabetically by country

Algeria	NEAL	Sonatrach
Australia:	CSIRO Solar Heat and Power Pty Ltd	University of NSW University of Sydney
Brazil:	CEPEL	Petrobras
Egypt	NREA	Lotus Solar Technologies
European Commission:	DG RTD	DG TREN
France:	CNRS	
Germany:	DLR Fichtner Solar FlagSol Framatone MERO	SBP Solar Millennium AG SOLO Kleinmotoren GMBH ZSW
Italy	CESI	
Israel:	Ben Gurion University Ormat Industries Rotem Industries	Solel WIS
Mexico:	IIE	
South Africa	ESKOM	
Spain:	ACS/COBRA CIEMAT INABENSA GAMESA IBERINCO	INITEC SENER SERLED SOLUCAR TECNICAL
United States:	Pratt and Whitney/ Rocketdyne Electric Power Research Institute Industrial Solar Technology Kearney & Associates KJC Operating Company Nexant (Bechtel Corp.) Reflective Energies	Stirling Energy Systems Sun•Lab (Sandia National Labs and National Renewable Energy Lab) U.S. Dept. of Energy

3.7 Summary of Achievements in 2006

Achievements within Task I activities are summarized below by activity within each Sector.

3.7.1 Sector I.1. Central Generation Systems

Central Generation Systems include large-scale parabolic trough, linear Fresnel, and power tower systems. Mark Mehos of the National Renewable Energy Laboratory is the Sector Leader.

Nevada Solar One

Contact: Gilbert Cohen Acciona Solar Power

Participants: Acciona Energia, Acciona Solar Power, Acciona North America, Solargenix Energy.

On February 11 2006, Nevada Solar One (NSO) groundbreaking ceremony took place at the construction site in Boulder City, Nevada. Construction of the 64-MW parabolic trough in Boulder City started immediately after this event. Plant construction is scheduled to end in April 2007 and commercial operation is planned for the summer of 2007.

NSO is the largest solar energy project to be built in the United States since 1991. It is also the largest renewable generating facility to be built in the State of Nevada. With a nominal capacity of 64 MW, NSO will annually produce more than 130,000 million KWh. NSO was initially developed by Solargenix Energy in 2003 and is jointly owned by Acciona Energia and Solargenix Energy. Acciona Energia purchased 55% of Solargenix Energy and formed a new Company named Acciona Solar Power.

NEVADA SOLAR ONE – ACCIONA SOLAR POWER

Figure 3.1 Nevada Solar One solar field

The power plant is composed of 357,000 m² of second generation parabolic trough collectors (SGX2) developed by Solargenix Energy with the collaboration of the National Renewable Energy Laboratory. SGX 2 is an improved space frame design and a natural evolution from the SGX 1 successfully used in the 1-MW Saguaro plant in Arizona. The new space frame was redesigned in order to reduce fabrication time and cost. The SGX2 collector is extremely accurate, light and easy to assemble without the need of any complicated or expensive fabrication jig.

Figure 3.2 Nevada Solar One administration and control building

The absorber tubes used in the project were produced by Solel in Israel and by Schott in Germany, approx. 30% and 70% respectively.

Figure 3.3 Nevada Solar One power block

The Reflector panels were produced by Flabeg in Germany. Several other mirror prototypes are installed as well for evaluation.

The power block located on the West side of the property used a 70-MW reheat steam turbine produced by Siemens in Sweden. Only a 2% supplement is allowed in Nevada, therefore, the plant has only a very small natural gas heater mostly used for freeze protection. NSO is a solar only system with 30 minutes of thermal storage used to minimize the effects of transients.

The administration and control building is a “green” building with many energy-saving features for lighting and air conditioning, e.g., orientation, insulation, and natural daylight monitors.

The project is located approx. 25 miles from Las Vegas and all the electricity produced will be distributed to the Nevada Power Company grid. Operation and maintenance will be provided by Acciona Solar Power.

PS10

Contact: Mr. Rafael Osuna González-Aguilar, Solúcar Energía, S.A.
Participants: Solúcar (E), Inabensa (E), Ciemat (E), DLR (D), Fichtner (D)
Funding: Co-funded by the European Commission under FP5 with 5,000,000€ and the Andalusian Regional Government with 1,200,000€. Total cost: 35,000,000€.
Duration: July 1, 2001 – December 31, 2005

Construction of the PS10 project, an 11-MW Solar Thermal Power Plant in Southern Spain has been completed. The main project goals for design, construction and commercial operation have been achieved. The plant is a first-of-its-kind Solar Central Receiver System (CRS) producing electricity in grid-connected mode.

The PS10 solar power plant, which is located in Sanlúcar la Mayor, 15 km west of the city of Seville, is promoted by Solúcar Energía, S.A., an Abengoa Group company, through the registered IPP Sanlúcar Solar S.A.

The project makes use of well proven technologies, like glass-metal heliostats, a pressurized water thermal storage system, and a saturated steam receiver and turbine. These technologies have been developed by European companies, and already tested and qualified at the solar test facility located at the Plataforma Solar de Almería.

In this sense the project avoids technological uncertainties, giving priority to scale-up, subsystem integration, demonstration of dispatchability, and reduction of O&M costs. The project also focuses on writing the first standards from the information compiled.

PS10 might itself be considered a solar tower technology milestone in market penetration, since it is the first plant based on this technology operating for the sale of electricity with a purely commercial approach.

The PS10 power tower/heliostat field technology has a solar field composed of 624 120-m^2 heliostats with a mobile curved reflective surface that concentrate solar radiation on a receiver

Figure 3.4 Aerial view of the PS10 power tower plant

Figure 3.5 Aerial view during plant construction

at the top of a 100-m tower. The receiver, which produces 40-bar 250°C saturated steam from thermal energy supplied by the concentrated solar radiation flux, has a cavity design to reduce radiation and convection losses.

The steam is sent to the turbine, where it expands, producing mechanical work and electricity. The turbogenerator output goes to a water-cooled 0.06-bar pressurized condenser. The condenser output is preheated by 0.8 bar and 16 bar turbine extractions. The output of first preheater is sent to a deaerator fed with steam from another turbine extraction. A third and last preheater is fed with steam coming from the receiver. This preheater increases the water temperature to 245°C. This flow is mixed with the flow of water returning from the drum, raising the temperature of water fed to the receiver to 247°C.

Figure 3.6 Aerial view of the tower

Figure 3.7 The four PS10thermal storage tanks

For cloud transients, the plant has a 20-MWh thermal capacity saturated water thermal storage system (equivalent to 50 minutes of 50% load operation). The system is made up of 4 tanks that are sequentially operated in order of their charge status. During full-load plant operation, part of the 250°C/40-bar steam produced by the receiver is employed to load the thermal storage system. When energy is needed to cover a transient period, the energy is recovered from the saturated water at 20 bar to run the turbine at 50% load.

The tower was designed to reduce the visual impact of such a tall structure (115 m total height), so the body of the tower is rather thin (8 m) when seen from the side. The front needs to be about 18 m wide to allocate the 14-m wide receiver. A large space has been left open in the body of the tower to give the sensation of a lightweight structure. An accessible platform at a height of 30 m provides visitors with a good view of the heliostat field lying north of the tower, and the Sevilla PV plant (1.2 MW_e,

Figure 3.8 PS10 in operation

2-axis-tracking, 2X-concentrating solar PV installation) south of the PS10 tower.

Inside the receiver at the top of the tower, concentrated solar radiation is transferred to the working fluid, where its enthalpy is increased. The PS10 receiver's cavity concept reduces radiation and convection losses as much as possible. The receiver is basically a forced-circulation radiant boiler with a low steam ratio at the panel outlet to ensure wet inner walls in the tubes. Special steel alloys were used in its construction in order to operate under high heat flux and temperatures. It was designed to generate over 100,000 kg/h of 40-bar/250°C saturated steam from thermal energy from concentrated solar radiation flux.

Solúcar is also promoting five more plants, PS20, AZ20 and Solnova50-1, Solnova50-2, Solnova50-3, in the same area where PS10 is being built, for a total of over 300 MW electric power,. PS20 and AZ20 are twin 20-MW_e tower plants based on the same concept as PS10. PS20 construction will be launched in the first part of 2006.

Literature: [3.35] and [3.36]

Solar Tres

Contact: Mr. Jose C Martin, SENER Ingeniería y Sistemas, S.A.

Participants: SENER (E)

Funding: The project is presently being developed by SENER. Co-funded by the European Commission under FP5 with 5.000.000 €; other fundings under negotiation. Total cost: 196.000.000 €. Duration: 01/01/2004 – 31/12/2008.

Figure 3.9 The 120 m² SENER heliostat under testing at the PSA

Figure 3.10 Molten salt panel under testing at the PSA

The 17-MW Solar Tres will be the first commercial molten-salt central receiver plant in the world. With a 15-hour molten-salt storage system and a high-temperature, high-efficiency thermal cycle, the plant will generate 110.6 GWh/yr, equivalent to 6500 hrs of full-load operation or a 74% utilization factor.

The plant will have a cylindrical, molten-salt, central receiver and a field of 2600 115-m^2 heliostats.

The molten-salt central receiver will be provided by SENER. In mid 2005, SENER and CIEMAT reached an agreement to jointly develop a testing program at the PSA for the SENER prototype panel. The testing campaign started at the end of 2006 and the first phase of testing is expected to finish in April 2007. Heliostat technology will also be provided by SENER.

The Project Company, GEMASOLAR2006, is already funded, and land rights and electrical connection have been secured. The site is located in Fuentes de Andalucia, near Seville, in Southern Spain. The permitting process is under way. Solar radiation data at the site have been recorded for more than one year. The site enjoys one of the highest radiation levels in Spain.

Basic plant design is under development by SENER and project construction is expected to start before the end of 2007.

AndaSol-I and AndaSol-II

Contact: Antonio Gomez (Cobra), Marcello Formica (Solar Millennium)

Participants: Solar Millennium AG (D), Cobra S.A (E),

Funding: Andasol-I funded under project finance scheme. Debt equity ratio: 80/20. EU-Grant of 5,000,000€. Andasol-II under project finance scheme. Debt equity ratio: 80/20.

The corner stone of the Andasol-I plant was laid on July 20, 2006. This plant, currently under construction, is planned to go into operation by spring 2008. It is to be Europe's largest solar thermal power facility.

The plant is in eastern Andalusia, in the province of Granada, in the Marquesado de Zenete in the municipal limits of Aldeire. It occupies 202 hectares, northwest of km. 313 on the A-92 highway from Guadix to Almería.

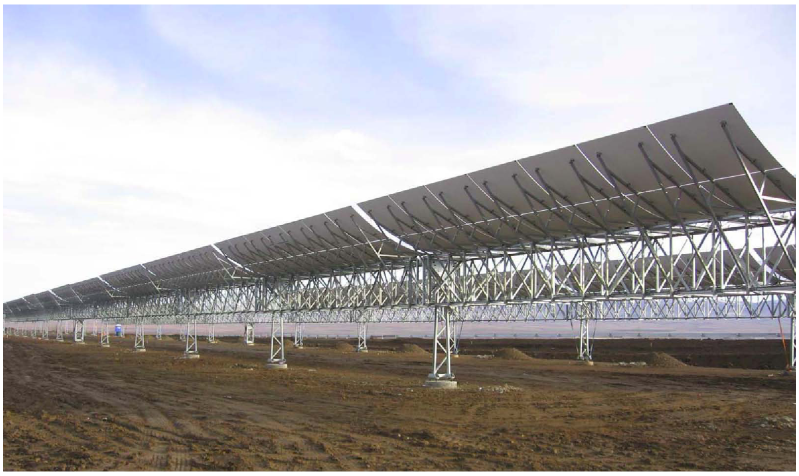

Figure 3.11 Andasol-I plant during construction stage

The parabolic trough power plant is being promoted by Solar Millennium and Cobra, and has been designed to produce 179.000.000 kWh of electricity a year, sufficient to supply power to a population of 200.000.

The AndaSol-1 solar thermal plant consists of a solar field of 510,120 m² of SKAL-ET type parabolic trough collectors, a 6-hour (+25 % reserve) molten-salt thermal storage system, and a Rankine cycle with a 49.9 MW_e net capacity.

The plant is designed for solar-only operation. The solar field is supplies up to twice the thermal energy that can be absorbed by the steam turbine. This surplus energy is stored in a thermal salt system parallel to normal operation for operating the turbine when the solar supply is below design point or when there is no solar supply at all (storage mode).

In direct operation mode, the heat transfer fluid (HTF) is circulated through the solar field to the steam generation system, where steam is produced at a temperature of 377°C and a pressure of 100 bar. The steam generation system consists of two parallel heat exchanger trains (pre-heater/steam generator/ super heater) and two, again connected in parallel, reheaters. The HTF fluid acts as the heat transfer medium between the solar field and the power block, is heated up in the solar collectors and cooled down while producing steam in the steam generator. This steam is sent to the power block, where it is expanded in a steam turbine that drives the electricity generator. The reheat steam turbine has a 38% efficiency.

On December 27, 2006, the financial closure of the Andasol-II project was achieved. This plant at current construction is planned to come into operation by autumn/ winter 2008.

Integrated Solar Combined Cycle in Algeria

Contact: *Rafael Osuna González-Aguilar,* Solúcar Energía, S.A.

Participants: Abengoa, Solucar, Abener, NEAL

In the frame of the new Algerian law on electricity and public distribution of gas for channeling n ° 02-01 of February 5, 2002 to satisfy the national demand to reach national goals for power using renewable energies. To increase the share of renewable energies to the national power consumption, Abengoa will construct a 150 MW Integrated Solar Combined Cycle power plant.

Figure 3.12 Location of the plant

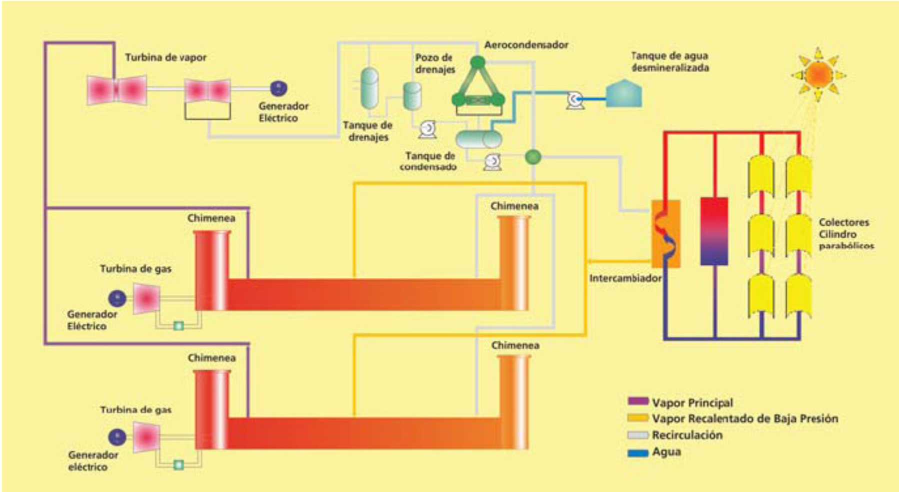

Figure 3.13 Scheme of the plant

The plant, located in Hassi R'Mel in northern Algeria, is composed of a conventional combined cycle and a solar field with a nominal thermal power of 95 MW^{th}.

The goal of this project is to integrate the solar thermal technology in a conventional power plant. This combined use reduces the cost and facilitates the deployment of renewable energies in new industrializing countries.

This project is being promoted by Solar Power Plant One (SPP1), an Abener and NEAL joint venture formed for this purpose, and will operate and exploit the plant for a period of 25 years. The Algerian state society, Sonatrach, will buy all of the power produced. The plant will be composed of a 25-MW solar field of parabolic trough technology that will provide complementary thermal energy to a 150-MW combined cycle.

The reflecting surface of the solar field will be over 180.000 m^2. This innovative project will use the heat generated in the same steam turbine that makes use of the waste heat from the gas turbine for electricity. This configuration is doubly effective. On one hand, it minimizes the investment associated with the solar field by sharing components with the combined cycle. It also reduces the CO_2 emissions associated with a conventional plant.

The solar field is composed of 216 solar collectors in 54 loops with an inlet heat transfer fluid temperature of 560 °F and an outlet temperature of 740 °F.

Kuraymat Integrated Solar Combined Cycle

Contact: Bothayna Rashed, General Manager of Planning & Follow up,

Participants: New and Renewable Energy Authority (NREA)

The Kuraymat project site is nearly 90 km south of Cairo and was selected due to its uninhabited, flat desert location, high-intensity direct solar radiation (2400 kWh/m^2/year), and its proximity to an extensive unified power grid, expanded natural gas pipelines, and sources of water (the River Nile).

The Integrated Solar Combined Cycle System (ISCCS) is currently projected to have the following specifications:

Table 3.3 *Kuraymat ISCCS specifications*

Overall Capacity	140 MW_e
Net Capacity	115 MW_e
Combined Cycle	73 MW GT + 76 MW ST
Solar Field	20 MW_e
Expected Total Power	852 GWh/a
Expected Solar Power	33.4 GWh/a
Solar Share	4% of total annual power

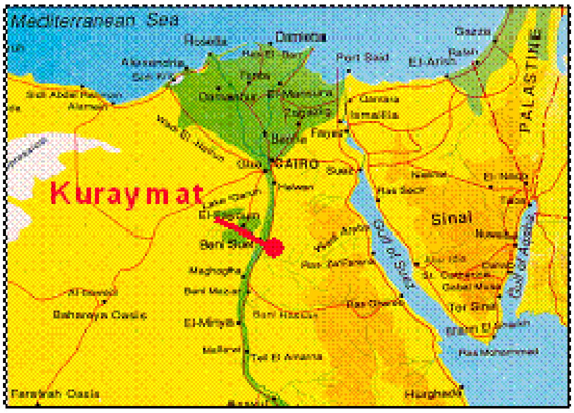

Figure 3.14 Project site

The solar field is comprised of parallel rows of Solar Collector Arrays (SCAs), sets of typical glass mirrors, which are curved in only one dimension, forming parabolic troughs. The trough focuses solar energy on an absorber pipe located along its focal line. The solar collectors are connected in series and parallel to produce the required thermal energy by tracking the sun from east to west while rotating on a north-south axis.

A heat transfer fluid (HTF), (typically synthetic oil) is circulated through the receiver heated to a temperature up to 400°C at 20 bar. The fluid is pumped to a heat exchanger to generate steam that can be superheated in the HRSG and integrated with the steam generated by the Combined Cycle (CC) before entering the Steam Turbine (ST) to generate electricity

Project Implementation:

NREA intends to implement the project under the following contracts:

- Solar island as EPC/O&M contract for engineering, procurement, construction, testing, commissioning and 2 years' operation and maintenance,
- Combined cycle island as EPC contract including interfacing with the Solar Island,
- 2-year contract for combined cycle island O&M, and
- Construction management

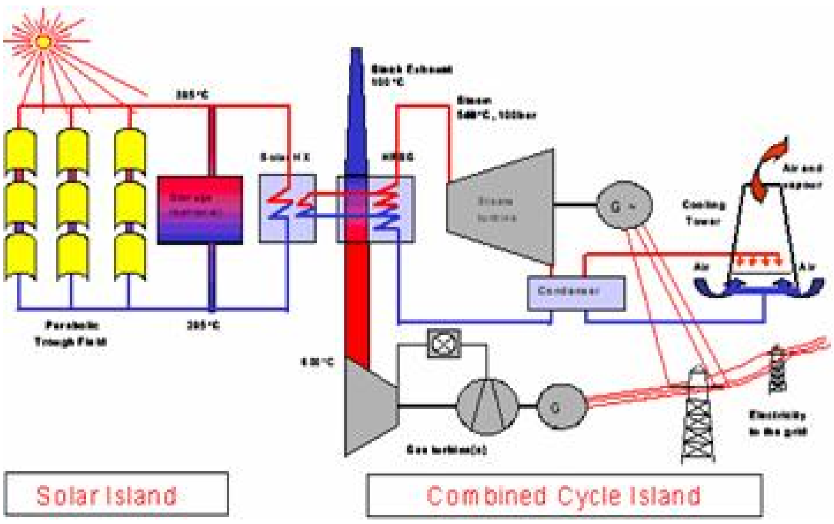

Figure 3.15 Proposed Project Cycle

Project Status

- Environmental Impact Assessment Study has been done and approved by Egyptian Environment Affairs Agency (EEAA)
- The conceptual design has been completed
- Civil works for site access roads are completed
- Technical study for cooling system water selection, based on which it was decided to use the nearby water from the Nile River
- Currently in pre-contract signature negotiations with the solar island and combined cycle island offers.
- Evaluating offers for project construction management.
- The project is expected to be operational by the end of 2009

El Nasr Pilot Solar Steam Plant

Contact: Eng. Amr A. Mohsen, Lotus Solar Technologies

Participants: Lotus Solar Technologies (EG), Fichtner Solar (G), New & Renewable Energy Authority (EG)

Funding: African Development Fund, total cost: 1.1 M$, duration 11/2001 – 4/2003

Publications: [3.39] [3.40]

The El Nasr project involves the construction of a pilot 1,900 m^2 parabolic trough field to produce 8 bar/175°C saturated process steam by flashing to supply a pharmaceutical factory. Plant construction was completed in September 2003. Steam was produced during the initial plant trials on September 18, 2003 and supplied to the factory as soon as the existing factory steam network was ready to receive solar steam in May 2004.

During 2004, the unmanned plant performed very well except that the steam production was lower than the contracted rate. Lotus investigations concluded that the very aggressive operating environment (air) inside the chemical factory led to rapid deterioration of both reflectance and absorptance beyond the design 5%/yr rate. A rehabilitation program was completed in 2005 and performance was restored. Periodic rehabilitation is now scheduled to combat rapid deterioration. Plant enlargement with an additional linear collector loop failed to raise the necessary funding, but is still planned.

During 2005 and 2006, Lotus continued operating the plant intermittently, at NREA request, as they continue to promise plant acceptance at some unspecified future date.

Figure 3.16 The El Nasr Solar Field

Production peaks of 892 and 852 kg/hr have been logged on July 30 and October 30, 2006, respectively, which exceeds the production rate of 850 kg/hr agreed with NREA on March 16, 2005 for the reference date of June 21, 2005.

Figure 3.17 Low temperature receiver module scheme

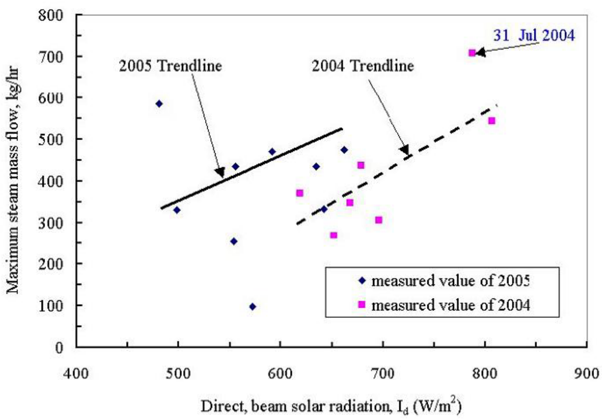

Figure 3.18 Comparison between plant productivity for 2004-2005

DIVA

<u>Contact</u>: Markus Eck, DLR

<u>Participants:</u> DLR (coordinator), Schott, Flagsol, FhG-ISE, KK&K, (Ciemat)

<u>Funding</u>: German Ministry for the Environment, Nature Conservation and Nuclear Safety.

<u>Duration:</u> Aug. 2005 – Sept. 2007.

An absorber tube has been developed and operated in the DISS test loop at Plataforma Solar de Almeria (PSA). The absorber tube, which is based on the Schott PTR70, is designed for direct steam generation (DSG) with an operating temperature of 400°C. At the end of the project, a commercial tube will be available which can be used in DSG demonstration plants in Spain. In a second work package, a detailed study will show the goals and possibilities for future development of absorber tubes for 500°C. An optical layer has been developed that withstands temperatures of 500°C in a vacuum atmosphere.

A key aspect in the project is the comparison of the direct steam generation with the state-of-the-art oil technology considering the overall efficiency, technical and economical parameters. Chances and risks are evaluated based on a number of plant configurations with different sizes and life steam parameters.

ITES

Contact person: Doerte Laing, DLR

Participants: DLR (coordinator), Züblin, Siemens

Funding: Funded by German Ministry for the Environment, Nature Conservation and Nuclear Safety.

Duration: May 2006 – April 2009.

The aim of the ITES-project is the development of a thermal energy storage system for parabolic trough power plants with direct steam generation. Steam is produced in the solar field by pre-heating, evaporating and superheating the water. The thermal storage system has to provide the same process when it is discharged. For this reason individual storage concepts are used for the three sections: Sensible heat storage in concrete material and latent heat storage in phase-change materials. Both types have already been examined in previous research projects.

The design and operation of a solar power plant with such

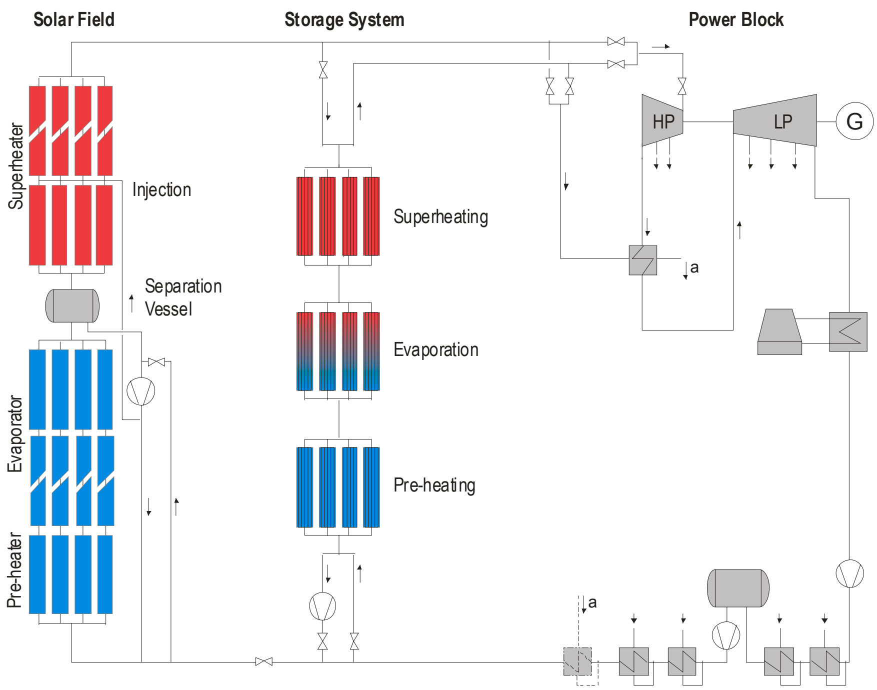

Figure 3.19 Schematic diagram of a direct steam generation power plant with thermal energy storage

energy storage is analyzed for transient behavior and yearly electricity production. The three storage modules for a steam temperature of 400°C are designed, erected and operated at the DISS test loop at the Plataforma Solar de Almeria (PSA). Further work-packages deal with increasing the storage temperature to 500°C and special control aspects for direct steam generation.

EuroDish and Other CSP Prospects in Italy

Contact: Vittorio Brignoli, CESI Ricerca SpA, GEN Dept.

Participants: DLR (coordinator), Züblin, Siemens

Funding: Funded by German Ministry for the Environment, Nature Conservation and Nuclear Safety.

Duration: May 2006 – April 2009.

During 2006 the EuroDish generator at CESI RICERCA in Milan served basically as demo plant. Students, individuals and representatives of potential Italian developers have visited the facility. Conversion of the Stirling unit to a hydrogen working fluid has been proposed for 2007. In the meantime, other projects on CSP proposed by other research entities in Italy have been accepted by the Research Ministry and are now expected to receive funding. CRS4 in Cagliari and Lecce University will run new experiments in the field of parabolic trough transfer fluids. Work should be performed in two new experimental areas in the next 3 years, with a total funding of 25 – 30 M€. Activities will be focused on new fluids able to reach performance competitive with synthetic oil and molten salt.

ENEA parabolic trough activities using molten salt as the transfer fluid continued. A new heat collector element was fabricated using the ENEA sputtering machine, and operating tests of this new component have started. A new agreement with ENEL for the construction of a 5 MW_e-equivalent parabolic trough solar field is under way and will become effective in 2007. The test plant will contribute to the production of electricity at the Priolo Gas Combined Cycle Power Plant according to the original projects. It will be the first example at reduced scale of parabolic trough ISCCS using molten salt as the primary fluid.

Figure 3.20 The molten-salt-cooled parabolic trough collector at ENEA Casaccia base – Rome

3.7.2 Sector I.2. Distributed Generation Systems

Distributed generation activities include dish/engine systems, mini-towers and modular schemes for troughs and Fresnel reflectors. Wes Stein, CSIRO Australia, is the Sector Leader.

SES Dish Stirling Systems

Contact: *Charles Andraka,* Sandia National Laboratories

Participants: Sandia National Laboratories, Stirling Energy Systems

Funding: US DOE; SES private investor funding

Stirling Energy Systems (SES) is developing a commercial Dish Stirling system, based on the McDonnell Douglas dish system, for deployment initially in large utility-size grid-connected fields. SES and Sandia continue to operate the 6-dish (150 kW) "Model Power Plant" (MPP) at Sandia to explore field communications and reliability issues and to validate changes in the next-generation design. In the next several months, SES will be constructing two new dishes at the MPP that incorporate a number of structural design changes to reduce costs and improve performance. This program will continue through 2008, with two additional dishes added to the MPP in late 2008 as well. SES has signed agreements for the purchase of power from two large plants in California. A plant for Southern California Edison (SCE) will be 20,000 dish systems (500 MW), expandable to 34,000 dishes. A plant for San Diego Gas and Electric will be 12,000 dishes, expandable to 36,000 dishes.

Liddelll CLFR Coal Saver Project

Contact: *Dr. David Mills, Peter Le Lièvre,* Solar Heat and Power Pty Ltd.

Participants: Solar Heat and Power Pty Ltd, Macquarie Generation

Progress and Funding:

Figure 3.21 SES MPP in operation at Sandia National Laboratories

Solar Heat and Power is continuing with the development of the CLFR project in Australia, and has built a full size 300-m long line as the first of three in a 15-MW_{th} project stage. The technology now uses larger 2.25-m-wide mirrors but only 10 instead of the former 12 in Stage 1. The receiver design is largely unchanged. Steam generation tests have begun and will be completed in May. The project will be connected to the adjacent coal fired plant later in 2007.

Figure 3.22 First 300 m line being erected.

Figure 3.23 Completed line in place.

SHP Australia has transferred its shareholding to a new company called Ausra Inc. based in Palo Alto, California. Ausra has received generous funding from Silicon Valley sources for projects and R&D. The basic CLFR is being significantly improved for the first US plants, and the new design, currently confidential, is being installed after mid-2007. Ausra will produce its own efficient selective coatings for the next generation of solar projects, and is developing thermal storage based upon steam and pressurized water; this is expected to be commercialized in 2008. Other technical developments are underway.

3.7.3 Sector I.3. CSP Market Development

The objective of Sector 3 is to identify, track, and facilitate entry into emerging markets of Concentrating Solar Power worldwide. Sandia National Laboratories acts as Sector leader.

This Sector addresses the collection and distribution to SolarPACES members of information about emerging market opportunities; the quantification of requirements and resources associated with each market or project; and market contacts for follow up actions. A second part of this activity involves developing contacts with the emerging markets, providing information about CSP to market representatives, and, if appropriate, arranging for information meetings on CSP technologies. A third activity is to identify and find ways to address barriers to CSP entry into specific projects or emerging market area. The Global Market Initiative started in this sector before becoming an activity of its own within SolarPACES.

1000 MW CSP Initiative in the Southwest U. S.

Contact: M. Mehos, NREL, mark_mehos@nrel.gov
T. Mancini, Sandia, trmanci@sandia.gov

Participants/Partners: U. S. Department of Energy, National Renewable Energy Laboratory, Sandia National Laboratories, U. S. Solar Energy Industries Association, U. S. Western Governors Association

Funding: $775K US

Duration: April 2003 - present

Publications: [3.41], [3.42], [3.43], [3.44]

This project was initiated in 2002 by a congressional request of DOE to investigate the "feasibility of 1000 MW of concentrating solar power in the Southwest by 2006." The initial activity, known as the 1000 MW Initiative, has grown and now includes: outreach to the southwestern states; the support of state-level activities in New Mexico, California, Arizona, and Colorado; and analysis in support of the Western Governors' Association (WGA) 30 GW Clean Energy Initiative.

In April of 2004 at the North American Energy Summit in Albuquerque, New Mexico, the Western Governors' Association resolved to evaluate diversification of Western energy resources. The mechanism for doing this is the 30 GW Clean and Diversified Energy Initiative for the West. In FY 2005, we provided significant support to the WGA Solar Task Force through a combination of in-house and subcontracted technical, policy, and market analyses. This effort continued into FY 2006 with the production of the final Solar Task Force Report issued in January 2006. Activities starting in FY2006 (since October 2005) and continuing through the present time included continuing support of the WGA Solar Task force, reporting of WGA report results to southwestern U.S., and continuing the development of tools to support CSP market development activities including GIS-based siting tools and market value and market penetration models. Accomplishments in each of these areas is described below.

Continued Support to WGA Solar Task Force: The DOE CSP Program supported the WGA Solar Task Force by participating in task force meetings, providing analysis of CSP costs and southwest market potential, and we supported the writing of the Solar Task Force Report.

Analytical Support to Southwest Stakeholders: In California, the CSP Market Transformation Team met with members of the California Energy Commission and California utilities to discuss implementing CSP projects within the regulatory/ incentive structure in the state. We contracted with Black and Veatch to perform an economic impact study for deploying CSP power generation in the state of California.

In New Mexico, members CSP Market Transformation Team met with the State of New Mexico Energy and Minerals Department and made presentations to the state legislature and Public Regulatory Commission. These discussions helped to impact the development of a resolution in support of extending Federal incentives for wind and solar development; an increase of the state's RPS from 10 to 20%; pending legislation to further incentivize solar deployment through property and sales tax relief; and the possibility of a future solar set aside within the state's RPS.

In Arizona, the team provided technical support to the State of Arizona as they reviewed and restructured their Environmental Portfolio Standard. We also made presentations on CSP technology to the State Corporation Commission and, in response to their request, performed an analysis of how existing state incentives would support CSP deployment in the state. The team is also supporting a utility consortium, being led by Arizona Public Service, to explore developing a CSP project in southwest.

Analytical Tools to Support These Efforts: NREL developed an initial U.S. CSP market penetration model to predict CSP market penetration as a function technology cost, cost of conventional technologies, and local and regional policies. The model called the Concentrating Solar Deployment System (CSDS) Model currently only supports analysis of a CSP parabolic trough system with thermal storage. Additional technology options will be added in the future.

NREL has also continued to develop GIS-based resource assessment tools that can be combined with other GIS data bases to provide CSP siting information to developers, state governments and utilities.

NREL has also developed an initial model of the potential impact that the development of a CSP project will have on the local, regional and state economy. This model is similar to the analyses done in Nevada, California, and New Mexico but allows us to perform initial estimates for any given region.

CSP Global Market initiative

The SolarPACES community is actively involved in the Global Market initiative, which was ratified at the 2004 Bonn Conference. The objective to launch a coordinated global initiative for concentrating solar power plants aimed at building 5,000 MW of large-scale CSP power projects and thereby significantly reducing the cost of this technology. SolarPACES coordination in this activity is carried out by the SolarPACES Executive Secretary, Dr. Michael Geyer, with the active support of ExCo members and the Task I operating agent. More information about the CSP Global Market Initiative appears in Part 2 of this report.

Database of Project and Market Opportunities

Recent years have seen a rapidly growing number of potential commercial CSP projects. Industry, researchers, financial and governmental organizations all interested in following the status of these projects, but maintaining information current has proven to be difficult and time consuming.

SolarPACES offers a dynamic information source and database that allows public access to up-to-date information on projects and market opportunities on its web pages: http://www.solarpaces.org/projects.htm and http://www.solarpaces.org/newprops.htm

Additional data on existing U.S. parabolic trough plants now exists on the recently updated Troughnet website supported through funding by the U.S. DOE. The project data base is located at http://www.nrel.gov/csp/troughnet/power_plant_data.html

3.8 Outlook

After two decades of slow transition, it is now undeniable that the R&D activities of SolarPACES member countries are starting to payoff construction of commercial solar thermal power projects in Spain and the U. S., with numerous additional projects developing at other sites around the world. The year 2006 brought about the first significant construction of CSP systems in over 15 years. Spain's leadership in creating a market for CSP technologies has clearly led to resurgence in interest in that country and worldwide. Policies in place or under consideration in many member countries are likely to result in the creation of a global market for CSP, resulting in an increase in technology options and market competition.

The vision that Concentrating Solar Power will provide an important, low-carbon contribution to electricity production over the coming decades is starting to be realized.

3.9 Meetings, Reports, Literature

Meetings:

One Task I meeting was held in 2006 in Sevilla, Spain in conjunction with the 13th SolarPACES symposium.

SolarPACES Reports:

[3.01] Proceedings of the 13th IEA-SolarPACES International Symposium on Solar Concentrating Solar Power and Chemical Energy Technologies, Seville, Spain, June 21-23, 2006 (CD).

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Part 6: Status Report Task IV: Solar Heat for Industrial Processes (SHIP)

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6 Task IV: Solar Heat for Industrial Processes

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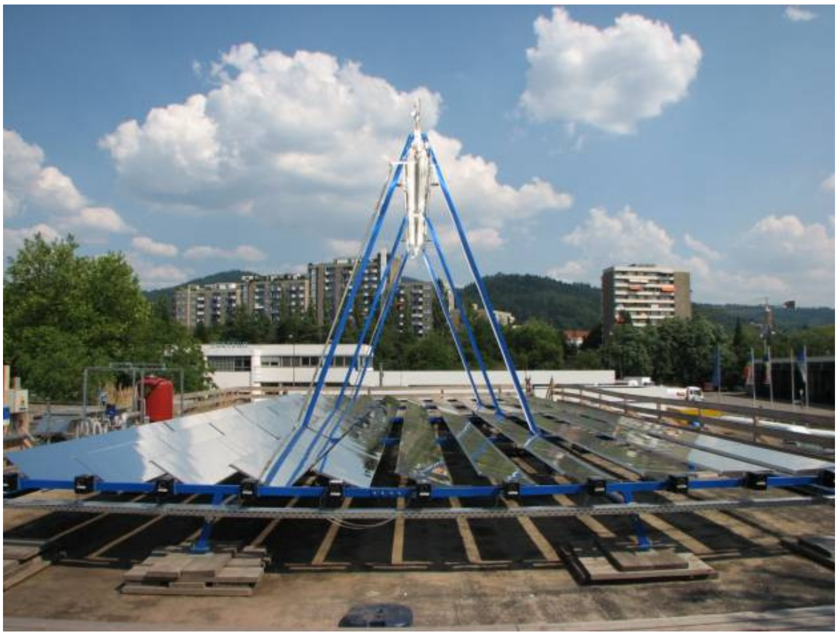

(Source: PSE, Freiburg)

Figure 6.1. PSE Fresnel Collector, rooftop installation to power a NH_3/H_2O Absorption Chiller

6.1 *Nature of Work and Objectives*

Around 154 million square meters of solar thermal collectors, corresponding to an installed capacity of 108 GW_{th}, had been installed worldwide by 2005. Until now, the widespread use of solar thermal plants has focused almost exclusively on swimming pools, domestic hot water preparation and space heating in the residential sector.

The use of solar energy in commerce and industry is currently insignificant compared to swimming pools and the household sector. Most solar applications for industrial processes have been used on a relatively small scale and are mostly experimental in nature. Only a few large systems are in use worldwide. However, if one compares the energy consumption of the industry, transportation, household and service sectors in OECD countries, industry has the highest share of energy consumption with approximately 30%, followed closely by the transportation and household sectors.

The major share of the energy, which is needed in commerce and industry for production processes and for heating production halls, is below 250°C. The low temperature level (<80°C) complies with the temperature level that can easily be reached using solar thermal collectors already on the market. The principles of operation of the components and systems apply directly to industrial process heat applications. The unique features of these applications lie on the scale on which they are used, system configurations, controls needed to meet industrial requirements, and the integration of the solar energy supply system with the auxiliary energy source and the industrial process. For applications where temperatures up to 250°C are needed, the experiences are rather limited and suitable components and systems are missing. Therefore, for these applications the development of high performance solar collectors and system components is needed.

To be able to make use of the huge potential for solar heat in industry and to open a new market sector for the solar thermal industry, SHC Task 33/IV is going to carry out studies, investigate the most promising applications and industrial sectors for solar heat and optimize, develop and test solar collectors for medium temperature applications (up to approximately 250°C). The development of integral solutions for solar thermal energy applications for given industrial processes (based on the "PINCH-concept") is also one of the main topics of this Task. Furthermore, the development of design tools (based on TRNSYS simulations) and a software tool for fast feasibility assessment, economic analyses and the design and erection of pilot plants in cooperation with industry are planned.

6.2 *Scope of the Task*

The scope of the Task is solar thermal technologies for converting solar radiation into heat, (i.e., starting with the solar radiation reaching the collector and ending with the hot air, water or steam transferred to the application.) The distribution system, production process and/or optimization of the production process are not the main topics of the Task. However, influences on the production process and the distribution system arising from the solar character of the heat source will be studied within the Task framework.

Applications, systems and technologies, which are included in the scope of this task, are:

- All industrial processes where heat up to a temperature of approx. 250°C is needed.
- Space heating of production or other industry halls is addressed, but not space heating of dwellings.
- Solar thermal systems using air, water, low-pressure steam or oil as a heat carrier, i.e. not limited to a certain heat transfer medium in the solar loop.
- All types of solar thermal collectors for an operating temperature up to 250°C are addressed: uncovered collectors, flat-plate collectors, improved flat-plate collectors - for example airtight collectors filled with inert gas, evacuated tube collectors with and without reflectors, CPC collectors, MaReCos (Maximum Reflector Collectors), or parabolic trough collectors.

6.3 *Organization and Structure*

To accomplish the objectives of the Task, the Participants are carrying out research and development in the framework of the following four Subtasks:

Subtask A: Solar Process Heat Survey and Dissemination of Task Results
(Lead Country: Italy)
Subtask B: Investigation of Industrial Energy Systems
(Lead Country: Austria)
Subtask C: Collectors and Components
(Lead Country: Germany)
Subtask D: System Integration and Demonstration
(Lead Country: Germany)

6.3.1 Collaboration with other IEA Programmes

Due to the complementary background and know-how of the participants of the Solar Heating and Cooling and the SolarPACES Programs, significant synergies were expected from collaboration. Therefore, it was agreed to cooperate with the SolarPACES Program on a "moderate level" according to the SHC "Guidelines for Coordination with other Programs."

6.3.2 Duration

The Task was initiated on November 1, 2003 and will be completed on October 31, 2007.

6.4 *Activities during 2006*

6.4.1 Subtask A: Solar Process Heat Survey and Dissemination of Task Results

Existing Plants and Potential Studies

There are currently about 84 solar thermal plants for process heat worldwide, with a total installed capacity of about 23.8 MW_{th} (33,991 m^2). These plants are located in 19 countries and cover 11 different industrial sectors, showing that solar thermal energy can be used fruitfully for many industrial applications. In 2006, several new plants have been reported in India, Italy, Spain Switzerland and Austria.

The results of the potential studies performed in participant countries have been updated, including the potential study for the Australian state of Victoria.

According to the latest assessment, extrapolating the outcomes of the studies carried out (Austria, Germany, Italy, Portugal, Spain, and Netherlands), the overall potential for solar thermal energy in industry in the EU25 is between 90 and 112 GW_{th} (128 – 160 million m^2). This would cover 2.5% of the total heat demand of the industrial sector.

This figure represents a relevant contribution to fulfilling the EU target for solar thermal power. For instance, solar process heat plants could deliver up to 64 TWh/year to industry, a remarkable contribution. This would be about 25% of the Renewable Energy Target for Europe as defined by the EREC (European Renewable Energy Council), which will be equal to 279 TWh/year by 2020.

The potential market volume also sounds astonishing: 112 GW_{th} (160,000,000 m^2) of new capacity installed for the European solar industry, while at the end of 2005 the total installed capacity of solar thermal collectors in Europe was about 11 $GW_{th.}$

Therefore, also considering a conservative scenario, a penetration rate of 10% of the above described potential would lead to a total market volume of 11.2 GW_{th} (16,000,000 m^2). If this global figure is spread over a 10-year installation program, an annual market of 1,600,000 m^2 will be reached (European market in 2005 was 2,000,000 m^2). The impact on new jobs would not be negligible either: 160,000 new jobs in ten years.

Industry Workshops

In 2006, two industry workshops were held. The first, "Solar Thermal for Heat Production in Industries", was held on March 31st at the University of Rome "La Sapienza". The seminar, promoted by the Province of Rome, the Region Lazio and the Italian Ministry of Industry, was attended by about 150 participants. The panel of speakers included policy makers, Task 33/IV experts and also representatives from solar thermal industry and small and medium business.

The second industry workshop was held on October 13th at the INETI in Lisboa (Portugal) and was attended by about 70 participants. The panel of speakers included Task 33/IV experts, experts in eco-design and sustainable efficiency measures for industry from INETI and also representative from the solar thermal industry, a Portuguese manufacturer of CPC collectors.

The presentations of both workshops are available for downloading at www.iea-ship.org/3_1.html.

Industry Newsletter

The third issue of the industry newsletter was published in English and in the languages of all participating countries at the end of January 2007. It will be also available for downloading at www.iea-ship.org.

6.4.2 SUBTASK B: Investigation of industrial energy systems

Matrix of Indicators

A "matrix of indicators" (MATRIX), which is a comprehensive database, was developed in Subtask B as a decision support tool for solar experts. This matrix will facilitate work with industry and the identification of suitable solar applications. MATRIX should make it possible to investigate and calculate the installation of solar heat in production processes without detailed knowledge of the relevant unit operations.

The investigation of these relevant industries has to focus on an integrated analysis of cooling and heating demands taking into account competitive technologies, when assessing the (economic) feasibility of solar thermal energy. Among those competing technologies are heat integration, cogeneration, new technologies and heat pumps, which are also described in the relevant parts of the MATRIX.

Expansion of the Existing Heat Integration Models

Most industries have demand heat for production and at the same time, produce a good deal of waste heat. Use of this waste heat has the advantage of competing with the heat demand of other processes. Reuse must be done at as high a temperature as possible. The most promising methodology for identifying the maximum heat recovery in a defined system is the pinch analysis. With this tool the minimum heating demand and the minimum cooling demand can also be identified. Within the work of Subtask B a computer program (Pinch Energy Efficiency – PE²), which calculates the recovery potential and

Figure 6.2. Front page of the PE² software, which was developed within Task 33/IV by JOINTS

designs the technically and economically feasible heat exchanger network for given processes has been developed. The new software PE² fulfills the needs of heat integration calculations in the promising industries.

6.4.3 Subtask C: Collectors and Components

Medium Temperature Collector Developments

Reports and discussions during the two experts meetings in Rome and Lisbon in 2006 showed that many development projects are now underway. And still more projects are starting to study new concepts for concentrating collectors in the 150 to 250°C temperature range. This very positive situation is considered to also be a result of the successful work of Task 33/IV.

For example, AEE INTEC reported on further development of Button Energy's Parasol One collector in Austria. This is a parabolic trough collector designed for a temperature range up to 200°C. Successful experiments in direct steam generation were carried out during the summer of 2006. Suitable heat transfer media for a first application in a solar cooling system were also investigated.

PSE GmbH in Germany is developing a Fresnel process heat collector for the 150 to 250°C temperature range. The first experimental collector was erected in December 2005 in Freiburg, Germany. The total reflector area of this collector is 88 m². It is being operated in a test loop for experimental research. And the second Fresnel process heat collector with a reflector area of 132 m² was already setup in a solar cooling system in Bergamo, Italy in summer 2006. The heat of the collector is used to operate an absorption chiller made by the Italian firm, Robur. First experience in operating the collector and absorption chiller and their interaction was acquired in summer 2006. The data measured while monitoring the collectors and cooling system have now been evaluated and development work will be continued.

Figure 6.3. The CCStaR collector developed by the Universitat de les Illes Balears, Spain

Development of a new collector was also started in Spain: The CCStaR collector applies the concept of fixed Fresnel reflectors and a moving receiver. Work was started at the Universitat de les Illes Balears in Mallorca. In June 2006, Tecnologia Solar Concentradora S.L. was founded for the purpose of industrial development of the CCStaR concept.

Finally, it should be mentioned here that a new parabolic trough collector has been developed in Australia. The NEP SOLAR Polymer Carrier PTC has about a 1-m aperture width and a new reflector design. It was set up for testing during summer 2006 and is scheduled to go on the market in 2007.

Medium Temperature Collector Testing

New medium temperature collectors require new testing facilities for collector performance measurements in the temperature range up to about 200°C. An important step was taken in summer 2006 concerning testing of process heat collectors. A "Round Robin" or intercomparison test by test labs was initiated. The testing institutions, Fraunhofer ISE in Freiburg, Germany, ITW in Stuttgart, Germany and INETI in Lisbon, Portugal, will carry out thermal-performance tests on a vacuum-tube collector with a CPC reflector. Three collectors were acquired for the Round Robin test and the thermal performance of all three of them was measured at Fraunhofer ISE with a recently designed Medium Temperature Test Stand (MTTS) with a solar simulator in the indoor test facility. The highest collector inlet temperature in these tests was 185°C. The laboratories at ITW and INETI will now perform their tests so that the results can be compared in the meetings in 2007. Recommendations for medium temperature collectors will be made based on conclusions drawn from the experience gained in these tests.

The stagnation behavior of large (medium temperature) collector fields is still a very crucial point which needs much more attention and further research in order to avoid stagnation problems in industrial applications of solar collectors.

In this context, Aiguasol Engineering, Spain, reports on their operating experience and stagnation behavior of the CONTANK system. Stagnation problems were due to the system load being considerably less than design point. The safety valve had to be opened several times due to excessive steam produced in the collector. Nighttime trough cooling in the collector field reduces the problem a little, but not sufficiently. The membrane expansion vessel has been redimensioned and research will continue.

Results of the ongoing German stagnation-proof projects indicate that degradation of the water-glycol fluid is caused mainly by high temperatures. Blocking by degraded glycol residue is especially risky in small collector absorber tubes with low heat losses that cannot be vacated well. The discussions showed that a lot of experience is still needed and there are no standard procedures for solving stagnation problems in existing plants. More experience is especially needed in large systems with collector areas of hundreds to thousands of m² (for process heat systems) based on solid experimental experience and knowledge.

6.4.4 Subtask D: System Integration and Demonstration

Up to now 9 pilot systems have been installed. In 2006, four new pilot systems were erected in the fields of seawater desalination (Fraunhofer ISE), breweries (AEE INTEC) and cooling (PSE). The special focus in 2006 was on breweries and seawater desalination.

Results of studies at one Austrian and three German breweries were presented and discussed at the expert meeting in Rome. The breweries studied cover a wide range of company sizes and applications. In Austria, and first monitoring results are now available from a brewery equipped with a solar thermal system. The solar heat, which is produced with a newly developed anti-reflective double glazed flat plate collector, is also used for the brewing.

The following table gives an overview of the pilot systems.

Plant, Country	Application	Installed capacity Collector type	Monitoring data available
Contank, Spain	Container washing	357 kW_{th} flat plate collector	YES
Carcavelos (BRISA) Portugal	Space heating and cooling	466 kW_{th} CPC	NO
ROBUR Italy	cooling	65.5 kW_{th} (132 m²) 132 m² fresnel collector	YES
Sea water desalination Gran Canaria, Spain	Sea water desalination	70 kW_{th} anti-reflective double glazed flat plate collector	YES
Sea Water Desalination plant, Aqaba, Jordan	Sea water desalination	50.4 kW_{th} flat plate collector	YES
Fruit juices Gangl, Austria	Pasteurizing bottle washing	42 kW_{th} flat plate collector	YES
Sunwash, Köflach, Austria	Car wash	30 kW_{th} flat plate collector	NO
Sunwash, Gratkorn, Austria	Car wash	30 kW_{th} flat plate collector	YES
Brewery Neuwirth, Austria	Brewing process	14 kW_{th} anti-reflective double glazed flat plate collector	YES

Figure 6.4. Sea water desalination in Gran Canaria, Spain (Fraunhofer ISE, Germany)

Ongoing work in the laundry and metal surface treatment sectors, respectively, will be discussed in more detail at the next experts meeting scheduled for March 28 - 30, 2007 in Cologne, Germany.

Another promising application is **factory space heating**. A review of 10 systems in Austria with solar fractions between 10 and 100% was prepared by AEE INTEC.

Design guidelines for space heating of factory buildings based on TRNSYS simulations are currently under preparation and will be available in a printed version by spring 2007.

6.5 *Work planned for 2007*

6.5.1 Subtask A: Solar Process Heat Survey and Dissemination of Task Results

Two booklets will be prepared, summarizing the main outcomes of the survey of existing plants for solar process heat and of the performed potential studies.

The next industry workshop will be organized in the framework of the 8th Task 33/IV experts meeting in Cologne (Germany) on 30 March 2007.

The third issue of the industry newsletter will be available by the end of January 2007 in English and in the languages of all participating countries.

6.5.2 Subtask B: Investigation of Industrial Energy Systems

In 2007 the focus of the work in Subtask B will be on the development of a tool for a cost analysis suitable for detection of all parameters that influence the economic performance of energy efficiency measures and the installation of a solar plant in an industrial process. Total Cost Assessment (TCA) was chosen as a method, because particular emphasis is here on costs related to environmental and health issues, which especially for solar energy use can result in a very different appraisement of costs and investment projects than conventional methods. Additional to the TCA tool a road map will be developed, which will provide companies with a decision making tool to find a tailor-made procedure for investments and/or operating options for consecutive projects protracting over a longer period with several investment phases or changes in operation. This road map will be an instrument to visualize the differences, advantages and disadvantages of viable investment or operating options and the expected results in terms of either costs or energy use for the different approaches.

Further the matrix of indicators will be completed with detailed data of the textile, electro plating and chemical industry.

6.5.3 Subtask C: Collectors and Components

Development of medium-temperature collectors will be continued in the various task projects involved.

Round robin testing of medium-temperature collectors is to be intensified. Experiences from these tests will be used to make recommendations for general medium-temperature collector testing.

Studies on materials testing will concentrate on reflectors for concentrating medium-temperature collectors.

In systems studies, more field test results will be discussed at the experts meetings in 2007. Data from monitoring pilot plants will be analyzed. This work will also contribute to the development of adequate collector testing and intercomparison.

The brochure "Medium Temperature Collectors" will be revised and supplemented with additional general information on the different categories of process heat collectors.

6.5.4 Subtask D: System Integration and Demonstration

The main focus in 2007 will be on completing contributions to the final deliverables, particularly the design guidelines on the task website and the pilot plant booklet. A numerical tool for early annual performance evaluation for design of potential applications, including economic analyses, will be developed to complement the process analysis and design support tools provided from Subtask B.

In Germany, the design of a pilot solar process steam generator with parabolic trough collectors at the site of a metal surface treatment plant is planned for development. However system installation is beyond the time frame of this task. It is endeavored to identify additional potential applications for concentrating and non-concentrating collectors and form consortia for further pilot installations in the most promising sectors as a follow-up activity, for which funding will be sought.

6.6 *Links with industry*

The Task defines two levels of participation for the solar industry:

- **Level 1.** An industrial participant at this level should expect to participate in an annual workshop organized by SHC Task 33 and receive a visit from a Task participant at least once during the duration of the Task, and to answer technical and marketing questions on solar heat for industrial applications (this activity is part of the system survey and the Subtask A dissemination activity).
- **Level 2**. An industrial participant at this level should expect Level 1 commitment and to participate in all Task meetings and to bring information and feedback from the market. Level 2 participation should be seen in close connection with the main participant of the country of origin of the industry.

A total of 15 companies from Austria, Italy, Spain, Portugal, Germany, Belgium, France and Brazil participate in the Task.

6.7 *Reports and Meetings*

6.7.1 REPORTS PUBLISHED IN 2006

- State-of-the-art report on medium temperature collectors
- Subtask B report

6.7.2 REPORTS PLANNED FOR 2007

- Report on medium temperature collector designs
- Report on pilot projects
- Report on potential studies
- Report on design guidelines – Space Heating of Factory Buildings

Furthermore a CD with the following content will be published:

- Demo version of the Pinch program PE²
- Matrix of Indicators
- Final task report
- Final management report

6.7.3 Meetings in 2003

First Experts Meeting, December 4 – 6th, Gleisdorf, Austria

6.7.4 Meetings in 2004

Second Experts Meeting, March 29 – 30, Brussels, Belgium
Third Experts Meeting, October 3 – 5, Oaxaca, Mexico

6.7.5 Meetings in 2005

Fourth Experts Meeting, February 23 – 25, Madrid, Spain
Fifth Experts Meeting, October 3 – 8, Kassel, Germany

6.7.6 Meetings in 2006

Sixth Experts Meeting, March 29 – 31, Rome, Italy
Seventh Experts Meeting, October 11 – 13, Lisbon, Portugal

6.8 *Task IV National Contacts*

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Part 5: Status Report
Task III:
Solar Technology and Advanced Applications

Operating Agent:
Christoph Richter
DLR TT-SF AS (Plataforma Solar de Almería)/

5 Task III: Solar Technology and Advanced Applications

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5.1 Nature of Work & Objectives

The objectives of this task deal with the advancement of technical and economic viability of emerging solar thermal technologies and their validation with suitable tools by proper theoretical analyses and simulation codes as well as by experiments in special arrangements and adapted facilities. For this purpose, procedures and techniques are defined for the design, evaluation and use of the components and subsystems to optimize concentration, reception, transfer, storage and application of solar thermal energy. In essence, the goals are to investigate innovative multi-discipline advances needed for the further development of concentrating solar thermal systems. This also concerns, among others, process heat applications, the utilization of solar concentration for the development of improved materials, and the introduction of hybrid solar/fossil power plant concepts.

Task III is an ongoing R&D-oriented effort with clearly defined technical objectives, time schedule and expected results. Activities are cost-shared, task-shared (either through SolarPACES or among SolarPACES participants), and/or information-shared. Cost-sharing and task-sharing activities involve cooperative efforts of two or more participants where either costs of activities or responsibilities for activities, respectively, are mutually agreed upon and shared by the Participants. Information sharing is used for the exchange and discussion of results of projects carried out independently by Participants, but of interest to all.

5.2 Task III Objectives 2007-2011

In the context of the growth of commercial CSP project activities, further development and improvement of all CSP plant components is an obvious Task III challenge. The findings of studies like Ecostar on the impact of technological R&D efforts to reduce the total cost CSP plants should be borne in mind and refined to efficiently allocate R&D funds to the most productive topics.

Development of supporting tools becomes an even more important issue. Further development of storage technology remains an important goal to maximize the CSP advantage by offering guaranteed capacity and operability with continuously increasing solar shares, as well as to offset the growing cost of fossil fuels in hybrid operation. Addressing issues like water availability (cooling, mirror cleaning) and environmental concerns accompanying CSP plant implementation has become an important activity and a task for identifying low or no water consumption options has been initiated.

While our industrial partners competitively pursue project development and component R&D, the following activities appear to be appropriate for collaboration in support efforts and to move the technology forward:

- **Guidelines for component performance measurements**, which can help component suppliers and plant operators to qualify and validate component specifications.
- **Prioritization of R&D activities with high impact on cost reduction.** The findings of studies like Ecostar on the impact of different technological R&D efforts on total CSP plant cost reduction will be further refined. In addition, SolarPACES Task III will work as a catalyst to set up international R&D projects for best use of funds to follow the roadmap laid out.
- **Reliability Evaluation of solar components and systems**. SolarPACES Task III will develop methods and procedures in order to predict lifetime performance of solar plant components and systems. This also includes the development of proven methods for long-term stability testing (e.g., accelerated aging).
- **Internationally standardized tools and methods for quality assurance of concentrator systems** to assure the optical quality of concentrators during installation and operation, including fast measuring systems for concentrator quality control and component performance characterization. Harmonization of simulation tools used to be able to offer reliable product and performance data to investors.

- **Comparison and evaluation of storage concepts** Define a methodology to compare and assess different storage concepts and collect design and operation data during testing in various locations
- **Power plant optimization for arid regions.** Power plant optimization for arid regions. Task III will assess efficient solar thermal power plant operating options at sites with low water availability based on experience with dry cooling in conventional power plant operation.

Task III activities reported in 2006 are summarized in Table 5.1. They are cost and/or task sharing, as marked in the right-hand column:

1. Cost shared activities created and coordinated through SolarPACES (Label C in Table 5.1)
2. Task shared activities created and coordinated through SolarPACES (Label T in Table 5.1)
3. Task shared activities created and coordinated by SolarPACES member countries (eventually with participation of non-member countries) which are of interest to SolarPACES (Label M in Table 5.1)
4. Activities of individual member countries, which are of interest to SolarPACES (Label I in Table 5.1)

Table 5.1. List of activities reported in 2005

Topics	Activity / Project	Contact	Sharing			
			I	M	T	C
Sector 1. Components and Subsystems						
Central Receiver	SOLHYCO	Heller	x			
Linear Fresnel	VDemo-Fresnel II	Morin		x		
	Fresquali	Platzer		x		
Sector 2. Supporting Tools and Test Facilities						
Test Facilities	Efcool	Richter			x	
Measurement	Opalmobil	Luepfert	x	x		
	Saphir	Ulmer	x	x		
	SolLab Radiometer Intercomparison Campaign	Neumann		x		
Sector 3. Advanced Technologies and Applications						
High Temp. Process Heat	CIEMAT-CENIM Agreement	Vázquez	x			
	SolarPRO	Martinez	x			

5.3 Summary of Achievements

5.3.1 Sector III.1: Solar Specific Technology, Components and Subsystems

This sector covers general activities and activities in the fields of:

- Central Receiver Systems
- Dish/Stirling Systems
- Linear Collectors (Parabolic Troughs, Fresnel)

- Storage

Solar hybrid power and cogeneration plants (SOLHYCO)

Contact: Peter Heller, DLR, Apartado 39, 04200 Tabernas, Spain. peter.heller@dlr.de

Participants: DLR (D), Turbec (S), CEA (F), Ciemat (E), Solucar (E), Ormat (I), GEA (PL), FTF (D), NEAL (Alg), FUSP (Bra), Vitalux (Bra), IIE (Mex)

Funding: EC FP6 STREP; 3.4 M€ total cost,

Duration: 42 months

The SOLHYCO project focuses on the development of a 100-kW$_e$ prototype solar-hybrid microturbine conversion system for cogeneration. Innovative project developments are:

- Solar-hybrid microturbine prototype unit based on a commercial microturbine
- New receiver based on a new high-performance tube technology
- Bio-fuel combustion system

The project started January 1, 2006. In the first year of the project, development of the bio-fuel combustion system was completed. The conceptual design for microturbine modification was completed, and first test runs of combustion components were made. The hybrid bio-fuel combustion system will be tested in Summer 2007 at the CESA-1 solar tower facility at the Plataforma Solar de Almeria. Development of the tube receiver manufacturing method was begun. Tube test sample thermo-mechanical characteristics will be thoroughly studied and tested in the lab during 2007. The receiver and turbine system will be ready for solar-hybrid testing in March 2008.

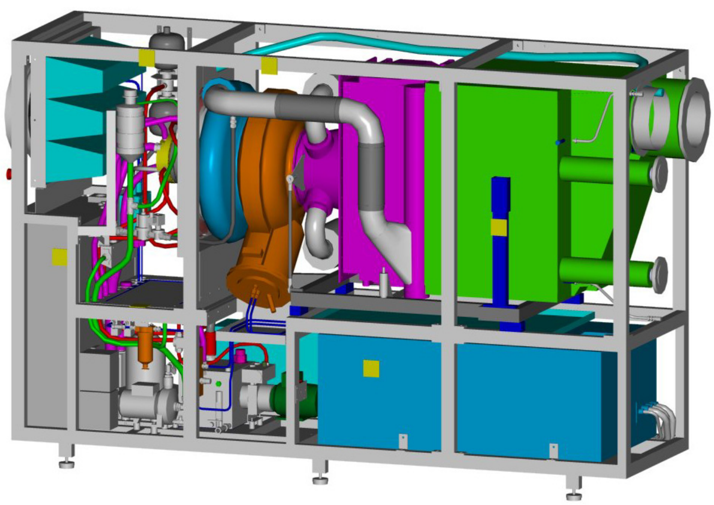

Figure 5.1 TURBEC turbine package (100 kWe) for cogen applications

LINEAR COLLECTORS (PARABOLIC TROUGHS, FRESNEL)

VDemo-Fresnel II – Development of high-temperature stable absorbers and front surface mirrors for atmospheric conditions and experimental evaluation of Fresnel collector components

Contact: Gabriel Morin, Fraunhofer Institute for Solar Energy Systems ISE

Participants: Fraunhofer ISE, DLR, PSE

Funding: German Ministry for Environment, Nature Conservation and Nuclear Safety (BMU): 382 t€, PSE: 56 t€

The main aim of this project was the preparation of a linear Fresnel collector power plant module. This entailed a series of materials development tasks and experimental testing of collector components.

Fraunhofer ISE developed a sputtered air-stable absorber coating that resists up to 450°C with a solar absorptivity of 94% and emissivity of 18%.

The second goal of the project was the development of a front surface reflector to be used in solar tower receivers as well as in secondary concentrators in the linear Fresnel collector. DLR simulated the potential for higher reflectivities and free design parameters (2-axial instead of 1-axial bending of the glass substrate).

Furthermore, Fresnel collector components were also experimentally qualified: A receiver erected by SPG was thermally qualified using an electric heater inside the tube. Component stability, temperature distribution and temperature-dependent heat loss were tested for temperatures up to 550°C. The accu-

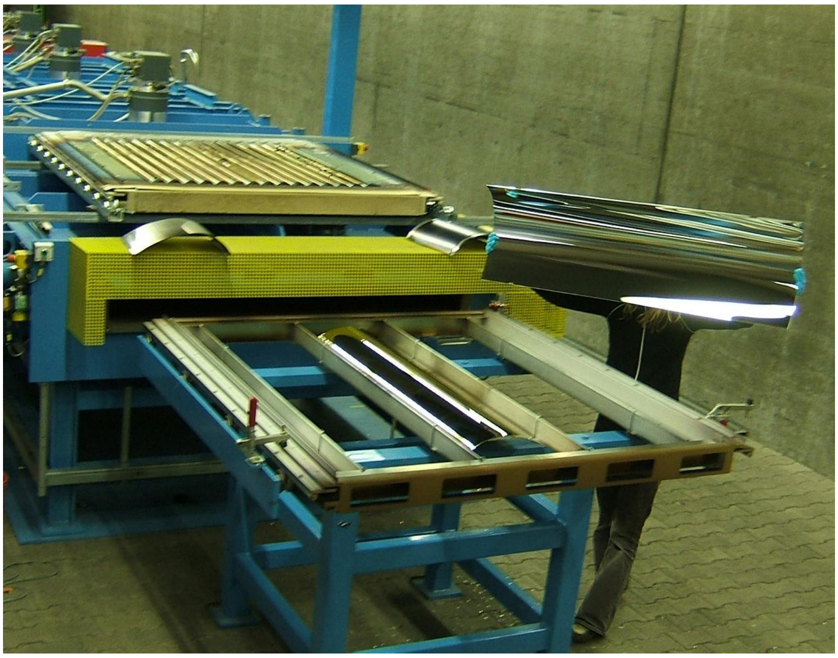

Figure 5.2 Front surface reflecting mirror coated in sputtering machine (background).

racy of different types of slightly bent primary mirrors for Fresnel collectors was determined by flux density measurements.

This project will be followed by a linear Fresnel collector demonstration plant which is currently under construction by MAN Ferrostaal at the Plataforma Solar de Almería, with co-funding of the BMU.

"Fresquali" – Qualification of Linear Fresnel Collectors; Adaptation and Development of Optical and Thermal Testing Techniques

Contact: *Dr. Werner Platzer,* Fraunhofer Institute for Solar Energy Systems ISE, Heidenhofstr. 2, 79110 Freiburg, Germany

Participants: Fraunhofer ISE

Funding: German Ministry for Environment, Nature Conservation and Nuclear Safety (BMU): 390 t€

The Linear Fresnel Collector is an attractive option for solar thermal power stations, as shown by previous projects and feasibility studies. MAN Ferrostaal Power Industries is currently erecting a demonstration collector in cooperation with Fraunhofer ISE and DLR at the Plataforma Solar de Almeria. To ensure industrial production lines and qualification, Fraunhofer ISE is developing measurement techniques for industrial application of Fresnel collectors and adapting them to their special properties and geometries in a German national project called FRESQUALI.

Optical and thermal qualification will help manufacturers and construction companies to control collector performance as stipulated in the specifications. Some properties of the key components, i.e., thermal receiver, secondary and primary mirrors, still have to be determined.

In the first months of the project, a reflectometric technique was adapted to the requirements of solar field characterization. With strip reflection, the shape and optical aberrations of

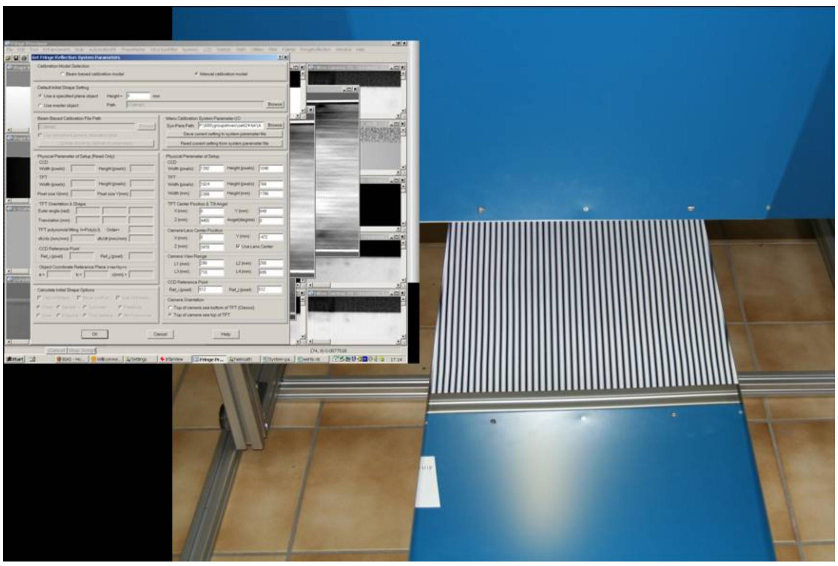

Figure 5.3 Strip reflection testing of primary mirror in a laboratory setup with screenshot of software evaluation tool

curved mirrors can be determined from camera pictures. Laboratory measurements using active pattern generation with projectors or flat screens have been developed to qualify the primary and secondary mirrors during production at the PSA. At the moment, a passive pattern technique using a printed pattern with sinusoidal grey strips is being developed for outdoor characterization of mounted mirrors. The technique is very flexible and may be adapted to parabolic mirror fields also.

Dust and dirt as well as degradation of mirrors may also reduce the output of solar thermal fields and have a noticeable impact on their economics. A mobile spectrometer is to be used for fast reflectometric characterization in a handheld device.

A special 3.4-µm wavelength thermal infrared camera can be used to study the temperature distribution of solar receivers behind the glass cover for non-destructive testing of absorber properties.

5.3.2 Sector III.2: Supporting Tools and Test Facilities

This sector covers the following activities:

- Simulation and Software Activities
- Networking / Standardization
- Measurement Systems
- Test facilities

Water efficient cooling of solar thermal power plants

Contact: Christoph Richter, DLR, DLR German Aerospace Center

Participants: DLR German Aerospace Center; NREL

Funding: BMU German Federal Ministry for the Environment (Efcool Project), DLR and NREL

Today’s solar thermal power plants are similar in design to conventional power plants and typically use wet cooling towers to achieve maximum performance. The water consumption of these systems ranges between 3-1/2 and 5 tons per MWh. Less than 3% of this water is used for mirror washing purposes. Dry-cooled systems suffer from a significant reduction in power output, an increase in parasitic power requirements, and higher capital cost, increasing the levelized energy cost (LEC) by 5 to10%.

Water availability is limited in the potential market regions for solar thermal power plants, and either environmental legislation limits its use for cooling purposes or water costs are significantly higher than for existing power plants. This creates a strong interest in the development of alternative cooling concepts with low water consumption.

The purpose of this activity is to identify and optimize cooling concepts for solar thermal power plants at sites with limited water availability and evaluate the impact of the different cooling options on the LEC. This includes an overview of existing cooling technologies, including different combinations of dry and wet cooling (hybrid systems) and the analysis of options to shift cooling load to evening and night hours via storage concepts, which may reduce the necessary investment and operation cost of the cooling system due to extended operation time and reduced ambient temperature. For the evaluation of these different options a simulation tool is developed to analyze the LEC based on the relevant weather conditions at different project sites. Recommendations for the design of suitable cooling systems, especially for parabolic trough plants operating with thermal oil as heat transfer fluid, are derived from the analysis of different case studies.

Publications: [5.06][5.07]

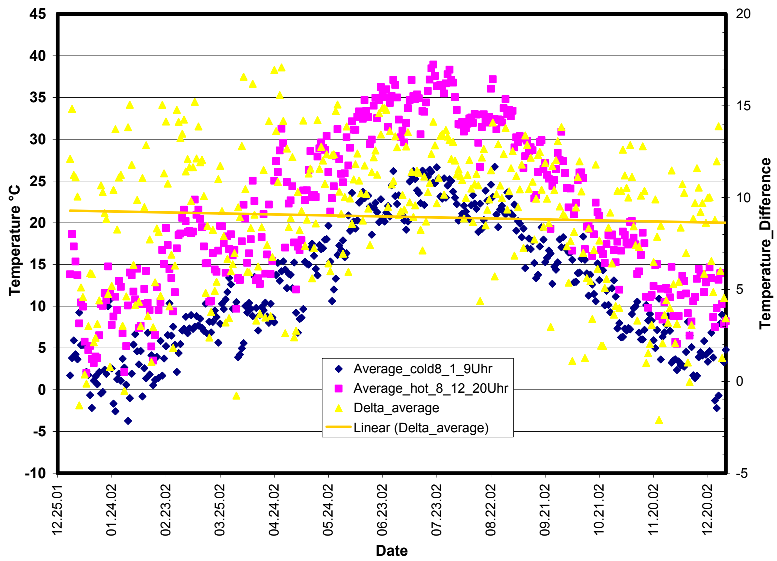

Figure 5.4 Yearly distribution of average night and day temperatures for a site in Morocco for assessment of storage potential for plant cooling

OPALmobil

Contact: Eckhard Lüpfert, Klaus Pottler, Steffen Ulmer, Marc Röger, DLR German Aerospace Center e.luepfert@dlr.de

Participants: DLR German Aerospace Center

Funding: BMU German Federal Ministry for the Environment, and DLR

The construction of solar thermal power plants with several thousands of square meters of collector area requires quality control measures for components, subsystems, and entire collector rows. The main objective of quality control is to ensure high optical performance for the whole solar field. Quality control, assembly documentation and performance measurements are required by investors. Based on previous R&D work in collector development and prototype qualification with photogrammetry, an automatic measurement system has been developed for use in solar field series assembly.

A new, fast, highly accurate method of optically measuring the reflector slope of parabolic troughs has been developed. It makes use of the absorber tube reflection in the concentrator as seen from some distance, and is therefore called the "absorber reflection method". Sets of absorber tube reflection images are taken with the concentrator at different angles. The reflector slopes are determined with image analysis algorithms and geometrical evaluation. EuroTrough measurements were verified against a reference measurement using high-resolution close-range photogrammetry. The new technique dramatically reduces the required measurement time.

The techniques have successfully been transferred to heliostat applications.

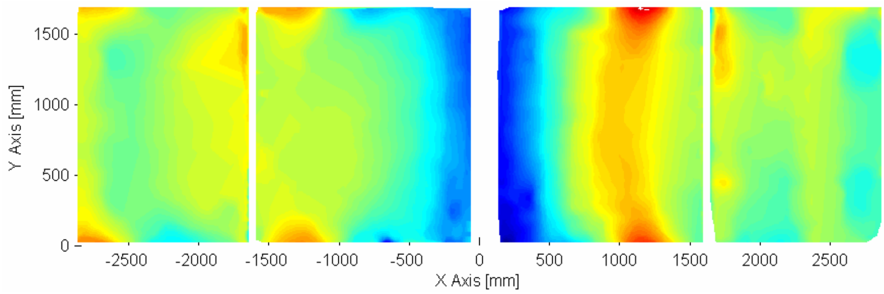

Figure 5.5 Deviation graph for EuroTrough reflector panel slope measured by the absorber reflection method

SAPHIR

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Participants: DLR German Aerospace Center

Funding: BMU German Federal Ministry for the Environment, and DLR

The optical quality of the heliostat field and the homogeneity of the flux density distribution on the receiver are key factors for the energy efficiency and economics of solar tower power plants. To achieve reliable, cost-effective improvements in heliostat field manufacture, erection and operation in solar tower power plants, new and improved measurement methods are needed.

In this project, DLR is developing a new optical measurement method that simplifies and optimizes erection and canting of heliostats and assures their optical quality before commissioning of the solar field. This method is based on the reflection of regular patterns in the mirror surface and their distortions due to mirror surface errors. This highly accurate, high spatial-resolution measurement is also very fast, making automatic measurement of entire heliostat fields possible in a reasonable time. Figure 5.6 shows an example of heliostat slope errors measured at the PSA.

Additional optical measurement methods are being developed to automatically check the tracking accuracy of the heliostat field during operation and further increase the efficiency of solar receivers. Existing measurement systems for temperature and flux density distribution on the surface of small-scale prototype receivers have been extended to monitoring and control of these parameters on large-scale receivers during operation of commercial power plants.

Based on the knowledge acquired in this project, relevant parameters for the assessment of heliostat fields during design, manufacturing and operation have been defined and appropriate methods for their measurement proposed.

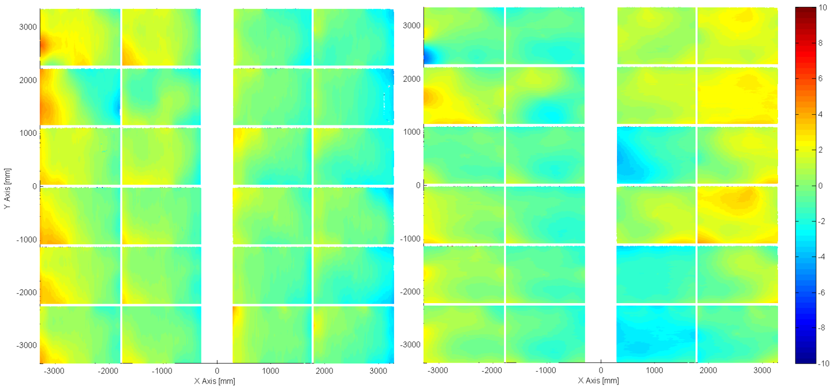

Figure 5.6 Horizontal slope deviation in milliradians (left) and vertical (right) of a heliostat at the Plataforma Solar de Almería measured with the reflection method

SolLab Radiometer Intercomparison Campaign 2006 'Intercomp 2006'

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Participants: CIEMAT, CNRS, DLR

Funding: by participant

For many years, solar laboratories around the world have joined forces, intensively cooperating in the field of concentrated solar irradiance measurements. This is expressed by past international campaigns aiming at the comparison of flux density sensors.

Intercomp 2006 was held by the SolLab European Laboratory Alliance to compare flux density sensors, and detect potential errors. SolLab was formed in 2004 by the Laboratoire Procédés, Matériaux et Energie Solaire (PROMES-CNRS), the Solar Research Division of DLR's Institute of Technical Thermodynamics (DLR), the Plataforma Solar de Almeria (PSA-CIEMAT) and the Swiss ETHZ Renewable Energy Carriers Laboratory (REC-ETHZ).

The flux density ranges were selected according to the specifications of the participating instruments:

- Low Flux Group I: 0 – 50 suns
- Low Flux Group II: 0 – 300 suns
- High Flux Group I: 0-1000 suns
- High Flux Group II: 0-5000 suns

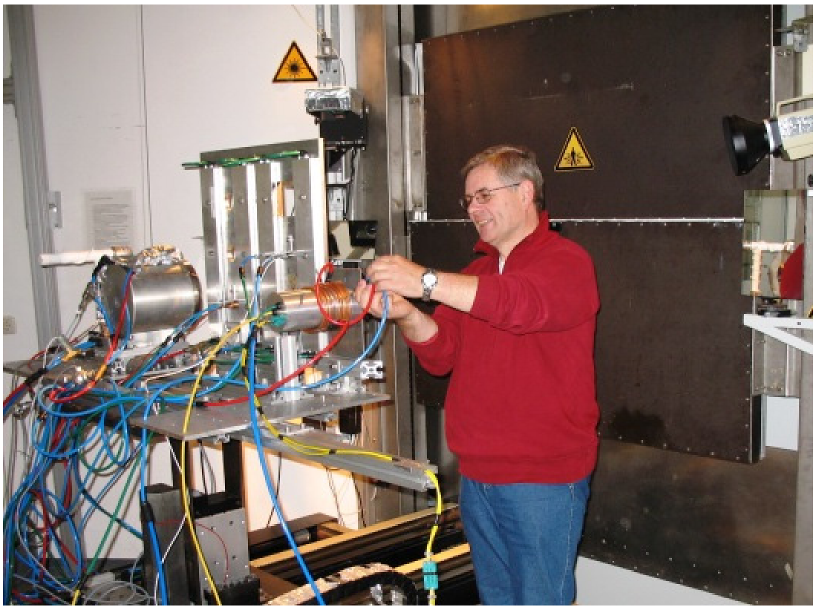

Figure 5.7 Alex Szubarga (CNRS) installing his calorimeter on the exposure platform in the DLR Solar Furnace.

11 different instruments (cold water calorimeters (see Figure 5.7), Gardon type sensors, Kendall radiometers, and a new type sensor brought by CNRS, were compared.

Calorimeters, Kendalls and the new CNRS sensor compared well, while the Gardon-type instrument data deviated more. The maximum deviation was on the order of 18%.

The campaign was successful, and each participating party was able to collect valuable information. Occasional comparative measurement has become an absolutely necessary task.

Publications: [5.08]

5.3.3 Sector III.3: Advanced Technologies and Applications

CIEMAT-CENIM Agreement for Thermal treatment of Metals with Concentrated Solar Energy and Characterization of Solar Concentrators.

Contacts: Prof. Dr. D. Alfonso Vázquez, CENIM – CSIC and Inmaculada Cañadas Martínez, Plataforma Solar de Almería - CIEMAT

Participants: Plataforma Solar de Almeria, CIEMAT (Spain). CENIM - National Center for Metallurgical Research, CSIC (Spain)

Funding: CENIM (CSIC), PSA (CIEMAT) Agreement (2006-2008)

A fluidized bed heated by concentrated solar energy was characterized as a thermal reactor for metallurgical applications. The bed uses typical foundry sand, which is an inert, cheap material of easily controlled size. The heat treatment rate depends on insolation and the amount of sand in the bed, which is heated and fluidized by a double gas circuit. Fluidizing air is preheated in a heat exchanger coil by solar-heated exhaust air. A temperature of 1100 K is easily reached, making it suitable for many metallurgical applications. Temperature stability remains good even during changes in direct insolation for short periods of time due to cloud transients or any other interruptions because the sand reactor mass has a high thermal inertia. Fluidized beds are characterized by temperature stability throughout the bed, so solid metal treatments at specific required temperatures are possible. This characteristic is also of great interest in gas-gas organic reactions or gas-solid organic catalytic reactions.

During 2006 foaming of aluminum alloys and hardening of steel by heating in the bed and quenching in water or oil were tested, demonstrating the feasibility of a solar heated fluidized bed as a thermal reactor for medium and high-temperature metallurgical applications.

Future applications to be tested during 2007 will include other thermal treatments, such as nitriding, carburizing, etc., to coat metals in reactive atmospheres, and cleaning soils contaminated by metallic zinc and zinc chloride salts at galvanizing plants.

SolarPRO - Development of a heat supply system based on concentrated SOLAR beam: testing and characterization of its application to several high-temperature industrial and waste removal PROcesses

Contact: Diego Martínez Plaza, Plataforma Solar de Almería-CIEMAT

Participants: Plataforma Solar de Almeria, CIEMAT (Spain). Coordinator. Mechanical and Material Engineering Dept., University of Seville (Spain). Institute of Ceramics Technologies. Castellón (Spain). Fluid Mechanics Dept., Polytechnic Catalonian University (Spain).

Funding: Spanish Science and Technology Ministry. National Program of Scientific Research, Development and Technology Innovation 2000-2003 (REN2003-09247-C04-01)

The aim of this project is to demonstrate the technological feasibility of using solar thermal energy to supply different industrial processes, other than electricity generation and common denominator of which is their high process temperature. For this purpose, the experience and knowledge gathered during the various central receiver technology projects and materials treatment activities will be combined in the Solar Furnace.

Figure 5.8 Assembly of processing plant with volumetric receiver at the PSA Solar Furnace

Processes studied have been classified in two basic groups:

- Industrial manufacturing processes.
- Solid wastes treatment processes.

SolarPRO has verified the enormous potential of applying solar thermal energy to the ceramic industry, solid waste treatment, and some materials treatments, such as sintering.

Publications: [5.01][5.02][5.03][5.04]

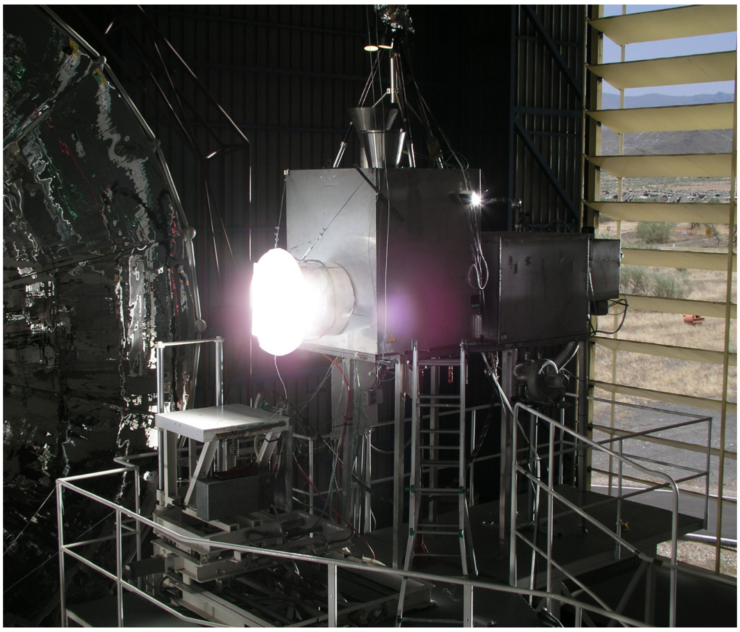

Figure 5.9 Fluidized bed with volumetric receiver in the PSA Solar Furnace

5.4 Outlook

CSP technology has experienced a strong growth in public and political awareness in several countries, especially Spain, during the last few years, creating an attractive market. Accordingly, projects are now underway or in an advanced stage of planning. This creates a stimulating environment for R&D work to further improve components, develop standardized testing methods and investigate advanced concepts for power plant design and operation. Therefore an important effort will be dedicated in the near future to further improve tools for quality and performance assurance especially in concentrator and receiver elements of CSP plants, demonstrate new storage concepts to drive cost down and assist power plant operation. A new activity regarding efficient water cooling of CSP plants is being initiated to address this important issue.

5.5 Meetings, Reports Publications

5.5.1 Meetings

Task meetings in 2006 were held at the 13th SolarPaces Symposium in Seville, Spain on June 25, 2006.

5.5.2 Literature

[5.01] Cañadas, I.; Téllez, F.; Rodríguez, J.; Martínez, D. "'SOLARPRO': A survey of feasible high temperature industrial applications of concentrated solar energy". Proceedings of 13th International Symposium on Concentrated Solar Power and Chemical Energy Technologies. ISBN: 84-7834-519-1. Seville (Spain) 20-23 June 2006

[5.02] Cañadas, I.; Martínez, D.; Téllez, F.; Rodríguez, J. "Feasibility Use of Solar Thermal Energy in High Temperature Industrial Processes" Proceedings of International Conference On Renewable Energies and Water Technologies. Roquetas de Mar - Almería (Spain). 6-8 Octubre 2006

[5.03] Cañadas, I.; Martínez, D.; Rodríguez, J.; Gallardo, J. M. *Sintering of Multilayered Copper Wires in a Solar Furnace*. PM 2004 Conference Proceedings Vol 2. 143-148. ISBN: 1899072152

[5.04] Rojas, E.; Cañadas, I.; *Calor Solar en Procesos Industriales;* Congreso Nacional sobre Energías Renovables (CONEERR2005). 14-16/11/2005 Murcia (SPAIN).

[5.05] I. Cañadas, D. Martínez, J. Rodríguez, B. J. Fernández-González, A. J. Vázquez-Vaamonde. "Procesamiento en Lechos Fluidizados Calentados con Energía Solar Concentrada": Proceedings of XIII Congresso Ibérico e VIII Ibero Americano de Energia Solar. Lisbon (Portugal). 9-10 November, 2006

[5.06] California Energy Commission, 2002, "Comparison of Alternative Cooling Technologies for California Power Plants Economics, Environmental and Other Tradoffs," CEC 500-02-079F, Feb 2002. http://www.energy.ca.gov/pier/final_project_reports/500-02-079f.html

[5.07] "Why every air cooled steam condenser needs a cooling tower" LUC DE BACKER Ph.D.; WILLIAM M. WURTZ; HAMON DRY COOLING;Presented at the 2003 Cooling Technology Institute Annual ConferenceSan Antonio, Texas – February 10-13, 2003

[5.08] Report of the Intercomp 2006, SolLab Radiometer Intercomparison Campaign 2006, DLR

Part 3: Status Report
Task I:
Solar Thermal Electric Systems

Operating Agent:
Mark S. Mehos
National Renewable Energy Laboratory

3 Task I: Solar Thermal Electric Systems

3.1 *Nature of Work & Objectives*

Task I addresses the design, testing, demonstration, evaluation, and application of concentrating solar power systems, also known as solar thermal electric systems. This includes parabolic troughs, linear Fresnel collectors, power towers and dish/engine systems. Through technology development and market barrier removal, the focus of SolarPACES Task I is enabling the entry of CSP systems into the commercial market place. The component development and research efforts of Task III (see Part 5 of this report) logically feed Task I as new components become parts of new systems. In return, the results of this Task I provide direction to Task III on new component needs.

3.2 *Organization and structure:*

The Task I Operating Agent is responsible for organization and reporting of Task I activities. These are separated into sub sectors, as designated by the Operating Agent and approved by the Executive Committee. Each sector is coordinated by a Sector Leader who is appointed by the Operating Agent and is responsible for coordinating activities within his Sector. Current Sectors are:

I.1 **Central Generation Systems**: includes technology activities primarily associated with large-scale parabolic trough, linear Fresnel and power tower systems. This sector is currently led by Mark Mehos of the National Renewable Energy laboratory in the USA.

I.2 **Distributed Generation Systems:** includes technological activities associated with dish/engine, and other systems capable of providing power on a distributed basis like mini-towers and modular schemes for troughs and Fresnel collectors. The Australian CSIRO currently leads this sector.

I.3 **CSP Market Development:** includes activities addressing financial, regulatory, environmental, marketing, dissemination and other largely non-technical issues. Task 1.3 focuses on identifying, tracking, and facilitating entry into emerging markets by the worldwide Concentrating Solar Power industry. Sandia National Laboratories, USA, leads this sector.

Task activities are cost-shared, task-shared (either through SolarPACES or between SolarPACES participants), and/or information-shared. Cost-sharing and task-sharing activities involve cooperative efforts involving two or more participants where either the cost of the activities or responsibilities are mutually agreed and shared. Information sharing is used for the exchange and discussion of results of projects carried out independently by Participants, but whose results are of interest to all.

Creation of a Task activity is based on the request of one or more of the participants and must be approved by the OA. Each activity has a lead individual designated by the Participants involved in the activity. The lead individual is responsible for coordinating the SolarPACES involvement, as well as regular reporting to the Task I OA.

Deliverables: The OA is responsible for general Task I reporting, including preparation of input to the IEA/SolarPACES Annual Report, and for maintaining a Program of Work describing ongoing and anticipated activities. Participants are responsible for detailed reporting on their respective activities. General reports (not containing proprietary information) are available to all Task participants, although the Participants in an activity may, at their option, limit the distribution of proprietary information. The activity lead is responsible for providing information to the OA for general reporting requirements. The OA is responsible for organizing one to two Task meetings per year to discuss activity status and progress.

One Task I meeting was held in 2006 in Seville, Spain in conjunction with the 13th SolarPACES symposium [3.01].

3.3 Status of the Technology

Concentrating solar power today is basically represented by four technologies: parabolic troughs, linear Fresnel reflectors, power towers and dish/engine systems. Of these technologies, only parabolic troughs have been deployed in commercial plants. Nine SEGS plants totaling 354 MW, originally built and operated by LUZ in California in the 1980s and 1990s, are continuing to operate today with performance of most of the plants improving over time. At the end of 2005 SolarGenix completed construction of a 1 MW parabolic trough plant for Arizona Public Service, the first new commercial CSP plant to begin operation in more than 15 years. Three additional CSP plants are currently under construction, PS10 and Andasol One in Spain, and Nevada Solar One in the U.S. PS10, a 10 MW saturated steam central receiver plant, and Nevada Solar One, a 64 MW parabolic trough plant, are expected to begin generating power in 2007. Andasol One, a 50 MW parabolic trough plant with 6 hours of thermal storage, is expected begin operating in 2008. Numerous other projects, described later in this report, are expected to begin construction in 2007. Many other projects are under various stages of development, primarily in Spain, northern Africa, and the southwest U. S.

Concentrating solar power offers the lowest cost option for solar energy today, with expected production costs of less than 20¢/kWh for early commercial plants with lower costs expected where additional incentives for CSP systems are available (e.g.

the existing U.S. Federal 30% Investment Tax Credit). As the cost of electricity from conventional generation technologies continues to rise, off-takers are becoming increasingly interested in CSP as a viable alternative to other renewable technology options. Concerns over global warming and the increasing likelihood of a global carbon constrained energy market, has further increased this interest.

The Chapter dealing with solar thermal power plants by Becker et al. in "*The future for Renewable Energy 2: Prospects and Directions*" edited by the EUREC Agency in 2002 (See reference [3.05]), provides a thorough, up-to-date summary of the status of the technology, a look at the road to the future, market inroads, and goals for RD&D, as seen from the standpoint of selected experts of the SolarPACES community. Chapter 6 of Volume 16 of the American Solar Energy Society (ASES) Advances in Solar Energy, written by Price and Kearney [3.06] provides a comprehensive discussion of the current status and future cost reductions related to parabolic trough technology.

Parabolic troughs are today considered to be a fully mature technology, ready for deployment. Early costs for solar-only plants are expected to be in the range of $0.17-0.20/kWh in sunny locations where no incentives are offered to reduce costs. In recent years, the five plants at the Kramer Junction site (SEGS III to VII) achieved a 30% reduction in operation and maintenance costs, record annual plant efficiency of 14%, and a daily solar-to-electric efficiency near 20%, as well as peak efficiencies up to 21.5%. Annual and design point efficiencies for the current generation of parabolic trough plants under construction in the U.S. and Spain are expected to be even higher based on the current generation of heat collection elements being furnished to the plants by both Solel and Schott. Several commercial trough projects are being pursued in Spain, the first one under construction is the 50-MW Andasol project that will use EUROTrough collectors and will have a 6-hour molten-salt heat storage system. Construction of the Andasol project near Granada began in 2006, with commissioning planned for 2008.

In the United States two commercial parabolic trough power plant projects are underway. The first is a 1-MW organic-rankine-cycle plant built by SolarGenix for Arizona Public Service. An organic Rankine cycle operates at lower temperature and efficiency than a steam-Rankine cycle and, potentially, will require lower operating and maintenance staffing. Construction was completed in December of 2005 and the plant startup started in January of 2006. SolarGenix is also nearing completion of a 64-MW trough project (conventional hot oil with a Rankine cycle power block) in Boulder City, Nevada (near Las Vegas) with operation scheduled for Spring of 2007.

Several options for hybrid solar/fossil plants exist. The integrated solar combined-cycle system (ISCCS) using trough technology has received much attention the past few years. Its advantage is lower solar electricity cost and risk in the near term, but this design's small annual solar fraction of about 10% is a concern to some [3.28]. New Energy Algeria (NEAL) selected Abener to build the first such project at Hassi-R'mel. The project will consist of a 150-MW ISCCS with 30 MW solar capacity. Similar project are under consideration in Egypt, Mexico, Morocco, and India.

Advanced technologies like Direct Steam Generation (DISS) are under development at the Plataforma Solar de Almería where research continues to compare direct steam, using a combination of sensible heat storage and latent heat storage, with oil based heat transfer fluids. Research on higher temperature heat transfer fluids and lower cost storage systems [3.17] are also being pursued.

Linear Fresnel systems are conceptually simple, using inexpensive, compact optics, and are being designed to produce saturated steam at 150-360 C with less than 1 Ha/MW land use. This technology may be suited for integration into combined cycle recovery boilers; i.e., to replace the bled extracted steam in regenerative Rankine power cycles or for saturated steam turbines. The most extensive testing experience at a prototype-scale is underway at the Liddell power station in Australia with very compact designs using multi-tower aiming of mirror facets. The first large proof-of-concept facility will be a commercial project started by the Solar Heat & Power Company, now Ausra, to integrate 36 MW of solar into an existing coal-fired power plant. In this hybrid plant, the 132,500-m^2 reflector field will supply 270°C heat to replace bled steam in the regenerative feed water heaters of the Rankine power cycle. Late in 2006, a 300-m-long array (5 MW_{th} delivery) was installed at the site. This is the first of three such arrays planned for this project stage. Connection to the Liddell plant is expected in 2007.

Power towers technology, a.k.a. central receiver technology, have completed the proof-of-concept stage of development and, although less mature than parabolic trough technology, are on the verge of commercialization. The most extensive operating experience has been accumulated by several European pilot projects at the Plataforma Solar de Almería in Spain, and the 10-MW Solar One and Solar Two facilities in California. After continuous technology improvement, CRS technology is predicted to reach efficiencies of 23% at design point and 20% annual performance.

Construction of PS10, the first commercial power tower, was completed by Solucar at its project site outside of Sevilla, Spain. The tower system uses a saturated steam receiver, producing 40 bar/250°C saturated steam to power a 10-MW saturated steam turbine. For cloud transients, the plant incorporates a thermal-oil storage system with a 20-MWh thermal capacity (1/2 hour at 70% load).

A likely more cost effective alternative to the saturated steam system developed for PS10 is the molten salt tower. This approach offers the potential for very low-cost storage that permits dispatch of solar electricity to meet peak demand periods and a high capacity factor (~70%). A molten-salt power tower three times larger than Solar Two is being designed by Sener for southern Spain. This plant is projected to achieve energy costs similar to trough technology, but with higher investment risk. Larger increases in plant size are projected to reduce energy costs significantly, achieving costs below that of advanced trough technology. Solar Tres, a 17--MW molten-salt tower under development by Sener, is projected to start construction late in 2007. Another 100-MW molten-salt plant is also under consideration in South Africa.

The use of volumetric air receivers for efficient integration into gas turbine cycles has been promoted in Europe and Israel using either open or closed loops, intermediate storage, and hybridization approaches in the SOLGATE, SOLAIR and Consolar pilot projects, but a commercial project is not yet underway.

Dish/engine systems are modular units typically between 5 and 25 kW unit size. Stirling engines have been used most frequently, although other power converters like Brayton turbines and concentrated PV arrays have been considered for integration with dish concentrators. The high solar concentration and operating temperatures of dish/Stirling systems has enabled them to achieve world-record solar-to-electric conversion efficiencies of 30%. However, due to their level of development, energy costs are about twice as high as those of parabolic troughs [3.05]. Dish/engine system development is ongoing in Europe and the USA. Reliability improvement is a main thrust of ongoing work, where the deployment and testing of multiple systems enables more rapid progress. Dish/Stirling systems have traditionally targeted high-value remote power markets, but industry is increasingly interested in pursuing the larger, grid-connected markets.

In Europe, Schlaich Bergermann und Partner have extensively tested several 10-kW systems, based on a structural dish and the Solo 161 kinematic Stirling engine at the Plataforma Solar de Almería. Follow-up activities based on the EuroDish design are being pursued by a European Consortium of SBP, Inabensa, CIEMAT, DLR and others. EuroDish prototype demonstration units are currently being operated in Spain, France, Germany, Italy and India. The EnviroDish project aims to transfer the former Eurodish system into small series production and deploy systems around the world.

In the USA, Stirling Energy Systems (SES) is developing a 25-kW dish/Stirling system for utility-scale markets. Six SES dish/Stirling systems are currently being operated as a mini power plant at Sandia National Laboratories' National Solar Thermal Test Facility in Albuquerque, NM, USA. SES has two power purchase agreements to install 800 MW of these 25 kW units in California, USA.

3.4 Program of Work in 2006

As summarized in Table 3.1 , Task I activities are organized by Sector. The focus of our efforts is on the testing of integrated CSP systems and support of commercial deployment projects. Activities listed in the table below (with contact person) are currently part of our Program of Work. In the sharing column, "I" refers to information sharing; "M" to task sharing by member countries; "T" to task sharing through SolarPACES; and "C" to cost sharing.

Table 3.1 Summarized Task I activities organized by Sector

Sectors and Activities	Contact	Sharing			
		I	M	T	C
Sector 1. Central Generation Systems	**Mark Mehos, NREL**				
Nevada Solar One	Cohen	x			
Solar Tres	Martín	x			
AndaSol I and AndaSol II Power Plant Projects	Gomez/Formica		x		
El Nasr Project	Mohsen	x			
DIVA	Eck	x			
ITES	Laing	x			
EuroDish and Other CSP Prospects in Italy	Brignoli	x			
Sector 2. Distributed Generation Systems	**Wes Stein, CSIRO**				
SES Dish/Stirling Systems	Andraka	x			
Liddelll CLFR Col Saver Project	Mills	x			
1000 MW CSP Initiative in the Southwest U. S.	Mehos/Mancini	X			
Sector 3. CSP Market Development	**Sandia**				
1000 MW CSP Initiative in the Southwest U. S.	Mancini/Mehos	x			
CSP Global Market Initiative	Geyer			x	x
Database of Project and Market Opportunities	Geyer			x	x

3.5 Participation and National Contributions

Task I is open to all IEA/SolarPACES member. Participation requires active involvement in an appropriate activity as described by the scope of Task I. Currently, all SolarPACES member countries except Switzerland participate in Task I.

3.6 Cooperation with Industry

Industry involvement is key to the system-level nature of Task I activities. Involvement can take forms ranging from a self-funded project lead to contractor status. Current participants are listed alphabetically by country in Table 3.2 below.

Table 3.2 Current participants listed alphabetically by country

Algeria	NEAL	Sonatrach
Australia:	CSIRO Solar Heat and Power Pty Ltd	University of NSW University of Sydney
Brazil:	CEPEL	Petrobras
Egypt	NREA	Lotus Solar Technologies
European Commission:	DG RTD	DG TREN
France:	CNRS	
Germany:	DLR Fichtner Solar FlagSol Framatone MERO	SBP Solar Millennium AG SOLO Kleinmotoren GMBH ZSW
Italy	CESI	
Israel:	Ben Gurion University Ormat Industries Rotem Industries	Solel WIS
Mexico:	IIE	
South Africa	ESKOM	
Spain:	ACS/COBRA CIEMAT INABENSA GAMESA IBERINCO	INITEC SENER SERLED SOLUCAR TECNICAL
United States:	Pratt and Whitney/ Rocketdyne Electric Power Research Institute Industrial Solar Technology Kearney & Associates KJC Operating Company Nexant (Bechtel Corp.) Reflective Energies	Stirling Energy Systems Sun•Lab (Sandia National Labs and National Renewable Energy Lab) U.S. Dept. of Energy

3.7 Summary of Achievements in 2005

Achievements within Task I activities are summarized below by activity within each Sector.

3.7.1 Sector I.1. Central Generation Systems

Central Generation Systems include large-scale parabolic trough, linear Fresnel, and power tower systems. Mark Mehos of the National Renewable Energy Laboratory is the Sector Leader.

Nevada Solar One

Contact: Gilbert Cohen Acciona Solar Power

Participants: Acciona Energia, Acciona Solar Power, Acciona North America, Solargenix Energy.

On February 11 2006, Nevada Solar One (NSO) groundbreaking ceremony took place at the construction site in Boulder City, Nevada. Construction of the 64-MW parabolic trough in Boulder City started immediately after this event. Plant construction is scheduled to end in April 2007 and commercial operation is planned for the summer of 2007.

NSO is the largest solar energy project to be built in the United States since 1991. It is also the largest renewable generating facility to be built in the State of Nevada. With a nominal capacity of 64 MW, NSO will annually produce more than 130,000 million KWh. NSO was initially developed by Solargenix Energy in 2003 and is jointly owned by Acciona Energia and Solargenix Energy. Acciona Energia purchased 55% of Solargenix Energy and formed a new Company named Acciona Solar Power.

The power plant is composed of 357,000 m² of second generation parabolic trough collectors (SGX2) developed by Solargenix Energy with the collaboration of the National Renewable Energy Laboratory. SGX 2 is an improved space frame design and a natural evolution from the SGX 1 successfully used in the 1-MW Saguaro plant in Arizona. The new space frame was redesigned in order to reduce fabrication time and cost. The SGX2 collector is extremely accurate, light and easy to assemble without the need of any complicated or expensive fabrication jig.

The absorber tubes used in the project were produced by Solel in Israel and by Schott in Germany, approx. 30% and 70% respectively.

The Reflector panels were produced by Flabeg in Germany. Several other mirror prototypes are installed as well for evaluation.

NEVADA SOLAR ONE – ACCIONA SOLAR POWER

Figure 3.1 Nevada Solar One solar field

Figure 3.2 Nevada Solar One administration and control building

Figure 3.3 Nevada Solar One power block

The power block located on the West side of the property used a 70-MW reheat steam turbine produced by Siemens in Sweden. Only a 2% supplement is allowed in Nevada, therefore, the plant has only a very small natural gas heater mostly used for freeze protection. NSO is a solar only system with 30 minutes of thermal storage used to minimize the effects of transients.

The administration and control building is a "green" building with many energy-saving features for lighting and air conditioning, e.g., orientation, insulation, and natural daylight monitors.

The project is located approx. 25 miles from Las Vegas and all the electricity produced will be distributed to the Nevada Power Company grid. Operation and maintenance will be provided by Acciona Solar Power.

Solar Tres

Contact: Mr. Jose C Martin, SENER Ingeniería y Sistemas, S.A.

Participants: SENER (E)

Funding: The project is presently being developed by SENER. Co-funded by the European Commission under FP5 with 5.000.000 €; other fundings under negotiation. Total cost: 196.000.000 €. Duration: 01/01/2004 – 31/12/2008.

The 17-MW Solar Tres will be the first commercial molten-salt central receiver plant in the world. With a 15-hour molten-salt storage system and a high-temperature, high-efficiency thermal cycle, the plant will generate 110.6 GWh/yr, equivalent to 6500 hrs of full-load operation or a 74% utilization factor.

The plant will have a cylindrical, molten-salt, central receiver and a field of 2600 115-m^2 heliostats.

The molten-salt central receiver will be provided by SENER. In mid 2005, SENER and CIEMAT reached an agreement to jointly develop a testing program at the PSA for the SENER prototype panel. The testing campaign started at the end of 2006 and the first phase of testing is expected to finish in April 2007. Heliostat technology will also be provided by SENER.

The Project Company, GEMASOLAR2006, is already funded, and land rights and electrical connection have been secured. The site is located in Fuentes de Andalucia, near Seville, in Southern Spain. The permitting process is under way. Solar radiation data at the site have been recorded for more than one year. The site enjoys one of the highest radiation levels in Spain.

Basic plant design is under development by SENER and project construction is expected to start before the end of 2007.

Figure 3.4 The 120 m^2 SENER heliostat under testing at the PSA

Figure 3.5 Molten salt panel under testing at the PSA

AndaSol-I and AndaSol-II

Contact:	Antonio Gomez (Cobra), Marcello Formica (Solar Millennium)
Participants:	Solar Millennium AG (D), Cobra S.A (E),
Funding:	Andasol-I funded under project finance scheme. Debt equity ratio: 80/20. EU-Grant of 5,000,000€. Andasol-II under project finance scheme. Debt equity ratio: 80/20.

The corner stone of the Andasol-I plant was laid on July 20, 2006. This plant, currently under construction, is planned to go into operation by spring 2008. It is to be Europe's largest solar thermal power facility.

The plant is in eastern Andalusia, in the province of Granada, in the Marquesado de Zenete in the municipal limits of Aldeire. It occupies 202 hectares, northwest of km. 313 on the A-92 highway from Guadix to Almería.

The parabolic trough power plant is being promoted by Solar Millennium and Cobra, and has been designed to produce 179.000.000 kWh of electricity a year, sufficient to supply power to a population of 200.000.

The AndaSol-1 solar thermal plant consists of a solar field of 510,120 m² of SKAL-ET type parabolic trough collectors, a 6-hour (+25 % reserve) molten-salt thermal storage system, and a Rankine cycle with a 49.9 MW_e net capacity.

The plant is designed for solar-only operation. The solar field is designed to supply up to double the thermal energy that can be absorbed by the steam turbine. That surplus energy is stored in a thermal salt system parallel to normal operation for operating the turbine when the solar supply is below design or when there is no solar supply at all (storage mode).

In direct operation mode, the heat transfer fluid (HTF) is circulated through the solar field to the steam generation system, where steam is produced at a temperature of 377°C and a pressure of 100 bar. The steam generation system consists of two parallel heat exchanger trains (pre-heater/steam generator/ super heater) and two, again connected in parallel, reheaters.

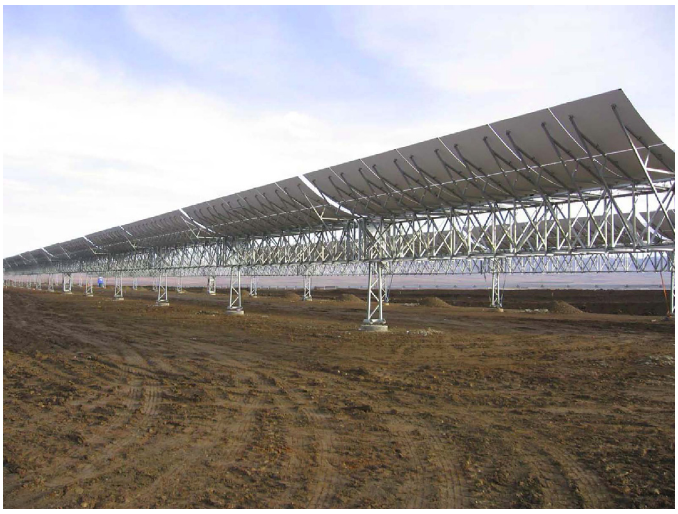

Figure 3.6 Andasol-I plant during construction stage

The HTF fluid acts as the heat transfer medium between the solar field and the power block, is heated up in the solar collectors and cooled down while producing steam in the steam generator. This steam is sent to the power block, where it is expanded in a steam turbine that drives the electricity generator. The reheat steam turbine has a 38% efficiency.

On December 27, 2006, the financial closure of the Andasol-II project was achieved. This plant at current construction is planned to come into operation by autumn/ winter 2008.

El Nasr Pilot Solar Steam Plant

Contact: Eng. Amr A. Mohsen, Lotus Solar Technologies

Participants: Lotus Solar Technologies (EG), Fichtner Solar (G), New & Renewable Energy Authority (EG)

Funding: African Development Fund, total cost: 1.1 M$, duration 11/2001 – 4/2003

Publications: [3.39] [3.40]

The El Nasr project involves the construction of a pilot 1,900 m^2 parabolic trough field to produce 8 bar/175°C saturated process steam by flashing to supply a pharmaceutical factory. Plant construction was completed in September 2003. Steam was produced during the initial plant trials on September 18, 2003 and supplied to the factory as soon as the existing factory steam network was ready to receive solar steam in May 2004.

During 2004, the unmanned plant performed very well except that the steam production was lower than the contracted rate. Lotus investigations concluded that the very aggressive operating environment (air) inside the chemical factory led to rapid deterioration of both reflectance and absorptance beyond the design 5%/yr rate. A rehabilitation program was completed in 2005 and performance was restored. Periodic rehabilitation is now scheduled to combat rapid deterioration. Plant enlargement with an additional linear collector loop failed to raise the necessary funding, but is still planned.

During 2005 and 2006, Lotus continued operating the plant intermittently, at NREA request, as they continue to promise plant acceptance at some unspecified future date.

Production peaks of 892 and 852 kg/hr have been logged on July 30 and October 30, 2006, respectively, which exceeds the production rate of 850 kg/hr agreed with NREA on March 16, 2005 for the reference date of June 21, 2005.

Figure 3.7 The El Nasr Solar Field

Figure 3.8 Low temperature receiver module scheme

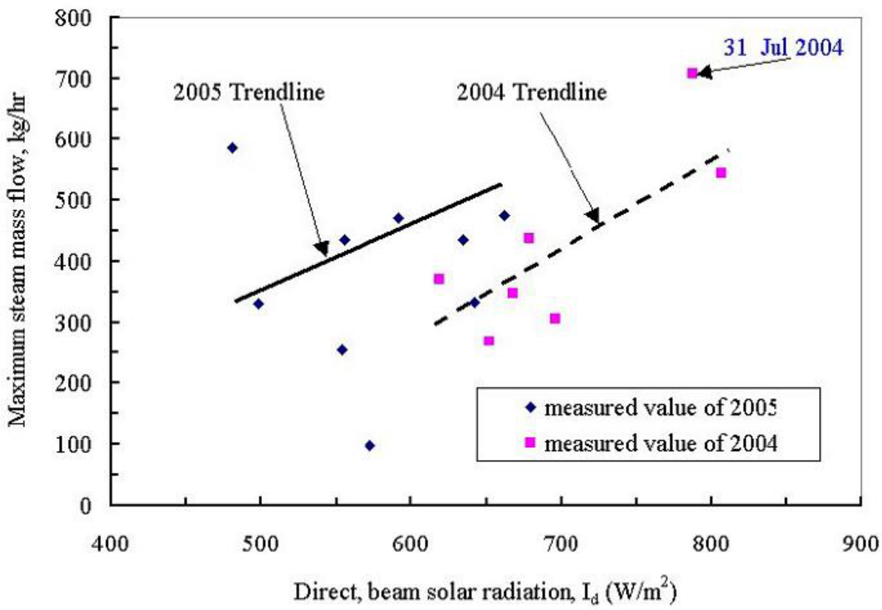

Figure 3.9 Comparison between plant productivity for years 2004 and 2005

DIVA

Contact: Markus Eck, DLR

Participants: DLR (coordinator), Schott, Flagsol, FhG-ISE, KK&K, (Ciemat)

Funding: German Ministry for the Environment, Nature Conservation and Nuclear Safety.

Duration: Aug. 2005 – Sept. 2007.

An absorber tube has been developed and operated in the DISS test loop at Plataforma Solar de Almeria (PSA). The absorber tube, which is based on the Schott PTR70, is designed for direct steam generation (DSG) with an operating temperature of 400°C. At the end of the project, a commercial tube will be available which can be used in DSG demonstration plants in Spain. In a second work package, a detailed study will show the goals and possibilities for future development of absorber tubes for 500°C. An optical layer has been developed that withstands temperatures of 500°C in a vacuum atmosphere.

A key aspect in the project is the comparison of the direct steam generation with the state-of-the-art oil technology considering the overall efficiency, technical and economical parameters. Chances and risks are evaluated based on a number of plant configurations with different sizes and life steam parameters.

ITES

Contact person: Doerte Laing, DLR

Participants: DLR (coordinator), Züblin, Siemens

Funding: Funded by German Ministry for the Environment, Nature Conservation and Nuclear Safety.

Duration: May 2006 – April 2009.

The aim of the ITES-project is the development of a thermal energy storage system for parabolic trough power plants with direct steam generation. Steam is produced in the solar field by pre-heating, evaporating and superheating the water. The thermal storage system has to provide the same process when it is discharged. For this reason individual storage concepts are

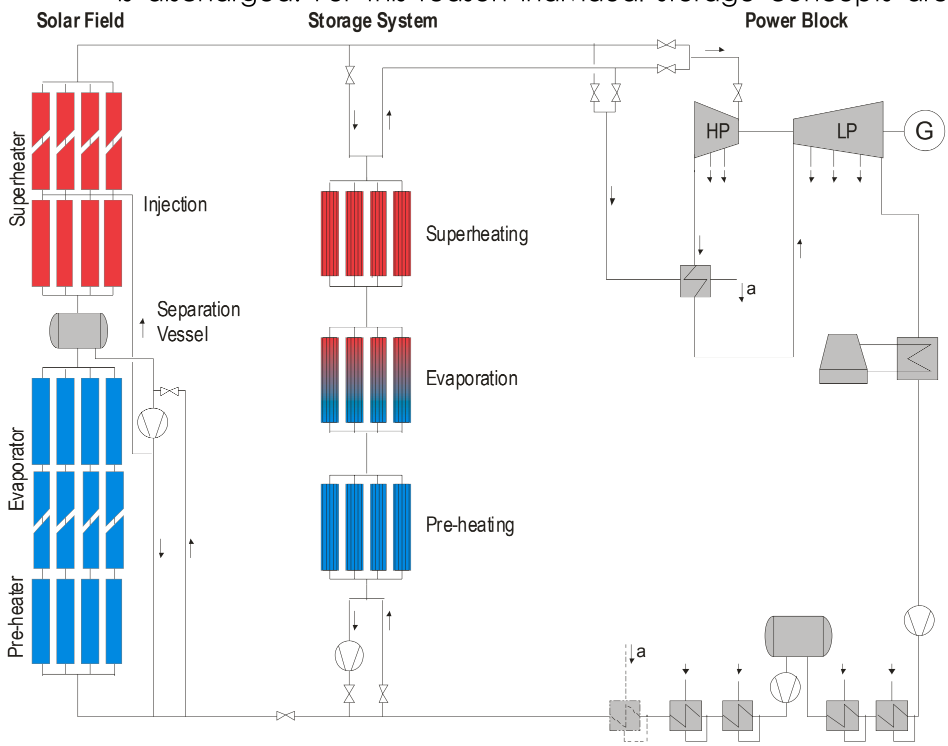

Figure 3.10 Schematic diagram of a direct steam generation power plant with thermal energy storage

used for the three sections: Sensible heat storage in concrete material and latent heat storage in phase-change materials. Both types have already been examined in previous research projects.

The design and operation of a solar power plant with such energy storage is analyzed for transient behavior and yearly electricity production. The three storage modules for a steam temperature of 400°C are designed, erected and operated at the DISS test loop at the Plataforma Solar de Almeria (PSA). Further work-packages deal with increasing the storage temperature to 500°C and special control aspects for direct steam generation.

EuroDish and Other CSP Prospects in Italy

Contact: Vittorio Brignoli, CESI Ricerca SpA, GEN Dept.

Participants: DLR (coordinator), Züblin, Siemens

Funding: Funded by German Ministry for the Environment, Nature Conservation and Nuclear Safety.

Duration: May 2006 – April 2009.

During 2006 the EuroDish generator at CESI RICERCA in Milan served basically as demo plant. Students, individuals and representatives of potential Italian developers have visited the facility. Conversion of the Stirling unit to a hydrogen working fluid has been proposed for 2007. In the meantime, other projects on CSP proposed by other research entities in Italy have been accepted by the Research Ministry and are now expected to receive funding. CRS4 in Cagliari and Lecce University will run new experiments in the field of parabolic trough transfer fluids. Work should be performed in two new experimental areas in the next 3 years, with a total funding of 25 – 30 M€. Activities will be focused on new fluids able to reach performance competitive with synthetic oil and molten salt.

ENEA parabolic trough activities using molten salt as the transfer fluid continued. A new heat collector element was fabricated using the ENEA sputtering machine, and operating tests of this new component have started. A new agreement with ENEL for the construction of a 5 MW_e-equivalent parabolic

Figure 3.11 The molten-salt-cooled parabolic trough collector at ENEA Casaccia base – Rome

trough solar field is under way and will become effective in 2007. The test plant will contribute to the production of electricity at the Priolo Gas Combined Cycle Power Plant according to the original projects. It will be the first example at reduced scale of parabolic trough ISCCS using molten salt as the primary fluid.

3.7.2 Sector I.2. Distributed Generation Systems

Distributed generation activities include dish/engine systems, mini-towers and modular schemes for troughs and Fresnel reflectors. Wes Stein, CSIRO Australia, is the Sector Leader.

SES Dish Stirling Systems

Contact: *Charles Andraka,* Sandia National Laboratories

Participants: Sandia National Laboratories, Stirling Energy Systems

Funding: US DOE; SES private investor funding

Stirling Energy Systems (SES) is developing a commercial Dish Stirling system, based on the McDonnell Douglas dish system, for deployment initially in large utility-size grid-connected fields. SES and Sandia continue to operate the 6-dish (150 kW) “Model Power Plant” (MPP) at Sandia to explore field communications and reliability issues and to validate changes in the next-generation design. In the next several months, SES will be constructing two new dishes at the MPP that incorporate a number of structural design changes to reduce costs and improve performance. This program will continue through 2008, with two additional dishes added to the MPP in late 2008 as well. SES has signed agreements for the purchase of power from two large plants in California. A plant for Southern California Edison (SCE) will be 20,000 dish systems (500 MW), expandable to 34,000 dishes. A plant for San Diego Gas and Electric will be 12,000 dishes, expandable to 36,000 dishes.

Figure 3.12 SES MPP in operation at Sandia National Laboratories

Liddelll CLFR Coal Saver Project

Contact: *Dr. David Mills, Peter Le Lièvre,* Solar Heat and Power Pty Ltd.

Participants: Solar Heat and Power Pty Ltd, Macquarie Generation

Progress and Funding:

Solar Heat and Power is continuing with the development of the CLFR project in Australia, and has built a full size 300-m long line as the first of three in a 15-MW_{th} project stage. The technology now uses larger 2.25-m-wide mirrors but only 10 instead of the former 12 in Stage 1. The receiver design is largely unchanged. Steam generation tests have begun and will be completed in May. The project will be connected to the adjacent coal fired plant later in 2007.

Figure 3.13 First 300 m line being erected.

Figure 3.14 Completed line in place.

SHP Australia has transferred its shareholding to a new company called Ausra Inc. based in Palo Alto, California. Ausra has received generous funding from Silicon Valley sources for projects and R&D. The basic CLFR is being significantly improved for the first US plants, and the new design, currently confidential, is being installed after mid-2007. Ausra will produce its own efficient selective coatings for the next generation of solar projects, and is developing thermal storage based upon steam and pressurized water; this is expected to be commercialized in 2008. Other technical developments are underway.

3.7.3 Sector I.3. CSP Market Development

The objective of Sector 3 is to identify, track, and facilitate entry into emerging markets of Concentrating Solar Power worldwide. Sandia National Laboratories acts as Sector leader.

This Sector addresses the collection and distribution to SolarPACES members of information about emerging market opportunities; the quantification of requirements and resources associated with each market or project; and market contacts for follow up actions. A second part of this activity involves developing contacts with the emerging markets, providing information about CSP to market representatives, and, if appropriate, arranging for information meetings on CSP technologies. A third activity is to identify and find ways to address barriers to CSP entry into specific projects or emerging market area. The Global Market Initiative started in this sector before becoming an activity of its own within SolarPACES.

1000 MW CSP Initiative in the Southwest U. S.

Contact: M. Mehos, NREL, mark_mehos@nrel.gov
T. Mancini, Sandia, trmanci@sandia.gov

Participants/Partners: U. S. Department of Energy, National Renewable Energy Laboratory, Sandia National Laboratories, U. S. Solar Energy Industries Association, U. S. Western Governors Association

Funding: $775K US

Duration: April 2003 - present

Publications: [3.41], [3.42], [3.43], [3.44]

This project was initiated in 2002 by a congressional request of DOE to investigate the "feasibility of 1000 MW of concentrating solar power in the Southwest by 2006." The initial activity, known as the 1000 MW Initiative, has grown and now includes: outreach to the southwestern states; the support of state-level activities in New Mexico, California, Arizona, and Colorado; and analysis in support of the Western Governors' Association (WGA) 30 GW Clean Energy Initiative.

In April of 2004 at the North American Energy Summit in Albuquerque, New Mexico, the Western Governors' Association resolved to evaluate diversification of Western energy resources. The mechanism for doing this is the 30 GW Clean and Diversified Energy Initiative for the West. In FY 2005, we provided significant support to the WGA Solar Task Force through a combination of in-house and subcontracted technical, policy, and market analyses. This effort continued into FY 2006 with the production of the final Solar Task Force Report issued in January 2006.

Activities starting in FY2006 (since October 2005) and continuing through the present time included continuing support of the WGA Solar Task force, reporting of WGA report results to southwestern U.S., and continuing the development of tools to support CSP market development activities including GIS-based siting tools and market value and market penetration models. Accomplishments in each of these areas is described below.

Continued Support to WGA Solar Task Force: The DOE CSP Program supported the WGA Solar Task Force by participating in task force meetings, providing analysis of CSP costs and southwest market potential, and we supported the writing of the Solar Task Force Report.

Analytical Support to Southwest Stakeholders: In California, the CSP Market Transformation Team met with members of the California Energy Commission and California utilities to discuss implementing CSP projects within the regulatory/ incentive structure in the state. We contracted with Black and Veatch to perform an economic impact study for deploying CSP power generation in the state of California.

In New Mexico, members CSP Market Transformation Team met with the State of New Mexico Energy and Minerals Department and made presentations to the state legislature and Public Regulatory Commission. These discussions helped to impact the development of a resolution in support of extending Federal incentives for wind and solar development; an increase of the state's RPS from 10 to 20%; pending legislation to further incentivize solar deployment through property and sales tax relief; and the possibility of a future solar set aside within the state's RPS.

In Arizona, the team provided technical support to the State of Arizona as they reviewed and restructured their Environmental Portfolio Standard. We also made presentations on CSP technology to the State Corporation Commission and, in response to their request, performed an analysis of how existing state incentives would support CSP deployment in the state. The team is also supporting a utility consortium, being led by Arizona Public Service, to explore developing a CSP project in southwest.

Analytical Tools to Support These Efforts: NREL developed an initial U.S. CSP market penetration model to predict CSP market penetration as a function technology cost, cost of conventional technologies, and local and regional policies. The model called the Concentrating Solar Deployment System (CSDS) Model currently only supports analysis of a CSP parabolic trough system with thermal storage. Additional technology options will be added in the future.

NREL has also continued to develop GIS-based resource assessment tools that can be combined with other GIS data bases to provide CSP siting information to developers, state governments and utilities.

NREL has also developed an initial model of the potential impact that the development of a CSP project will have on the local, regional and state economy. This model is similar to the analyses done in Nevada, California, and New Mexico but allows us to perform initial estimates for any given region.

CSP Global Market initiative

The SolarPACES community is actively involved in the Global Market initiative, which was ratified at the 2004 Bonn Conference. The objective to launch a coordinated global initiative for concentrating solar power plants aimed at building 5,000 MW of large-scale CSP power projects and thereby significantly reducing the cost of this technology. SolarPACES coordination in this activity is carried out by the SolarPACES Executive Secretary, Dr. Michael Geyer, with the active support of ExCo members and the Task I operating agent. More information about the CSP Global Market Initiative appears in Part 2 of this report.

Database of Project and Market Opportunities

Recent years have seen a rapidly growing number of potential commercial CSP projects. Industry, researchers, financial and governmental organizations all interested in following the status of these projects, but maintaining information current has proven to be difficult and time consuming.

SolarPACES offers a dynamic information source and database that allows public access to up-to-date information on projects and market opportunities on its web pages: http://www.solarpaces.org/projects.htm and http://www.solarpaces.org/newprops.htm

Additional data on existing U.S. parabolic trough plants now exists on the recently updated Troughnet website supported through funding by the U.S. DOE. The project data base is located at http://www.nrel.gov/csp/troughnet/power_plant_data.html

3.8 *Outlook*

After two decades of slow transition, it is now undeniable that the R&D activities of SolarPACES member countries are starting to payoff construction of commercial solar thermal power projects in Spain and the U. S., with numerous additional projects developing at other sites around the world. The year 2006 brought about the first significant construction of CSP systems in over 15 years. Spain's leadership in creating a market for CSP technologies has clearly led to resurgence in interest in that country and worldwide. Policies in place or under consideration in many member countries are likely to result in the creation of a global market for CSP, resulting in an increase in technology options and market competition.

The vision that Concentrating Solar Power will provide an important, low-carbon contribution to electricity production over the coming decades is starting to be realized.

3.9 *Meetings, Reports, Literature*

Meetings:

One Task I meeting was held in 2006 in Sevilla, Spain in conjunction with the 13th SolarPACES symposium.

SolarPACES Reports:

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Part 7: Status Report Task V: Solar Resource Knowledge Management

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7 Task V: Solar Resource Knowledge Management

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7.1. Nature of Work and Objectives

The goal of the IEA 'Solar Resource Knowledge Management' Task is to provide the solar energy industry, the electricity sector, governments, and renewable energy organizations and institutions with the most suitable and accurate information on the solar radiation resources at the Earth's surface. These data should be easy to access, understandable and high-quality. The scope of solar resource assessment information includes historic datasets and currently derived data products using satellite data and atmospheric modeling.

The three main objectives to be achieved in this Task are to:

- Provide further standardization and benchmarking of international solar resource data sets,
- Provide improved data reliability, availability and accessibility in formats that address specific user needs, and
- Develop methods that improve the quality and spatial and temporal coverage, with customized solar resource products, including reliable solar radiation forecasts.

Better data accessibility and standardization will shorten the time needed for planning. More accurate and more detailed information on solar irradiance helps improve solar energy system efficiency and allows it to be adapted to the irradiance characteristics of specific sites. Forecasting will increase the value and acceptance of the solar energy produced.

7.2. Scope of the Task

This task focuses on the development, validation, and access to solar resource information derived from satellite-based platforms and surface-based stations. It will define standards for intercomparison of irradiance data with respect to energy applications. Various quality control procedures for solar irradiance time-series will be reviewed and if possible improved. Benchmarking of solar resource products against reference measurements will help the user to better identify uncertainties and select products which are sufficiently reliable. The Task examines means by which the data can be made easily available to users through various web-based hosting schemes and distributed networks. Further, options for forecasting solar radiation in various time-scales from hours to several days will be developed. Past and future climate variability of the solar resource will be investigated to estimate the uncertainty of solar yields.

7.3. Organization and Structure

The objectives of Task V will be achieved through task-sharing activities defined in a coordinated work plan. Work is carried out by participants from 17 institutions in 7 countries and the EU. In 2006, Austria became a new member by contributing with a project on solar radiation forecasting through the Solar Heating and Cooling Implementing Agreement (SHC). The work plan is structured in three subtasks:

Subtask A: Standardization and Benchmarking of Solar Resource Products

The main goal of this Subtask is to ensure worldwide intercomparability and acceptance. This covers:

a) Coherence and benchmarking of models producing solar irradiance values from satellite data.
b) Accessibility and coherence of ancillary model input data such as atmospheric conditions and land-surface parameters.
c) Sensitivity analyses.
d) Ground truth validation with high-quality data.
e) Definition of validation protocols and measures of end-product confidence.
f) Cross-satellite platform and cross-model comparisons

Subtask B: Common Structure for Archiving and Accessing Data Products

The objective of this Subtask is to provide a user-oriented information system, such as a distributed data system, for archiving and accessing solar resource data. Key subtask activities to meet this objective are:

a) Evaluate the Legal Aspects of Accessing Solar Resource Data: This activity focuses on establishing copyright and proprietary rights for data that is to be made available through the distributed data system, and to establish appropriate protocols with each participating institution for making the data generally available to the public.

b) Identify commonly-used software by end users: This activity examines available or needed software for use by industry and other users to access the information system.

c) Develop data exchange protocols and metadata: Various data exchange protocols will be examined and one will be selected and documented.

d) Develop a prototype data networking procedure: A prototype web-based system will be developed whereby a user can request information of a certain type and format, and the information system provides the response or responses that most closely fulfill the request.

e) Identifying resource providers: A worldwide network of data providers will be set up, and the techniques for data exchange among the providers will be investigated.

f) User prototype testing: This activity defines a prototype that can be accessed by users, and increases awareness of the data-exchange system among external users.

g) Define automatic access by commercial applications: This activity will enable fast, automatic access of resources through the information system by using commercial applications.

h) Develop a 'solar micro-siting' test application: A case study in micro-siting of a solar energy system will be developed to demonstrate the benefits of the information system.

Subtask C: Improved Techniques for Solar Resource Characterization and Forecasting

The purpose of this Subtask is to conduct essential R&D to improve the accuracy and spatial and temporal coverage of current techniques, including the introduction of solar resource forecasting products. Key activities to meet this objective are:

a) Improve Satellite Retrieval Methods for Solar Radiation Products: This activity will focus on key model input parameters and methodologies, such as cloud indices, radiative transfer schemes, aerosol data retrieval, and treatment of snow and other surface albedo artifacts. The activity also addresses ways of improving the spatial resolution of satellite-derived broadband solar resource products.

b) Climatological analysis of solar resources: to ascertain future impacts on system performance due to climate variation, this activity includes the analysis of long-term surface and satellite-derived data sets and climate models, specifically addressing natural long-term fluctuations associated with the ocean-atmosphere system, such as the Southern Oscillation/El Niño.

c) Forecasting of solar radiation: This activity investigates different approaches for developing solar resource forecasts based on global numerical weather predictions and extrapolation of cloud motion vectors from satellite data.

7.3.1. Collaboration with other IEA Programs

Knowledge of solar resources is highly important for all forms of solar energy applications. Therefore, SolarPACES Task V is an IEA collaborative task working with the Solar Heating and Cooling (SHC) and Photovoltaic Power Systems (PVPS) Implementing Agreements. The SHC ExCo coordinates the 'Solar Resource Knowledge Management Task', where it is called SHC Task 36. Collaboration with SolarPACES and PVPS is kept at a 'minimum level' according to the SHC 'Guidelines for Co-ordination with other Programs'.

7.3.2. Duration

The Task began on July 1, 2005 and is planned to continue until June 30, 2010.

7.4. ACTIVITIES DURING 2006

7.5. Second Experts Meeting

Following the First Experts Meeting held at DLR in Oberpfaffenhofen, Germany, in November 2005, a Second Experts Meeting was held in Denver, Colorado on 7-8 July 2006, just before the Solar 2006 Conference which was held at the same location. 12 experts, plus two more participants by video conference, attended the meeting, representing all the participating countries except Spain. Each subtask leader led detailed discussions on ongoing activities and plans within their subtask. There were additional discussions regarding the relationship of the Task to the Global Earth Observing System of Systems (GEOSS) Program, the Global Energy and Water Experiment (GEWEX) Program of the World Meteorological Organization (WMO), and the UNEP (United Nations Environmental Program) Solar and Wind Energy Resource Assessment (SWERA) Program. A key outcome of the meeting was a clearer focus on critical subtask activities leading to modifications to the Task Work Plan. Following the meeting, many of the task participants gave presentations in three related sessions at the Solar 2006 Conference organized by the American Solar Energy Society (ASES).

7.1.1 Data User Questionnaire

During 2005, a Data User Questionnaire was developed and issued to gather key information on data requirements. It aims to find out how industry, government agencies, universities, and others are using available solar resource data, what the shortcomings are and which additional products are desired. Results of the survey will be used as input for the design of the information system (Subtask B) as well as for some of the products coming out of all the Subtasks. During the transition to the new SHC website currently under preparation, the JRC in Ispra, Italy has agreed to support the Task's website at http://re.jrc.cec.eu.int/iea-shc-task36. It is hosting the questionnaire and other related documents.

7.1.2 Collaboration with the Group on Earth Observations

The G8 countries came to the conclusion that Earth observation by satellites and surface-based measurement networks require better worldwide collaboration. To improve the situation, they initiated the Group on Earth Observations (GEO), which will be setting up the Global Earth Observation System of Systems (GEOSS) in the coming years. GEOSS combines the effort of space agencies, weather services and other environmental monitoring services. Most activities are strongly user-oriented and will be guided by what are called 'Communities of Practice'. One of these is related to requirements of the energy sector. Renewable energy applications are known to receive huge benefits from Earth observation activities, but fossil fuel energy applications also recognize advantages. Thus, the GEO Energy Community of Practice serves all energy applications.

Task participant Marion Schroedter-Homscheidt of DLR was appointed Co-Chair of the GEO Energy Community of Practice. On August 28-29 2008, she attended the Energy Management Experts Meeting at the WMO in Geneva, Switzerland. Although there is currently no formal relationship between the IEA and the GEO, collaboration of the Solar Resource Knowledge Management Task with GEOSS appears to be advantageous. The IEA Task can advise this Community of Practice. The GEOSS solar energy sector is closely aligned with the scope of the IEA Task. Many ideas from the IEA Task's Work Plan, e.g., the user questionnaire and roadmapping, are serving as examples for other energy sectors. Results like those of the IEA Task's questionnaire will be submitted to the GEO Board of Ministers in November 2007 as a contribution to the GEOSS Strategic 5-10 year plan.

7.1.3 New Subtask C Leader:

In 2006, the original Subtask C Leader, Dr. Richard Meyer, left DLR for SunTechnics GmbH in Hamburg. Dr. Meyer remains active in the Task as Task Representative to the SolarPACES ExCo and by contributing to Subtask A. This provides an additional direct participation of the private sector. However, he is no longer able to lead Subtask C, which deals mainly with R&D. Responsibilities for leading this Subtask have been assumed by Dr. Detlev Heinemann of Carl von Ossietzky Universität Oldenburg, EHF (Germany).

7.5.1. Achievements in the Subtasks

Subtask A: Standard Qualification of Solar Resource Products

A common structure for the presentation of first-order measures for the quality model (Mean Bias MB and Root Mean Square RMS-deviations) was agreed upon.

Two different procedures for the characterization of second order measures (match of modeled to measured distribution functions) had been applied to various data ensembles. Both methods offer qualitatively similar results. Qualitative ranking of the procedures remains to be done.

The European Solar Radiation Atlas algorithm for computing irradiance on inclined surfaces was implemented as a prototype service in SoDa for application to the HelioClim-1 or –2 databases. It was recently tested against measurements made in PVPS Task 2. Preliminary results show fairly good agreement between measurements and satellite estimates. This agreement is better than observed between measurements and RetScreen outcomes (which exploits ground stations) which is encouraging. Nevertheless, it was concluded that the software should be further checked before performing more detailed analyses.

As a forerunner of the possible outcome of a benchmarking scheme taking end-use accuracy into account, intercomparison applying global horizontal irradiance products from different sources was performed for a selected region in Germany, using data for 2005. The yield of PV-systems in that region was analyzed as an end-use metric. The results were presented at the 21st European Photovoltaic Solar Energy Conference. [Beyer, H. G., Drews, A., Rindelhardt, U. (2006): 'Irradiance maps applied for the performance assessment of PV systems - a case study for the federal state of Saxony', *21st European Photovoltaic Solar Energy Conference & Exhibition*, Dresden, Germany, 04.09. -08.09.2006]

As an example of the analysis of long-term accuracy of satellite-derived irradiance products, a study was performed using 9 years of data from a large number of radiation stations operated by the German weather service. The results have been summarized in an article submitted to *Theoretical and Applied Climatolog*, [Drews, A., Lorenz, E., Hammer, A. and Heinemann, D.: 'Long-term accuracy assessment of satellite-derived global irradiance time series with respect to solar energy applications'].

Subtask B: Common Structure for Archiving, Processing, and Accessing Resource

The on-line questionnaire, hosted by a server at JRC, was open to the public until early 2007. Several servers of relevance, e.g., NASA, Satel-Light, SoDa, and PV-GIS, announced the questionnaire to create awareness and increase the number of responses. Results will be published in several forms. One will be a document on the various web sites that announced the questionnaire providing feedback to those who filled it out. Another form will be an article in Solar Energy. Since solar projects are often requested to perform an analysis of user/client needs, this publication is expected to establish a baseline that could be used by many projects to avoid duplicating efforts.

Metadata procedures recommended by the WMO are being evaluated. A first implementation of metadata was performed in an SQL ground measurement database.

The Open Source Jonas program was implemented and tested. This middleware may be the candidate for the final prototype ensuring communication among web services.

One problem identified in the SoDa Service and in web services in general, is the inability of web services to handle situations in which one service in a chain, or plan, of services, is removed. Using a manually defined plan, we designed a prototype based on SoDa that is able to select an equivalent service to meet the request. This prototype is fully operable, but it has not been decided whether to make it the new version of the SoDa Service.

An article by 'Gschwind B., Ménard L., Albuisson M., Wald L., Converting a successful research project into a sustainable service: the case of the SoDa Web service. *Journal of Environmental Modeling and Software*, 21, 1555-1561, 2006, doi: 10.1016/j.envsoft.2006.05.002.' was published. Of particular interest are the lessons learned from clients for re-engineering such a service. They will be applied to Subtask B.

A web service permitting companies to create ASCII files that can be entered into GIS mapping software was developed. This service exploits the HelioClim-1 database. Clients produced maps for the Balkans, Gambia, Mali and Sicily. There is an ongoing JRC effort for automated exploitation of the HelioClim-2 database to feed the PV-GIS tools.

A web service was developed to automatically connect to NCAR/NCEP forecasts. The next step will be to include this service in SoDa. This may serve as a baseline to test performance of forecast models.

Subtask C: Improved Techniques for Solar Resource Characterization and Forecasting

Following the 2nd Experts Meeting in Denver, the Subtask was given a new clearer structure. Contents mainly remain constant, but the related work is now grouped in only 3 instead of 7 activities. Reporting of 2006 Subtask C achievements follow the new Subtask C structure below.

C.1 Improving Satellite Methods for Solar Radiation Products:

This now includes the 'solar micro-siting' action, which is the improvement of mainly satellite-based methods towards the 1 km scale. Optionally this activity can also cover the development of spectral and angular-resolved solar products derived from satellite data. This activity will be led by Prof. Richard Perez, SUNY, USA.

C.2 Climatological Analysis of Solar Resources

This activity analyzes long-term changes in solar radiation conditions based on measurements, satellite data and climate and weather models (see Figure 7.1 for an example of the output of this task). If solar energy becomes more important and funding becomes available, actions for seasonal forecasting and decadal prediction would be added to this activity. This activity is led by Dr. Paul W. Stackhouse, NASA, USA.

C.3 Forecasting of Solar Radiation

This activity now covers all forecast horizons from now-casting up to a few hours to short-term forecasting up to 3 days and mid-term forecasting up to 2 weeks. Most emphasis at the moment is on now-casting and short-term forecasting. The mid-term horizon could be added if funds become available. This activity is led by Dr. Elke Lorenz, Universität Oldenburg, Germany.

C.1: Improving Satellite Methods for Solar Radiation Products

- NASA/LaRC and SUNY/A evaluated the use of sub-grid variability to increase resolution of long-term data products) (Perez et al., Proc. of the ASES Solar 2006 conference, Denver, July 2006).
- Work on a concept paper for solar micro-siting started during a visit of a NASA/LaRC scientist to DLR IPA in Oberpfaffenhofen. The paper discusses options for a field campaign, which should provide new insights into the nature of the solar radiation field at highest temporal and spatial resolution. The basic plan is to spread many radiometers around a central station with a roughly logarithmical increase in spacing. Intervals should start at around 100 m and increase to several kilometers to bridge the gap from very high resolution in the center up to large boxes as covered by the NASA-ISCCP, DLR-ISIS or NASA-SSE datasets. This work will contribute to the development and validation of new retrievals employing operational satellite data with a spatial resolution in the 1 km range, and allow for better understanding of the scaling effects and representativeness of single sites for large boxes, which also improves validation options for the medium to large-scale solar maps.

C.2: Climatological Analysis of Solar Resources

- NASA/LaRC prepared for the reprocessing of SSE Release 6.0. This shall result in improved solar irradiance maps based on more than 20 years of data. This is an action, which is also part of the Radiative Flux Assessment (RFA) of GEWEX (Global Energy and Water Cycle Experiment), which also covers analysis of satellite datasets vs. long-term surface measurements sites, and inter-comparison with other products like DLR-ISIS (presented at ASES).
- NASA/LaRC manages databases and results of the GEWEX Radiative Flux Assessment.
- The DLR-ISIS (Irradiance at the surface based on ISCCP) dataset was completed and now covers the full time period from July 1983 to end of 2004 in 3 hourly time-steps. As it is based as closely as possible on real atmospheric optical depth and covers more than two decades, it makes it possible to analyze changes in irradiance conditions during this long-time period. The DLR-ISIS data set is available at the website http://www.pa.op.dlr.de/ISIS. This global dataset offers global horizontal irradiance as well as direct normal irradiance (see Figure 7.1).
- The Ph.D. thesis of Sina Lohmann and a related paper in the Journal of Solar Energy by Lohmann, et al. went to press. They describe the DLR-ISIS method and first results with intercomparison to reanalyze data. Results on solar irradiance derived from atmospheric models do not seem to be able to reproduce observations. This reduces chances that climate models and seasonal forecasting of solar irradiance will be successful soon.

Figure 7.1.

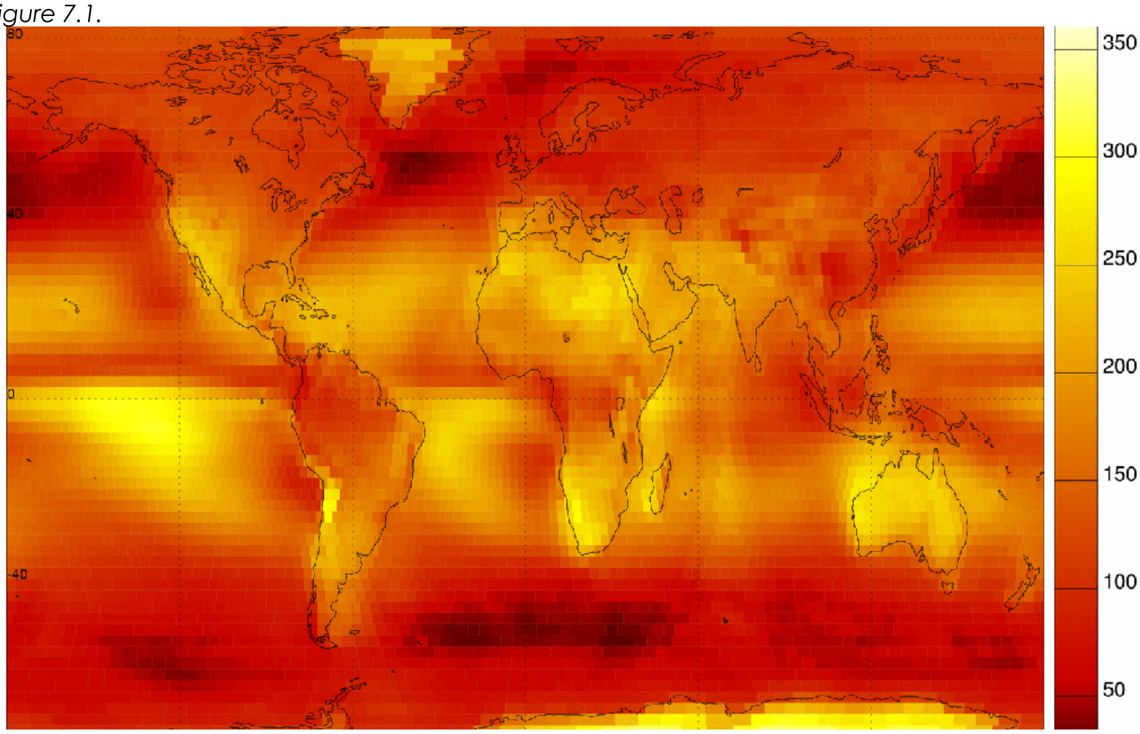

Figure 7.2. DLR-ISIS data set indicating the average direct normal irradinace in the years 1984-2004 (Lohmann, 2006).

- Collaboration of DLR-IPA with the University of Oregon in Eugene led to two papers describing long-term changes in solar irradiance in the Pacific Northwest USA. Another paper of Lohmann et al. (accepted for publication in Geophysical Research Letters) shows an increase in availability of direct irradiance since the late 1970s, while another paper by Riihimaki et al. at the ASES conference reveals relatively stable conditions for global horizontal irradiance.
- The inter-comparison of NASA-SSE and DLR-ISIS satellite-derived long-term data by Meyer et al. (2006, Proc. of the ASES Solar 2006 conference, Denver July 2006) time-series shows very good agreement for global horizontal irradiance (GHI). The mean bias on average is 0.4 W/m², which is equal to an annual sum of less than 4 kWh/m². Earlier reports on reduced GHI can not be confirmed by either satellite datasets. SSE and ISIS reveal that from 1984 to 2004 there is more likely a slight worldwide increase, but this result is not significant. At least DLR-ISIS shows a strong increase in direct normal irradiance (DNI) for many regions in the world. DNI derived from NASA-SSE, however, requires reprocessing, which is now underway.

C.3: Forecasting of Solar Radiation

- A conference paper on now-casting and short-term forecasting (Lorenz, et al., Proc. of the ASES Solar 2006 conference, Denver July 2006) was presented.

- A PhD thesis 6/2006 (M. Girodo) and paper (7/2007) on mesoscale modeling for short-term forecast of solar irradiance has been completed.
- NASA/LaRC, together with SUNY/A, evaluated NOAA's digital forecast database for applicability for solar energy forecasts (paper presented at Solar 2006).

7.2 *Work Planned for 2007*

7.2.1 Subtask A: Standard Qualification of Solar Resource Products

Hochschule Magdeberg (H2M) and CIEMAT will continue comparison of procedures for checking the quality of modeled distribution functions for design a common method.

The application of the proposed measures and schemes will be tested for various data sets, building upon the work on the long-term accuracy started at Oldenburg. Universität Oldenburg, H2M, Meteocontrol and CIEMAT will continue to analyze models for the spectral characteristics of the irradiance. This will include the development of respective measures of model quality, applicable for benchmarking.

Testing irradiance estimates against Task 2 PVPS measurements will be continued. This will cover both the irradiance on inclined surfaces and the resulting energy yield of the PV-systems (Ecole des Mines / Armines, H2M).

NASA/LaRC is making GEWEX Radiative Flux Assessment datasets available to the Task. These include:

- The intention of making the extended GEBA database available for validation
- The PNNL analysis of BSRN measurements for use in SRKM validation and benchmarking activities

This activity will implement and validate current and new NASA products with agreed upon sets of statistics using common surface radiometer measurements, contributing results to the team for validation in clear and cloudy conditions as a function of location.

7.2.2 Subtask B: Common Structure for Archiving, Processing, and Accessing Resource

- NASA-SSE release 6.0, providing the latest datasets and large sets of parameters to the solar energy industry, is scheduled for 2007. It will provide an interactive prototype to access dataset parameters over the Internet.
- Provide a link to the IEA Task and to the user survey on the next NASA-SSE release
- Proceed with writing documentation on the prototype for non-specialists. It will be distributed in the Task.
- Prepare an article for Solar Energy based on this documentation.
- Based on this same documentation and on experience gained by the Task (NASA, SoDa, PV-GIS, Satel-Light, SOLEMI), prepare documents for property rights.

- Analyze questionnaire returns and produce a document on user requirements. This document will feed the subtasks. Prepare an article for Solar Energy.
- Proceed with the specifications document for the first prototype.

7.2.3 Subtask C: Improved Techniques for Solar Resource Characterization and Forecasting

C.1: Improving Satellite Methods for Solar Radiation Products

- Universität Oldenburg is further improving a scheme to better account for cloud shadow effects. This strongly enhances correlation of ground-based measurements and satellite retrieved solar irradiance in hourly and shorter time resolution.
- DLR IPA will process a synthetic satellite image based on 1-D and 3-D radiative transfer calculation to provide a test bed for further development of new retrieval schemes.
- NASA's new SSE Release 6.0 is to include results from the GEWEX SRB SW Rel 2.7 which is scheduled for release in Dec 2006/Jan 2007. Release 6.0 is a complete list of atmospheric inputs used to generate the current version that will be provided to the team as necessary.
- In collaboration with SUNY/A, NASA/LaRC plans to analyze methods to improve direct and diffuse SW irradiance estimates for clear and cloudy sky conditions.
- Development and evaluation of the effect of improving angular distribution models on the solar irradiance estimates for the NASA method. Angular Distribution Models inherently include uncertainties due to lack of homogeneity.
- Development and evaluation of new aerosol inputs to solar irradiance (NASA/LaRC, and DLR DFD).
- Meteotest plans to generate worldwide climatologies of AOT550 and TL (2000-2005) based on MODIS, MISR and AERONET.
- Continued testing and development of a method to impose higher resolution solar resource maps with long-term data sets (collaboration with SUNY/A).
- JRC, EC, is implementing high-resolution digital elevation models (SRTM-3) to study the influence of terrain on modeling the solar radiation at various resolutions.

C.2: Climatological Analysis of Solar Resources

- Report on results of the GEWEX Radiative Flux Assessment project relevant to the Task in terms of long-term data sets. This project aims at benchmarking the accuracy and precision of long-term top-of-atmosphere and surface radiation fluxes of which solar irradiance is a key component. GEWEX-RFA will study many solar irradiance data sets participating in the Task and will provide a framework for evaluation of other datasets.
- Meteotest will provide Task 36 with data after 1990 from the GEBA (Global Energy Balance Archive) dataset. These time-series should be analyzed for changes.

- Long-term time series analysis of NASA's solar irradiance datasets using GEBA and other measurements (see Subtask A).
- Begin evaluation of possible use of NASA seasonal to inter-annual forecast model for seasonal irradiance forecasts. (Collaboration with NASA Goddard Space Flight Center (GSFC)).
- Begin evaluation of Climate scenario solar irradiance forecasts (collaboration with NASA Goddard Institute for Space Science (GISS).
- Meteocontrol: Germany plans to better describe year-to-year variability in solar radiation, as input for risk calculation.

C.3: Forecasting of Solar Radiation

- Report by Universität Oldenburg on now-casting up to 6 hours based on extrapolation of cloud motion vectors derived from satellite images (12/2006)
- Continued evaluation of short-term forecasts comparing the USA NOAA National Digital Forecast Database parameters with measurements. Identify other short-term models and missing parameters needed for improved solar irradiance forecasts (collaboration with SUNY/A)
- Continued evaluation of operational global radiation forecasts with the WRF/ MM5 model (Meteotest).
- Build up of a model for WRF model global radiation output statistics (Meteotest).

7.3 *Links with Industry*

Several small to large companies are directly participating in the Task: Meteocontrol GmbH, SunTechnics GmbH, and Meteotest AG. Blueskywetter of Austria also joined the task at the end of 2006. The audience for Task results includes technical laboratories, research institutions, and universities involved in developing solar resource data products. More importantly, data users, such as energy planners, solar project developers, architects, engineers, energy consultants, product manufacturers, and building and system owners and managers, as well as utilities, are the final beneficiaries of the research, and will be informed through targeted reports, presentations, web sites, handbooks and journal articles.

7.4 *Reports Published in 2006*

- 4 Papers presented at the American Solar Energy Society's Solar 2006 conference in Denver, July 2006 and published in the Proceedings. These papers include:

- 'Solar Resource Knowledge Management: A New Task of the International Energy Agency', by David S. Renné, Richard Meyer, Hans-Georg Beyer, Lucien Wald, Richard Perez, and Paul Stackhouse

- 1 Paper on the IEA Task and its connection to GEOSS presented at the IGARSS conference, July-August 2006 titled 'Towards Designing an Integrated Earth Observation System for the Provision of Solar Energy Resource and Assessment' by P. W. Stackhouse, Jr., D. Renné, H. -G. Beyer, L. Wald, R. Meyer, M. Schroedter-Homscheidt, R. Perez, and M. Suri (see Figure 1 below)

- 1 Solar Energy paper (Lohmann et al., 2006a)
- 1 Geophysical Research Letters paper in press (Lohmann et al., 2006b)
- 1 paper published in Journal of Environmental Modeling and Software (Gschwind et al. 2006)

7.5 Meetings in 2006

Second Experts Meeting, Denver, Colorado: 7-8 July, 2006

7.6 Meetings Planned for 2007

3rd Experts' Meeting, JRC (Ispra) Italy on 12-14 March 2007, including the kick-off meeting for the MESoR Project.

4th Experts' Meeting planned for November 2007 in Europe.

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Part 8: Key Institutions and Persons

8 SolarPACES Key Institutions and Persons

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