International Energy Agency (IEA)

Solar Power and Chemical Energy Systems

SolarPACES

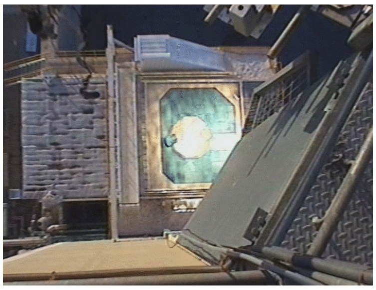
Annual Report 2000

Edited by W. Grasse and M. Geyer

in cooperation with

R. Pitz-Paal, A. Steinfeld, C. Tyner

Deutsches Zentrum für Luft- und Raumfahrt e.V.



Cover Photo:

(by: WIS, Rehovot, Israel)

Shown on the cover page is the illuminated CPC collector of an innovative power tower plant pilot experiment (CONSOLAR project) at the Weizmann Institute of Sciences (WIS). In this new concept, the solar beam radiation from a concentrating heliostat field is redirected by a secondary reflector mounted at the top of a tower (top photo of the two on this page) into a large vertical-axis CPC installed on the ground (this page below, looking in direction of the beam coming from the tower reflector). In comparison to conventional power-tower designs, this concept would have the advantage of a ground mounted solar receiver or reactor avoiding heavy loads on top of a tower (see also under 3.6.1 in Chapter 3).

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April, 2001

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.

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Chairman, SolarPACES
Executive Committee

Foreword

I am pleased to report that, in the year 2000, concentrating solar technologies (CST) moved across a major threshold: a CSP (concentrating solar power) ***opportunity*** became a set of CSP ***business projects***. In the U.S., two industry giants, Bechtel and Boeing, joined hands in a consortium with the Spanish company Ghersa to pursue power tower design, construction, and operation in Spain for one simple and compelling reason -- they expect the undertaking to make a profit. Just as with traditional business ventures, the consortium is financing teams of engineers, accountants, lawyers, marketers, and other experts to consummate a deal and execute a project because they believe the return on this investment will be equal to, or better than, the return on other investment opportunities available to them. They also recognize the advantages to be gained from early entry into an emerging market segment. As a further move in this direction, Bechtel has established a subsidiary, Nextel, whose mission is not only to share the lead in the Spanish tower venture, but also to pursue other solar opportunities worldwide.

Fortunately for CSP, this example of a business venture is not unique. Two other European consortia have also formed and are taking steps similar to Bechtel and Ghersa. They are drawn by the same business attractions. In short, for all the parties involved, these actions are little more than typical business moves, adopted after unemotional, hard-nosed analysis of the benefits to be gained. For CSP, however, this is a new experience, a sort of ***coming of age***.

Readers of the SolarPACES Annual Report will be aware, of course, that the Spanish ventures are "primed" by a renewed hope (based on Spain's Royal Decree 2818) for the near-term publication—and approval—of incentive premiums to cover the additional cost of renewable energy. Most will know that the Spanish Congress recently identified solar thermal power plants as a specific renewable technology eligible for the subsidy. Many

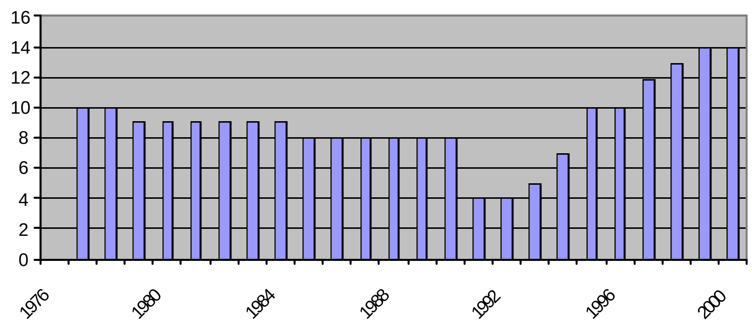
will surmise that the interested firms are also plying the European Union and other potential investors for contributions or low-cost loans to help offset the large capital expenditure involved. However, none of this equates to a guarantee to pay all costs as might occur in some World Bank or government-funded projects. In the end, it's still a business decision, based on the expectation (i.e., risk) that the income from the energy produced by the resulting facility will allow the developers not only to repay the investment, but also to earn a profit.

Spain's business ventures notwithstanding, emerging opportunities of all types continue to be a critical part of CSP's motivating lifeblood. In my view, the signs are increasingly positive. Egypt is still a likely candidate for one or more integrated solar combined cycle system (ISCCS) plants, with strong government backing and support from both the World Bank/GEF (Global Environment Facility) and the country's newly privatized utility. The GEF has also targeted Mexico for a $50 million trough-hybrid plant and India for a 35 MW ISCCS-trough plant. These are previously cited – but still attractive – CSP possibilities that inevitably seem to languish, for interminable periods, in GEF's "pending" category awaiting funding. We can only hope the activities in Spain help to spur more aggressive action in other regions of the world.

There are other newly emerging opportunities, as well. The Australian government has committed to several new renewable energy installations and, as of this writing, two of four projects called for concentrating solar technologies. Italy has adopted principles affirming renewable energy systems as a key element in addressing Kyoto global warming concerns and cited CST as offering high return in the Italian climate. In the United States, a rejuvenation of sorts is occurring. A newly galvanized industry is showing its muscle and demanding greater Federal attention to CSP. There is talk of a U.S. Solar Sunbelt Initiative, although I cannot yet report how the new Administration and the American Congress will respond.

The Executive Committee, itself, reflects a positive trend. Italy, in addition to recently endorsing sustainable energy principles, has also petitioned to join our IEA SolarPACES group. I expect an official invitation to be extended following our May 2001 meeting in Mexico. This addition would bring our total membership to 15 and continues the steady growth of the group since its low point in 1991-1992 (see accompanying

Executive Committee Membership



graph showing membership levels from 1977 to 2000).

As in past years, this report documents the activities for the year 2000 under the SolarPACES Implementing Agreement---and the report itself has its own changes. It has more concise technical progress reports and project descriptions, making it substantially less voluminous. We have continued to include a number of photos and charts and hope that, in the process, we have crafted a more readable document. It will be distributed to a wider audience than in the past, and this will hopefully translate into a wider readership. We invite your comments on these changes.

And speaking of changes, SolarPACES has a new Executive Secretary, following the retirement of Wilfried Grasse. Wilfried held this position from the inception of SSPS (Small Solar Power Systems) in 1977 until the final meeting of SolarPACES (Solar Power and Chemical Energy Systems) in late 2000. His belief in—and strong commitment to—the success of both SolarPACES, as an organization, and CST, as an alternative to fossil fuels, contributed greatly to the successes that were achieved.

Our new Executive Secretary is Dr. Michael Geyer, the head of DLR's permanent delegation at the Plataforma Solar de Almería in Spain. Michael also brings a long history in CSP and a strong commitment to the job, and SolarPACES is fortunate to have someone with his ability to continue in this critical role.

In closing, I offer the following observations. I believe that our individual country achievements in CSP cost reduction and performance improvement, when taken collectively on a worldwide scale, have brought us to the brink of the successful commercial activity we have been working towards. However, the road from this point is not all downhill. I am convinced that, like the efforts in Spain, the next phase of commercial CSP plants will be realized only through multi-corporate, multi-national efforts where both talents and risks are shared internationally. Therefore, I am looking forward to continued interactions and even stronger working relationships among the SolarPACES member countries to make the next several CSP opportunities a reality—wherever located. Given the commitments being made in this multi-party beginning, it is my further opinion that concentrating solar technologies will indeed play a pivotal role in generating clean, reliable power in the coming two decades of the new millennium!

Gary D. Burch, Chairman
SolarPACES Executive Committee

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List of Acronyms

ACRE	Australian Cooperative Research Centre for Renewable Energy
ADEME	Agence de l'Environnement et de la Maîtrise de l'Energie (F)
AGO	Australian Greenhouse Office
AGRICE	Agriculture pour la Chimie et l'Energie (F)
ANU	Australian National University
AR	anti-reflectance
ASR	automobile shredder residue
BET	back electron transfer reaction
BFE	Swiss Federal Office of Energy
BMBF	German Ministry of Education and Science
BOO	build own operate
BOT	build operate transfer
CAM	Comunidad Autónoma de Madrid (E)
CC	combined cycle
CCD	charge coupled devices
CDM	Clean Development Mechanism
CEPEL	Centro de Pesquisas de Energia Electrica (BR)
CHESF	São Francisco Hydroelectric Company (BR)
CICYT	Comisión Interministerial de Ciencia y Tecnología (E)
CIEMAT	Centro de Investigaciones Energéticas Medioambentales y Tecnológicas (E)
DER	Departamento de Energías Renovables (E)
CLFR	compact linear fresnel reflector
CNRS	Centre National de la Recherche Scientifique (F)
COP	Conference of the Parties to UNFCCC
CPC	compound parabolic collector
CSIC	Consejo Superior de Investigaciones Científicas (E)
CSIRO	Commonwealth Scientific and Industrial Research Organisation (AUS)
CSP	Concentrating Solar Power
CSR	Circumsolar Ratio
CST	Concentrating Solar Technology
CU	University of Colorado (USA)
DAAD	German Academic Exchange Service
DECC	Dish Engine Critical Components Project
DG	Directorate General (EC)
DISS	DIrect Solar Steam
DISTAL	Dish Test Facility in Almería (Spain)

DLR	Deutches Zentrum für Luft-und Rauhmfahrt e.V. (D)
DNI	Direct Normal Irradiation
DOE	U.S. Department of Energy
DRUV	Diffuse Reflectance UV Spectroscopy
DSG	Direct Steam Generation
EC	European Commission
EIB	European Investment Bank
ESIP	Ecole Supérieure d'Ingénieurs de Poitiers (F)
ESTIA	European Solar Thermal Industry Association
ET	emission trading
ETH	Eidgenoessische Technische Hochschule (CH)
EU	European Union
ExCo	Executive Committee (SolarPACES)
FFR	falling film reactor
FID	flame ionization detector
FQE	formal quantum efficiencies
GC	gas chromatography
GEF	Global Environmental Facility (WB)
GHG	greenhouse gas
HCM	Human Capital and Mobility (EC)
HFM	heat flux microsensors
HFS	heat flux sensor
HHV	higher heating value
HRSG	heat recovery steam generators
ICCD	intensified charge coupled devices
IEA	International Energy Agency
IEA-REU	IEA Renewable Energy Unit
IEA-REWP	IEA Renewable Energy Working Party
IHP	Improving Human Potential (EC)
INETI	Instituto Nacional de Engenharia e Tecnologia Industrial (P)
IPCC	Intergovernmental Panel for Climate Change
IPP	independent power producers
ISCCS	integrated solar combined cycle system
JI	joint implementation
KFM	Kyoto flexible mechanisms
KfW	Kreditanstalt für Wiederaufbau (D)
LC	liquid chromatography
LHV	lower heating value
LIF	laser-induced fluorescence
LIP	Large Installations Programme (EC)

LPG	liquid petrol gas
LSGC	Laboratoire des Sciences du Génie Chimique (F)
MAGNET	Management and Governance Network
MCPA	2-methyl-4-chlorophenoxyacetic acid
MDF	direct flux measurement system
MME	Ministry of Mines and Energy (BR)
MTBF	mean time between failure
N/A	not available
NEFF	Swiss National Energy Research Foundation
NMR	nuclear magnetic resonance spectroscopy
NREA	New and Renewable Energy Agency (EGY)
NREL	National Renewable Energy Laboratory (USA)
NRW	North Rhine Westfalia (Nordrhein-Westfalen) (D)
NSTTF	National Solar Thermal Test Facility (USA)
O&M	operation and maintenance
OA	Operating Agent
OECD	Organization for Economic Cooperation and Development
OET	outdoor exposure testing
OMW	olive mill wastewater
ONE	Moroccan National Electric Utility
OPPS	Office of Project and Market Opportunities (MA)
ORC	organic Rankine cycle
PCDD	polychlorinated dibenzo-dioxins
PCU	power conversion unit
PDF	Project Preparation and Development Facility (GEF)
POW	Program of Work
PSA	Plataforma Solar de Almería (E)
PSA	pressure swing absorption
PSI	Paul Scherrer Institute (CH)
PV	photovoltaics
RECs	Renewable Energy Certificates (AUS)
RENIPplan	Renewable Independent Power Planner
RFP	requests for proposals
RFQ	requests for qualifications
RMT	roof-mountable trough
RRPGP	Renewable Remote Power Generation Program (AUS)
RSPCL	Rajasthan State Power Corporation
RTD	Research Technology Demonstration
RTS	resistance temperature sensor
SEGS	Solar Electric Generating Systems
SEIA	Solar Energy Industries Association (USA)
SSPS	Small Solar Power Systems (IEA)

START	Solar Thermal Analysis, Review and Training
STEC	Solar Thermal Electric Components
STEPS	Expert System for Solar Thermal Power Stations
TCD	thermal conductivity detector
TEC	thermoelectric converters
TG	thermogravimetry
TIPP	Trough Integration into Power Plant
TMR	Training and Mobility of Researchers (EC)
UNDP	United Nations Development Program
UNEP	United Nations Environmental Program
UNFCCC	United Nations Framework Convention for Climate Change
UPS	Uninterrupted Power Supply
VOCs	volatile organic compounds
WB	World Bank
WIS	Weizmann Institute of Science (IL)
XPS	X-ray photoelectron spectroscopy
ZT	Figure of merit for rating semi conductors

Part 1: Report of the SolarPACES Executive Committee for 2000

by
Wilfried Grasse

SolarPACES
Executive Secretary
(until end 2000)

1 Report of the SolarPACES Executive Committee for 2000

Part 1 of this report, which gives an overview of results and achievements of the SolarPACES Implementing Agreement in 2000, is submitted to the IEA by the SolarPACES Executive Committee as stipulated in Article 3(f) of the Implementing Agreement.

Part 2 describes system aspects of the latest generation of Concentrating Solar Power (CSP) Plants now underway, outlining solar electricity technologies and systems, their development status and market potential.

The more detailed, technically substantial, non-proprietary information on the progress of the SolarPACES Project and its results is given by the three SolarPACES Operating Agents in Parts 3, 4 and 5 of this report.

As in previous years, it is also the aim of the Annual Report for the year 2000 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 The SolarPACES Implementing Agreement and its Members

The year 2000 marks the 24th consecutive year of collaboration under the SolarPACES Implementing Agreement. It continues to be as vital as it was in the beginning, or even more so (see graph in the Foreword).

SolarPACES was initiated in 1977 as the SSPS (Small Solar Power Systems), a cooperative cost-sharing project totaling approximately US$60 million. Two dissimilar concentrating solar power plants were designed in the project's **Stage 1** by ten Contracting Parties from Austria, Belgium, Germany, Greece, Italy, Spain, Switzerland, Sweden, the United Kingdom and the United States. All of these countries, with the exception of the UK, continued the project through **Stage 2** (Building, Testing and Evaluation) which was completed in Almería, in Southern Spain, at the end of 1984. In the course of the subsequent **Stage 3**, eight countries (all but Greece) proceeded with solar-related research and development in various forms, especially on advanced concentrating solar and solar chemical applications. The two SSPS power plants, together with the Spanish CESA-1 facility, were transformed into what has since become the world's most versatile solar test center, the **"Plataforma Solar de Almería" (PSA),** which continues to be the site of a wide range of cooperative international concentrating solar (thermal) technology (CST) testing and development efforts. In 1991, Germany, Spain, Switzerland and the USA decided to go on to a **Stage 4** and sought increased participation from both OECD/IEA-member and non-member countries.

Fig. 1.1 shows the Contracting Parties and Executive Committee (ExCo) members from the **now 14 member countries**, indicating their home institutions and distinguishing between government, public R&D institution, industry, or electric utility. Two more countries, India and Italy, and the German company FLABEG Solar International, have expressed their interest in membership which may become effective in 2001.

The SolarPACES members share a common vision, that by 2010/15 CST will be making a significant contribution to clean, sustainable energy services in the world's sun-belt.

In the scenario of environmental and climatic hazards and continued depletion of our most valuable fossil energy resources that we will face in the coming years, CST can provide crucial solutions to energy problems within a short time.

Successful introduction in this market will reduce costs and help pave the way for more advanced CST systems, including processes capable of producing gas and liquid fuels and chemicals that will penetrate a much broader range of markets.

Country	Represented by	Govt.	R&D Institute	Industry	Electric Utility	ExCo Member
AUS	Consortium of Utilities				X	Wolfgang Meike **(ExCo Vice)**
BRA	CEPEL		X			Rubem Brito
EGYPT	NREA	X				M.Sami Zannoun
EC	DG-RESEARCH DG-TREN	X				Philippe Schild Günther Israel
FRA	CNRS		X			Alain Ferriére
GER	DLR		X			Manfred Becker
ISR	WIS		X			Michael Epstein **(ExCo Vice)**
MEX	IEE				X	Jorge Huacuz Villamar
RUS	IVTAN	X				Evald Shpilrain
RSA	ESKOM				X	Louis von Heerden (acting)
SPA	CIEMAT		X			Maria Luisa Delgado
SWI	PSI		X			Paul Kesselring
UK	Avantica, Solargen			X		Robert Judd Adrian Gaye
USA	DOE	X				Gary D. Burch **(ExCo Chair)**

Fig. 1.1 SolarPACES Contracting Parties as of December, 2000
(For Information: India and Italy expressed interest in membership which could become effective as soon as 2001)

It is widely acknowledged that concentrating solar power (CSP) systems represent the lowest-cost solar energy in the world today. Power generation by CST plants is even nearing cost-effectiveness comparable to fossil-fired plants and will be among the early opportunities for the technology to enter the market place.

1.2 Objectives and Strategies

The following objectives are planned to expand the SolarPACES role from one which, until the mid-90s, has been largely technology development, to one addressing the full range of activities necessary to overcome barriers to wide-scale adoption of solar thermal technology:

1. Support **TECHNOLOGY** development by leveraging national resources for RD&D through international cooperation.
2. Support **MARKET** development to reduce financial, political, market and institutional hurdles to the commercialization of solar thermal technology.
3. Expand **AWARENESS** of the potential of solar thermal technologies (including long-term fuel supply and solar chemistry) for addressing world energy and environmental problems.

SolarPACES Strategies for Reaching its Objectives

Technological Development of CSP

Development of concentrating solar power technologies is the nucleus of the SolarPACES Implementing Agreement. National research and development resources are leveraged through international cooperation. The core SolarPACES strategies for technology development are:

- Continue intensive cooperation among SolarPACES members in research, development and demonstration through cost, task and information sharing activities.
- Emphasize continued development of advanced components and alternative system designs to reduce future system costs.
- Continue longer-term research on advanced fuels, chemicals, and other technologies for the future. Facilitate increased industrial participation in development and demonstration projects.

Market Introduction of CSP

Concentrating solar power projects face numerous non-technology-related barriers to achieving wide-spread contributions to sustainable energy and a cleaner environment. To achieve the SolarPACES vision, market obstacles and threats must be overcome, for which the following strategies were developed:

- Sponsor market identification and assessment studies to analyze potential customer requirements and establish early economic applications and long-term opportunities relative to competing conventional and renewable technologies.
- Develop and implement strategies for early multinational projects. Offer and provide SolarPACES expertise in combination with international financial community and host country support for select projects.
- Actively support project evaluations and development by the World Bank (and similar agencies) through cost-shared international reviews, partnerships with the Bank, and sponsorship or support of specific projects.
- Pursue financial engineering of projects in developing countries. Engage specialized financial expertise to assist in financial formulation of international solar thermal projects.
- Facilitate expanded international industrial cooperation by pursuing opportunities to bring together international partnerships of industrial concerns, including financing institutions.
- Intensively pursue protection of intellectual property developed through SolarPACES activities. Engage appropriate international legal advisors to develop processes to make this a selling point for SolarPACES activities, rather than a drawback.

- Identify and promote regulatory action on non-technical competitiveness issues, including tax equity, conventional energy subsidies, externalities, and market entry incentives.

Expand Awareness of Concentrating Solar Power

In spite of 20 years of united effort, concentrating solar power technologies are still unknown to the majority of power market decision makers, regulators, investors, developers and industry. The following strategies are designed to expand awareness of the potential of solar thermal technologies (including long-term fuel supply and solar chemistry):

- Expand SolarPACES membership, particularly to lesser developed countries in the world's solar belt. Actively promote formalized industrial and user partnering with SolarPACES.
- Establish an information dissemination program to contact governments, financial institutions and developers. For example, establish "road shows", poster sessions, elevator speeches, etc. and aggressively pursue opportunities to promote the technology through international non-solar (i.e. financial, environmental, third-world development) conferences, workshops, government and international agencies, etc.
- Team with IEA and other international working groups (photovoltaics, wind, geothermal, etc.) to bring a unified message on renewables to appropriate governments, agencies, financial institutions, etc.

1.3 Nature and Scope of Cooperation

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 activities.

According to IEA guidelines, supervisory control of SolarPACES is vested in the Executive Committee (ExCo), see **Fig.1.2.** It is assisted by an *Executive Secretary*, who provides managerial and technical support to the ExCo and Operating Agents.

The three Task Annexes to the Implementing Agreement formed in 1991 continue to be valid today:

Task I: Concentrating Electric Power Systems

Task II: Solar Chemistry Research

Task III: Concentrating Solar Technology and Applications

Fig.1.3 shows participation of the Contracting Parties in these three Tasks.

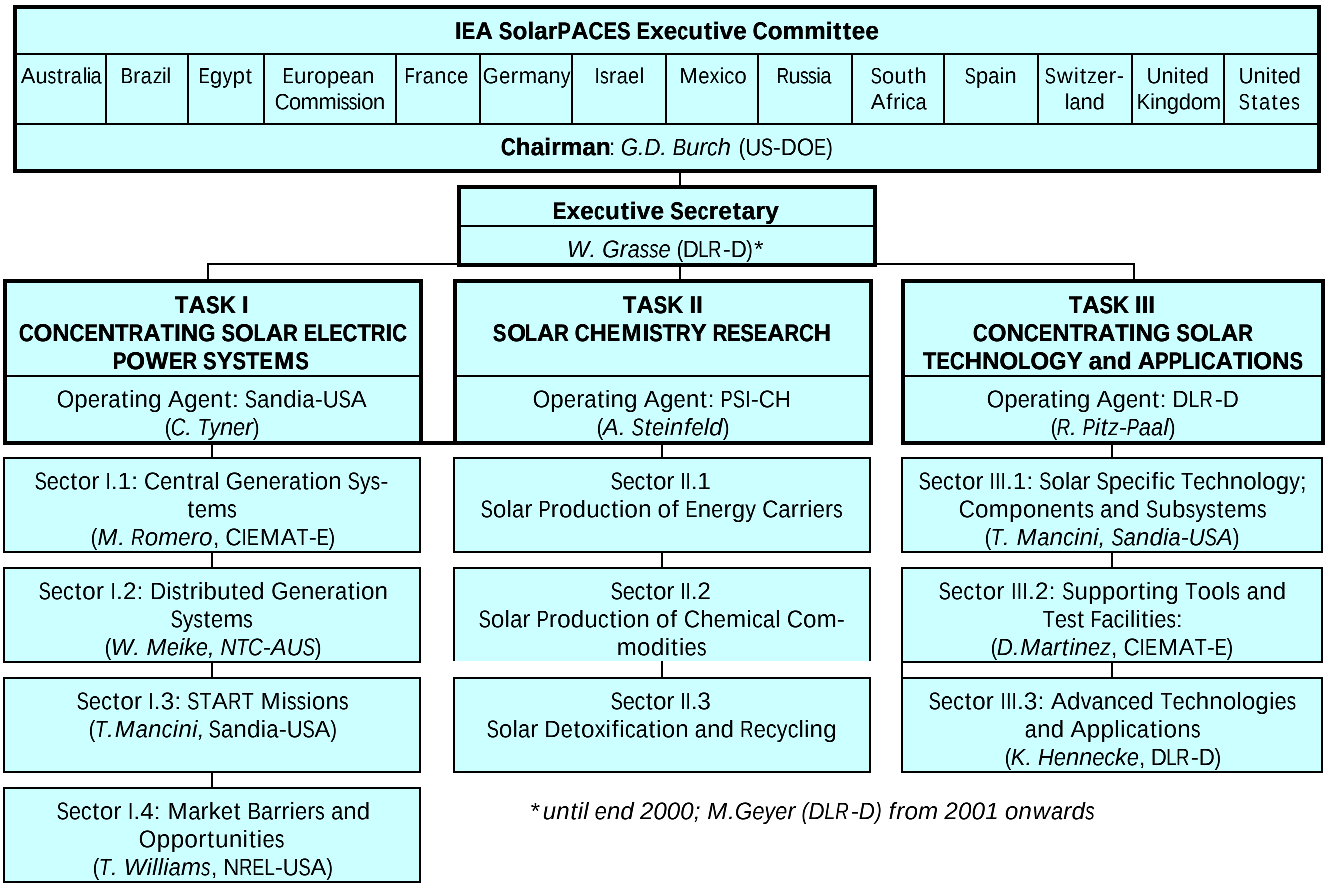

Fig. 1.2 Organization of the SolarPACES Implementing Agreement in 2000

SolarPACES Task	AUS	BRA	EC	EGY	F	D	IL	MEX	RFA	RUS	E	CH	UK	USA	Other Partners:
I. Concentrating solar Electric Systems	x	x	x	x	x	x	x	x	x	x	x		x	(X)	Cooperation with: World Bank, Industry, Utilities. Contacts with: Netherlands, Japan, Denmark Austria, Portugal, Italy
I.1 Central Generation	(X)														
I.2 Distributed Generation														(X)	
I.3 START Missions														(X)	
I.4 Market Barriers …														(X)	
II. Solar Chemistry	x	x	x		x	x	x			x	x	(X)		x	
II.1 Production of Energy Carriers												(X)			
II.2 Chemical Commodities												(X)			
II.3 Detoxification & Recycling												(X)			
III Technology and Advanced Applications	x	x	x		x	(X)	x	x	x	x	x	x		x	
III.1 Solar-Specific Technologies						(X)									
III.2 Supporting Tools											(X)				
III.3 Advanced Applications														(X)	

(X) = leadership
x = participation

AUS=Australia; BRA=Brazil; EC= European Commission; EGY=Egypt; F=France; D=Germany; IL=Israel; MEX=Mexico; RFA=Republic of South Africa; RUS=Russia; E=Spain; CH=Switzerland; UK=United Kingdom; USA=United States of America

Fig. 1.3 Participation in SolarPACES Tasks; contributions and cooperation (Status: end 2000)

1.4 Tasks and Work Program

Since 1977, IEA/SolarPACES has pursued a focused program of research and development in the field of concentrating solar power and chemical energy systems. Systematic development of the three CSP technologies, troughs, towers, and dishes, has led to the ever-increasing ability of these technologies to concentrate and harness solar energy for electricity production and other uses with efficiency, reliability, and cost effectiveness.

Commercial applications from a few kilowatts to hundreds of megawatts are now feasible, and plants totaling 354 MW have been in operation in California since the 1980s. Plants can function in dispatchable, grid-connected markets or in distributed, stand-alone applications. They are suitable for fossil-hybrid operation or can include cost-effective storage to meet dispatchability requirements. They can operate worldwide in regions having high direct-normal insolation, including large areas of Africa, Australia, China, India, the Mediterranean region, the Middle East, the southwestern United States, and Central and South America. Commercial solar plants have achieved costs of about 12¢/kWh (the lowest cost of any solar technology), and the potential for cost reduction will ultimately lead to costs as low as 5¢/kWh. (All costs are in U.S. dollars ($) or cents (¢).)

Of all the renewable technologies available for large-scale power production today and for the next few decades, CSP is one of a few with the potential to make major contributions of clean energy because of its relatively conventional technology and ease of scale-up. It is clear that the technologies are now nearing readiness for full-scale market introduction, and SolarPACES is poised to play a key role in this new phase.

To facilitate the entry of CSP into the international energy market, SolarPACES has broadened its focus. Looking ahead strategically, it will continue to cooperate closely on research and technology development in CSP and solar chemistry. However, we have also initiated activities supporting project development, overcome non-technical barriers, and build up worldwide awareness of the relevance of CSP applications to current problems of energy and the environment.

As in previous years, collaboration among SolarPACES members and partners is coordinated under the three Task Annexes. In the current organization, shown in **Figs. 1.2** and **1.3,** each Task is led by an Operating Agent who operates the Task under his supervision and responsibility, subject to the Annexes which form part of the Implementing Agreement in accordance with the law of the home country.

Task activities are cost-shared, task-shared (either through SolarPACES or between SolarPACES participants), or information-shared. Cost- and task-sharing activities cooperation between two or more participants where either costs or responsi-

bilities for activities are mutually agreed upon and shared by the participants. Information sharing is the exchange and discussion of results of projects carried out by participants independently, but of interest to all.

1.4.1 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 electric) systems, including parabolic troughs, power towers, and dish/engine systems. The focus of Task I efforts is on ultimate application of complete systems and the needs associated with getting them to the marketplace. Activities are divided into sectors. The 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. START Missions, implementing the SolarPACES Solar Thermal Analysis, Review, and Training Missions to evaluate the needs of potential user countries and help them initiate activities to implement the technology. This activity also provides technical support to the World Bank and GEF on concentrating solar power activities.

I.4. Market Barriers and Opportunities, addressing financial, environmental, regulatory, and marketing issues.

1.4.2 TaskII: Solar Chemistry Research

Solar energy can be converted into chemical fuels which can be stored for long periods of time and transported over long distances. Solar energy can also assist in the processing of energy-intensive and high-temperature materials. Solar energy can be used for treating polluted air, water, and soil, and for recycling waste materials.

Task II encompasses RD&D activities dealing with solar-driven thermochemical and photochemical processes. Its activities are currently grouped into three sectors:

II.1 Solar Production of Energy Carriers, addressing processes such as solar upgrading of fossil fuels, direct conversion of solar energy into chemical energy carriers, reduction of metal oxides and flash pyrolysis of biomass.

II.2 Solar Processing of Chemical Commodities, including production of fullerenes, aluminum, lime, fine chemicals, and pertinent analytical and experimental evaluation.

II.3 Solar Detoxification and Recycling of Waste Materials, dealing with photocatalytic processes for the treatment of industrial or agricultural wastewater, of gaseous emissions, and their verification in a pre-industrial scale.

Task II participants work mainly in universities and research institutes. However, more and more industrial contacts are being established, especially in the field of solar detoxification.

1.4.3 Task III: Concentrating Solar Technology and Applications

CST plant components and subsystems are on the brink of commercialization, though the current market is still small. The potential for cost reduction is high, but there are few potential suppliers and close international cooperation in applied RD&D between industry and publicly financed institutes would be advantageous. At present, the focus is on improvement of performance and reliability and reduction in cost. Task III activities are organized in three sectors:

III.1 Solar Specific Technology Components and Subsystems, concentrating on collectors/heliostats and receivers for parabolic trough or central receiver systems and on hybrid solar/biogas and dish/Stirling systems.

III.2 Supporting Tools and Test Facilities, including analytical simulation and software development (e.g. for the integration of parabolic troughs into fossil fired power plants); networking and standardization; flux and sunshape measurements; development of high-flux facilities; organization of the access to existing large-scale facilities (like the Plataforma Solar de Almería, in which case particular financial support is given by EC).

III.3 Advanced Technologies and Applications, including materials development and testing, process heat applications and advanced hybrid solar/biomass plant concepts.

Under Task III, intense cooperation between RD&D institutes and industry (German, Israeli, Spanish and American companies – see Chapter 5) has been implanted.

1.4.4 Non-Task related Activities under Direct ExCo Control

Activities performed under the direct responsibility of the Executive Committee and managed by its Executive Secretary concern

- Expanding awareness of the potential of solar thermal technologies through increasing membership, establishing an information dissemination program and teaming up with IEA and other international working groups.
- Providing training and/or on-the-job opportunities for post graduate students and young engineers (Scholarship Program).
  ?? Preparation and celebration of biannual Executive Committee meetings and annual reports to the International Energy Agency and partners in cooperation.

1.5 Achievements in 2000

1.5.1 Program of Work

SolarPACES cooperative activities cover technological research, development, demonstration, dissemination of results, and expansion of awareness.

	Total No. of Activities	Form of Cooperation		
		Information Sharing	Task Sharing by Member Countries	Task Sha throug SolarPA
Executive Committee	2	---	---	---
Task I Concentrating Solar Electric Systems	23	8	7	5
Task II Solar Chemistry	42	32	2	---
Task III Technology and Advanced Applic.	20	7	5	7
	87	47	14	12

(Status: end 2000, Ref.: Chapt

Fig. 1.4 Form of Cooperation in Task Annexes I-III and Executive Committee
***REMARK**: listed here only the predominant form of cooperartion; note that in sometimes more than one form of cooperation is marked for one activity*

Under the 1999-2002 Program of Work (PoW), a total of 87 joint activities were performed in 2000 (see **Fig. 1.4)**.

Of those activities, 17% were cost-shared and 30% were task-shared (with approx. half initiated through SolarPACES and the other half through member countries). 53% of all activities were information-sharing, with two thirds of these under Task II alone (Solar Chemistry, with its predominantly basic R&D).

Cost-sharing and task-sharing activities involve cooperation between two or more participants where either costs or activities or responsibilities are mutually agreed upon and shared by the participants. Information-sharing makes it possible for all SolarPACES partners to benefit from the results of domestic RD&D activities in other countries.

1.5.2 Resources

Regarding the total human resource capacity of such cooperation, figures were evaluated for the last time in 1999, however, in so far as their order of magnitude, these are still applicable for 2000.

Some **40 person-years** per year and an investment of approx. **US$5 million** were directly allocated to the POW. However, exchange of results, information and experiences relate to much larger personnel and investment volumes, which might be as much as **10 or more times** greater.

In addition to these resources, there is also a joint budget to which all SolarPACES members contribute equally. In 2000, this budget amounted to 300,000 Deutsche Mark (DM) and covered activities of the Secretary (39%), publications, START-Missions, scholarships (27%), travel, meetings and symposia (34%).

Thanks to the membership of EC-DG Research (formerly DG XII)**, and DG-TREN** (formerly DG XVII) **in SolarPACES and close working relations with these two General Directorates, CST and CSP-related project grants obtained under the EC 5th Framework Program helped substantially in realizing the SolarPACES Program of Work. References for such support are given in Parts 3, 4 and 5.**

1.5.3 Achievements with regard to the Strategic Plan

The following summary of the most important achievements in 2000 follows the structure of the SolarPACES Strategic Plan, as it was reviewed and updated in 1999.

CSP Technology Development

SolarPACES has been a worldwide catalyst in CSP development and dissemination of information for 24 years.

Its most outstanding achievements have been:

- Construction and operation of the two IEA SSPS plants which later became the basis for the Plataforma Solar de Almería (PSA), the world's most versatile **CST test center**. The PSA, now a dependency of the Spanish CIEMAT, is still the core SolarPACES test facility;
- **Parabolic trough** development initiated by the SSPS (and continued as SolarPACES) laid the groundwork for the nine commercial California SEGS plants, which have a total capacity of 354 MWe;
- Experimental system **operation and maintenance (O&M)** cost reduction study performed at five of the nine SEGS plants resulted in an O&M cost reduction of approx. 40% (from 0.06 to approx. 0.03 US$/kWh) and a net production increase of

almost one third, so that the current cost of parabolic-trough electricity is already down to about 12 US¢/kWh and promising to come down further to 4-6 US¢/kWh over the next 15-20 years;

- Experimental and analytical performance studies on **power towers** operated with different coolants, begun in 1983 was still ongoing in 2000, when evaluation of Solar Two performance was completed and provides input for new power tower projects in Spain;
- Development of the air-cooled **volumetric receiver** concept and its experimental verification at the PSA, soon to be employed by the Spanish PS10 plant in Sanlúcar near Seville (see Chapter 3);
- Successful testing of six 7-kWe **dish/Stirling** prototype systems with innovative designs at the PSA;
- Definition of future development requirements in the so-called **technology roadmapping** documents**,** completed for parabolic troughs, and begun for dishes and molten-salt towers;
- Development of the new RD&D field, **"Solar Chemistry"**, in which photochemical and thermochemical processes are solar driven, e.g., for the production of energy carriers or the detoxification of industrial wastes.

On-going CSP plant technology development aims at further cost reduction for electricity generation, and increasing confidence in design data as well as operational reliability. In this regard, the major achievements in 2000 can be summarized as follows:

- Technology development, as well as analytical studies for the simulation of CSP integration into fossil or biogas-fired plants in **solar hybrid systems** that are considered a pragmatic next step for CSP market introduction; relevant activities are going on under the Trough Integration into Power Plants (TIPP) projects (see 3.6.1 in Part 3 and 5.6.2 in Part 5), SOLBIO, REFOS, BioDish (see 5.6.1 and 5.6.3 in Part 5);
- Increasing engagement of, and widening **cooperation with solar industry** in hardware development, e.g., in the framework of the four Integrated Solar Combined Cycle plants with support of the Global Environmental Facility (GEF) in Egypt, India, Mexico and Morocco, the Spanish CSP plants, AndaSol, SolarTres and PS10; the Israeli CONSOLAR project, the new-generation subsystem developments, DISS (Direct Solar Steam), EUROTrough, USA Trough, heliostat developments, EuroDish and USA-Dishes. For further details see 3.6 in Part 3, and also 5.6 in Part 5;
- Up-dating **software tools for analysis and simulation** of CSP system or subsystem performance, e.g., lessons learned from the US-Solar-Two for application in the Spanish Solar Tres, TIPP (see above) for the evaluation of hybrid power plants, reliability database for dishes, STEPS – Expert System

for CSP systems and the TRNSYS software library. Details of these achievements are given in 3.6 and 5.6 in Parts 3 and 5, respectively;

- Intensified international cooperation related to the development of **measurement devices** , e.g., high flux and sunshape (see 5.6 in Part 5).

Increasing international cooperation in the field of **Solar Chemistry** can be illustrated by the amount of scientific and technological activities, which grew from 10 in 1999 to 42 in 2000. Major achievements in 2000 were (see also Part 4):

- Technological experiments with new processes for **solar production of energy carriers**, e.g., the SynMET-Process of co-production of zinc and syngas, or **chemical commodities,** e.g., fullerenes, lime.
- Involvement of the **chemical industry** in solar chemistry projects, e.g., SOLASYS for the solar upgrading of fossil fuels; foundation of the European industrial consortium SOLARDETOX® for the implementation of turn-key plants for the solar treatment of hazardous and non-biodegradable water contaminants.

Market Development and Technology Development

If CSP-technology is to achieve sustained market penetration, large projects (up to 100 MWe) must be developed, otherwise, economies of scale and mass-production techniques (essential to lowering the cost of solar energy) will not be achieved.

SolarPACES is helping to identify the most promising projects and is supporting their realization in a multitude of ways. Such activities are organized under Task I subtasks **“START-Missions”** and **“Market Barriers and Opportunities”.**

Under the label **START** (Solar Thermal Analysis, Review and Training), SolarPACES has nominated a team of experts from its member countries, that is ready to visit selected sunbelt countries upon their invitation.

- <u>In the past</u> (1996-1998), these **START teams** have visited Jordan, Egypt, Brazil, and Mexico and have been instrumental in launching project feasibility studies in Egypt and Brazil. The START Program of SolarPACES has fully proven an effective means for the deployment of solar thermal power plant technology. It is now backed by close cooperation with the World Bank (agreement signed in 1997) and with other international financing institutions.
- In January <u>2000</u>, representatives of all SolarPACES member countries were invited to support the Egyptian colleagues at their investors’ conference initiating the second phase of the first privately funded **Egyptian 120-140 MWe** ISCCS (integrated solar combined cycle system) plant.

- Also in 2000, updating of the briefing material, and two out-reach events were accomplished. The START team actively attended the ENERGEX Conference in Las Vegas/Nevada-USA (in July); a series of presentations was made (in October) in the Middle East: Lebanon; Syria and Jordan (see 1.8.4 below).

Activities under "**Market Barriers and Opportunities**" emphasize developing a better understanding of the requirements (both technical and non-technical) that solar thermal electric systems must meet to be successful in the world marketplace and provide customer information on the benefits of CSP. Details in 3.6.1 in Pat 3. Achievements in 2000 were:

- Contacts were established with entities involved in **project development** in Australia, Egypt, India, Mexico, Morocco, South Africa, and Spain;
- A **Database** of "Project and Market Opportunities (OPPS)" was compiled and is publicly accessible via the Internet (www.eren.doe.gov/simulat); it allows tracking the status of on-going CSP projects;
- An Expert System for Solar Power Stations (**STEPS**) was developed for solar power plant site assessment and applied for Morocco; STEPS material is available at www.dlr.de/steps;
- A fast, user-friendly software tool for technical and economic simulation of renewable power projects (**RENIPplan**) was developed with EC funding. It is applicable for parabolic trough plants, dish/Stirling systems, wind parks, and grid-connected PV systems;
- An international initiative for "Non-Discriminating **Integration and Standardization** of CSP Technology" with members from SolarPACES and the GEF was established; they jointly applied to the EC for funding (see 5.6.2 in Part 5).

1.5.4 Expanding Awareness

The SolarPACES strategic plan defines particular strategies for expanding awareness of the potential of CST/CSP (including long-term fuel supply and solar chemistry). Activities and achievements in 2000 in this regard were:

- Distribution of SolarPACES Annual Reports (beyond IEA) and **publication** of Proceedings of the SolarPACES Symposia, operating and maintaining a **Website** (www.solarpaces.org, at present under complete review), distribution of approx. 6,000 copies of the semi-annual **SolarPACES Newsletters**;
- **10th International SolarPACES Symposium** on Concentrating Technologies was held in Sydney Australia and jointly organized under the common label **"Renewable Energy for the New Millennium",** with ESAA (Electricity Supply Association of Australia), and IEA-PVPS (Photovoltaic Implementing Agreement);

- Growing **SolarPACES membership** with India, Italy and the German FLABEG-Solar-International company applying for membership (final decision on Indian membership forthcoming in 2001 only if the IEA is able to eliminate their concerns regarding proprietary rights);
- Contacts were made and maintained throughout the year with representatives of sun-belt nations, mostly **developing or emerging countries**, and the organizations which are concerned with their development. Particular events addressed Brazil, Egypt, Lebanon, India, Jordan, Morocco, South Africa, Syria, UNEP, UN-ESCWA, EC-IRESMED, IEA, GEF;
- Continued mutual consultations with the **World Bank** in support of their involvement in large-scale commercial CSP plant deployment (in Brazil, Egypt, India, Mexico, Morocco);
- Enhancing **cooperation with industry**, which materialized in joint developments, joint applications, and joint ventures in addressing international decision makers in the energy field;
- Continuation of **SolarPACES Scholarships**, whereby postgraduate students or young engineers received grants combined with opportunities to work at solar facilities in SolarPACES member countries; in 2000, 1 Egyptian and 1 Mexican engineer were trained at the PSA in Spain and 2 young scientists from the UK and Germany worked at the WIS in Israel;
- Support of the PSA "**Access to Large-Scale Facilities** Program", through which European researchers may carry out their own research at the PSA (funded by EC DG-Research).

1.5.5 Scale of Activities

The calendar of SolarPACES related activities in the year 2000 was as follows:

January

18th -19th   Investor's Workshop for Solar Thermal Plants in Egypt, organized by the two Egyptian ministries of "Electricity and Energy" and "Planning and International Co-operation", in Cairo, Egypt (inter alia, all SolarPACES members were invited)

February

3rd -4th   Journées Chimie, Soleil, Energie, Environment" in St. Avold, France (Task II)

March

5th-7th   58th SolarPACES Executive Committee Meeting in Sydney, Australia

8th-10th   10th International SolarPACES Symposium on Concentrating Technologies, Sydney, Australia, as part of the "three-event" conference "Renewable Energy for the New Millennium", jointly organized by ESAA

	(Electricity Supply Association of Australia), IEA-PVPS (Photovoltaic Implementing Agreement) and IEA-SolarPACES
14th	Semi-annual Task III Working Meeting, in Sydney / Australia
15th	Semi-annual Task I Working Meeting in Sydney, Australia
16th	Annual Task II Working Meeting in Sydney, Australia

April

	THESEUS – project progress meeting with Solar PACES (*M.Geyer*) participation, in Crete (Task I)

May

16th - 17th	Annual EuroCare meeting– Infrastructure Cooperation Network (funded by EC-DG Research), at CNRS - IMP in Odeillo (Task III)
25th	Presentation (*by M.Geyer*) of Solar Thermal Technologies to UNEP Expert Group, in Paris

June

17th	Parabolic Trough Workshop of SunLab and US Industry; in Madison, Wis., USA (Task I)

July

23rd-28th	8th International Energy Forum "Energex 2000", multiple participation from Task I and Task III with funds from the SolarPACES START Program

August

21st- Sept 8th	Task III: International Radiometer Intercomparison Campaign "InterComp 2000", at DLR in Cologne/ Germany

September

19th -20th	Task III related Working meeting EuroCare – Infrastructure Co-operation Network (funded by EC-DG Research), in Strassbourg, France, organized by EC-DG TREN
19th-20th, 25th	59th SolarPACES Executive Committee Meeting in Cairo/Egypt
23rd	Combined semi-annual Task I / Task III Working Meetings in Hurghada, Egypt with special emphasis on collaboration with Egypt
28th-29th	Task III-Workshop on Simulation of Solar Thermal Power Systems, at DLR in Cologne. Germany

October

2nd -5th SolarPACES co-sponsoring (together with UN-ESCWA and the German Goethe-Institute/Beirut) the Expert Group on "Dissemination of Renewable Energy in the ESCWA Member States – Chances and Challenges", with presentations on SolarPACES and CSP-Development Status *by W.Grasse and M.Geyer,* in Beirut, Lebanon

8th Seminar on "Electricity Generation with Solar Power Plants", with a presentation *(by W.Grasse)* on IEA-SolarPACES program and status of CSP developments; Joint invitation by University of Damaskus and German Goethe-Institute/Damaskus, in Damaskus, Syria

9th Seminar on "Renewable Energy Sources" with a presentation *(by W.Grasse)* on CSP developments and their chances in Jordan; meeting with the Jordanian Minister of Energy concerning membership in SolarPACES
Joint invitation by the Ministry of Energy, the National Energy Research Center (NERC) and the Ger-man Goethe-Institute/Amman, in Amman, Jordan

9th - 13th "The IEA Renewable Energy Week" with meetings
- of Working Parties Chairs,
- of REWP Chair with Chairmen of Agreements,
- of REWP (Working Party on Renewable Energy)

(*SolarPACES represented by W.Meike and R.Pitz-Paal)*

23rd-25th Presentation (*by R.Kistner*) of Solar Thermal Project Opportunities at the EC-ALTENER II – Conference, in Nice, France

24th Presentation (*by M.Geyer*) of Solar Thermal Project Opportunities in the Mediterranean at EC's final meeting of the IRESMED project on the Integration of Renewables in the Mediterranean, in Brussels/EC

November

1st-4th *M.Geyer* attended the Prebid Conference for the Indian 100-140-MWe ISCCS Project, in Jaipur, and met with a representative of the Indian MNES concerning Indian membership in SolarPACES

11th Presentation (*by M.Geyer*) of SolarPACES to the Italian CESI and ENEA to prepare Italian membership in SolarPACES, in Rome, Italy

12th Presentation (by M.Blanco and R.Pitz-Paal) of solar thermal lead proposals at EC's Information Meeting for its 6th Framework Program, in Brussels/EC

30th "Evening Talks" on Solar Thermal Power, with German parliamentarians - *G.Eisenbeiß together with KfW and German solar thermal industry* – upon invitation of the German Parliament, Berlin, Germany

December

7th Presentation of SolarPACES (*by M.Geyer)* at the SolarEXPO 2000, Verona, Italy

1.6 Future SolarPACES Priority Actions

When the new SolarPACES Executive Secretary (*Michael Geyer*) was elected at the 59th ExCo Meeting in October, 2000, he recommended a plan for priority actions to further advance commercialization of Concentrating Solar Thermal Power (CSP) to be implemented in close cooperation with industry, international implementing entities, and host countries of the world's solar belt (which are mostly developing or emerging countries). This plan for action is summarized below:

CSP has been identified by the European Union (EC) as well as by the World Bank (WB) and the Global Environmental Facility (GEF) as an excellent option for providing a significant fraction of the renewable bulk electricity which constitutes an essential part of the package of measures required to comply with the Kyoto Protocol. The GEF and other organizations recognize the value of developing clean, sustainable CSP plants and offer significant economic incentives, such as grant funding, to deploy initial plants. What appeals to these organizations is that the embodied energy of a CSP plant is recovered after less than 1.5 years of operation orders of magnitude less carbon dioxide per GWh are produced on a life-cycle basis than competing fossil-fired plants.

Within the EC Fifth Framework Program, several approaches to fostering the commercial success of CSP technology in Europe have been launched. All of these projects are **delayed due to non-technical barriers**, resulting in essential additional costs for the industry involved and reducing the likelihood of replication projects, endangering the successful entry of CSP on the market at all. These barriers are related to discriminating regulations related to certification regulations, permitting and grid integration, as well as a lack of standards for systems and components. One major reason for this is the lack of information by the policy makers and implementing bodies, since the technical background of CSP is not appropriately defined to serve for non-discriminative legislation. For this purpose, SolarPACES is now joining forces with the **IEA Renewable Energy Unit** (IEA-REU), with the various Solar Thermal **Industrial Associations** (ESTIA,

SEIA), as well as with the UNDP and GEF networks to identify and remove such barriers by the following means:

- The current national **tariff/power-exchange conditions** and CSP project licensing procedures in the lead market countries need to be reviewed and licensing flow diagrams generated. Based on these flow diagrams, gaps in regulations and discriminating power exchange and CSP system licensing regulations need to be identified. The corresponding modifications and amendments to national tariff conditions and licensing regulations to remove such gaps/discriminations need to be recommended. The power purchase conditions, licensing procedures and progress of the four ongoing GEF-sponsored CSP projects in Egypt, India, Mexico and Morocco, should be monitored to identify barriers that may hinder future replication and to elaborate recommendations for cooperation with UNEP/GEF and KFM.
- The generic characteristics of **CSP grid integration** must be specified. Current grid integration regulations for CSP projects need to be investigated in order to identify discriminating issues (like issues of special capacity penalties, plant dispatching and synchronization of CSP generation and customer load). Corresponding modifications and amendments to the national grid connection regulations need be recommended to remove such gaps/discriminations.
- Successful CSP certification requires the elaboration of generic definitions for pure **solar and hybrid CSP systems** and methodologies for the determination of the renewable energy content in the electricity generated from CSP. The current status of Green-Label implementation processes for CSP must be analyzed in lead market.
- Specific **legal texts** for CSP certification need to be drafted according to the results of the above analysis.
- Cooperation and coordination must be established with responsible **international implementing bodies** (UN-FCCC, COP, IEA, GEF) to determine how to include CSP certification in Emission Trading **(ET)**, Clean Development Mechanism **(CDM)**, and Joint Implementation **(JI)**.

Simultaneously with the above, the three SolarPACES Tasks, as coordinated by their Operating Agents from the US, Switzerland and Germany, will continue with the 1999-2002 Program of Work previously outlined.

1.7 References and Publications

Reference documents and publications by, or initiated by, the SolarPACES Executive Committee, or publications to which Solar-PACES contributed, are listed. Some of these documents (marked ***INT***) are for internal distribution only.

Further reports and publications are listed in Parts 3, 4 and 5.

[1.01] **IEA-Implementing Agreement** for the Establishment of a Project on Solar Power and Chemical Energy Systems, SolarPACES (as amended to September 24, 1997).

[1.02] **IEA SolarPACES Strategic Plan** "Entering the 21st Century", 1999

[1.03] **SolarPACES Program of Work** (1999-2002), 1999 (***INT***)

[1.04] **SolarPACES Annual Reports to the IEA,** Reporting on Activities and Results: 1989-91, 1992/93, 1994, 1995, 1996, 1997, 1998, 1999, (ed. by W. Grasse in cooperation with , M. Becker, A. Steinfeld, C. Tyner)

[1.05] **Concentrating Solar Power in 2001**, An IEA-SolarPACES Summary of Status and Future Prospects," by C. Tyner, G. Kolb, M. Geyer, M. Romero, 2001 (in printing).

[1.06] **SolarPACES START-Mission Reports:** to Egypt (February, 1996), to Jordan (March, 1997), to Brazil (April, 1997), to Mexico (October, 1998) – ***(INT)***

[1.07] **Solar Thermal Presentation Material – CD-ROM,** with up-dated viewgraphs and papers presented by W. Grasse and M. Geyer/IEA-SolarPACES, 2000, provided for the participants of the Expert Group Meeting on Disseminating Renewable Energy Technologies in UN-ESCWA Member States, Beirut/Lebanon, October 2-5, 2000.

[1.08] **Concentrating Solar Power: A Promising Option** – Slide show of 53 viewgraphs referring to 6 chapters: (A) Power Generation and Climate Change, (B) Electricity Generation with Fossil Thermal Power Plants (C) Adding Solar Boilers to Thermal Power Plants, (D) Economics and Financing (E) Concentrating solar Independent Power Project – IPP, (F) Concentrating solar Power Examples (CD-ROM, 1998 – for EC-GDXVII by TFC and DLR) – also contained in Beirut-CD as quoted above.

[1.09] **Proceedings of the International SolarPACES Symposia** The most recent proceedings are:

?? 9th SolarPACES-Symposium (held on June 22-26, 1998 in Font Romeu-Odeillo, France, in *Journal de Physique IV*, EDP Sciences, France, March 1999
?? 10th SolarPACES-Symposium (held on March 8-10, 2000 in Sydney, Australia, ed. by H.Kreetz, K.Lovegrove, and W. Meike, 2000.

[1.10] **IEA publications with contributions from Solar-PACES**:

?? Key Issues in Developing Renewables (IEA/OECD)
?? International Energy Technology collaboration: Benefits and Achievements, IEA/OECD, Paris, 1996.
?? Benign Energy? The Environmental Implications of Renewables, IEA/OECD, Paris, 1998.
?? The Evolving Renewable Energy market, published for the IEA-REWP, by Novem BV, The Netherlands, 1999.

[1.11] **Solar Chemistry**, "Special Issue" in *Solar Energy*, Vol.65, 1999 (Proceedings of the International Symposium on Solar Chemistry, PSI, Switzerland)

[1.12] **Roadmaps for CSP Technologies**, by SunLab, USA
?? Parabolic Trough Technology Roadmap: A Pathway for Sustained Commercial Development and Deployment of Parabolic Trough Technology, 1999 (available at www.eren.doe.gov/sunlab/Documents.htm)
?? Parabolic Dish Roadmap (ongoing)
?? Molten-Salt Tower Technology Roadmap (ongoing)

[1.13] **STEPS** – Expert System for Solar Thermal Power Stations (being developed by DLR/Germany for solar power plant site assessment; (available at www.dlr.de/steps)

[1.14] **Solar Thermal Power – The Seamless Solar Link to the Conventional Power World**, Geyer, M. and Quaschning, V., in Renewable Energy World, vol.3 no.4, July/August, 2000.

[1.15] **Status Report on Solar Thermal Power Plants** by Flabeg Solar International, Cologne, Germany, 1996.

[1.16] **Cost Reduction Study for Solar Thermal Power Plants**, Report prepared for the World Bank by Enermodal Engineering in association with Marbek Resource Consultants, Washington, USA,1999.

Part 2: System Aspects of the Present Generation of CSP plants now underway

Solar Electricity Technologies and Systems,
their Development Status and Market Potential

by
Dr. Michael Geyer
DLR at the Plataforma Solar de Almería
SolarPACES Executive Secretary
(as of 2001)

2 System Aspects of the Present Generation of CSP Plants now underway;

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(as of 2001)

2.1 Introduction

May, 2000, was the deadline for submitting proposals for pre-qualification for implementation of the first hybrid fossil solar project with private participation in Kuraymat (Egypt). Over twenty international consortiums have submitted their qualification documents for the financing, construction and operation of this 135-MWe combined cycle power plant with 200,000-300,000m² of solar field. The incremental costs of solar electricity production over a conventional fossil power production will be covered by a grant from the Global Environmental Facility (GEF), the world environmental fund of the industrial nations that is administered by the World Bank. Among the interested bidders are such well-known project developers as BP, ABB, Duke Energy, ENEL, Mahrubeni, Unión Fenosa and others. This shows the revived interest of the power players in concentrating solar power as a future clean power option.

Also some of the main sponsors of energy investments in the developing world, i.e. the World Bank Group, the Kreditanstalt für Wiederaufbau (KfW) and the European Investment Bank (EIB) have recently been convinced of the environmental promises and the economic perspectives of CSP technologies: Only in spring of this year, the Board of the Global Environmental Facility (GEF) approved grants for first solar thermal projects in Egypt, India, Mexico and Morocco for a total of approx. US$ 200 million.

The dramatic worldwide decrease in interest rates and capital costs has significantly increased the attractiveness of investments

in capital-intensive renewable projects, including CSP. Private venture capital for CSP project development and green power investment funds are now becoming available in Europe.

Last, but not least, the crude oil price again recently hit US$ 35/barrel.

Against this background, this chapter gives an overview of the development status of the present generation of CSP plants, presents current project developments and solar thermal IPP opportunities and analyzes their economic and financial feasibility.

2.2 Solar Thermal Power Generation

Solar thermal power is one of the main candidates for providing a major share of the clean renewable energy needed in the future because

- Solar radiation is the largest renewable resource on earth. Approximately 1% of the world's deserts if occupied by solar thermal power plants would have been sufficient to generate the entire world electricity demand for the year 2000.
- This energy source is more evenly distributed in the sunbelt of the world than wind or biomass, providing more locations for CSP plant sites.
- It is among the most cost-effective renewable power technologies with near-term power generation costs in the range of 12 to 20 US¢/kWh and of 5 to 10 US¢/kWh for long-term. And it is the lowest cost solar electricity in the world, promising future cost competitiveness with fossil-fuel.
- It is a well-proven and demonstrated technology. Over 100 years of accumulated operating experience by nine parabolic-trough solar thermal power plants feeding over 9 billion kWh of solar-based electricity into the Californian grid, demonstrate the soundness of the concept.
- It is now ready for more wide-spread application if we start more intensified market penetration immediately.

Accelerated application will lead to further innovation and cost reduction to meet the challenge of competitive conditions in the next millennium.

All concentrating solar thermal power (CSP) technologies rely on four basic key elements: concentrator, receiver, transport-storage, and power conversion.

The concentrator captures and concentrates solar radiation, which is then delivered to the receiver. The receiver absorbs the concentrated sunlight, transferring its heat energy to a working fluid. The transport-storage system passes the fluid from the receiver to the power-conversion system; in some solar-thermal plants a portion of the thermal energy is stored for later use. As solar thermal power conversion systems, Rankine, Brayton, Combined or Stirling cycles have been successfully demonstrated. Two emerging solar thermal power generation concepts are presented here more in depth.

- The Parabolic Trough or Solar Farm consists of long parallel rows of identical concentrator modules, typically using trough-shaped glass mirrors. Tracking the sun from East to West by rotation on one axis, the trough collector concentrates the direct solar radiation onto an absorber pipe located along its focal line. A heat transfer medium, typically oil, at temperatures up to 400ºC, is circulated through the pipes. The hot oil converts water to steam, driving the steam turbine generator of a conventional power block.

The Solar Central Receiver or Power Tower is surrounded by a large array of two-axis tracking mirrors, called heliostats, reflecting direct solar radiation onto a fixed receiver located on the top of a tower. Within the receiver, a fluid – water, air, liquid metal and molten salt have been tested – transfers the absorbed solar heat to the power block where it is used to heat a steam generator. Advanced high temperature power tower concepts, which heat pressurized air up over 1000 °C in order to feed it into the gas turbines of modern combined cycles, are now under investigation.

The inherent advantage of CSP technologies is their unique ability for integration into conventional thermal plants. All of them can be integrated as "a solar burner" in parallel to a fossil burner into conventional thermal cycles and provide, with thermal storage or fossil-fuel backup, firm capacity without the need of separate backup power plants and without stochastic perturbations of the grid.

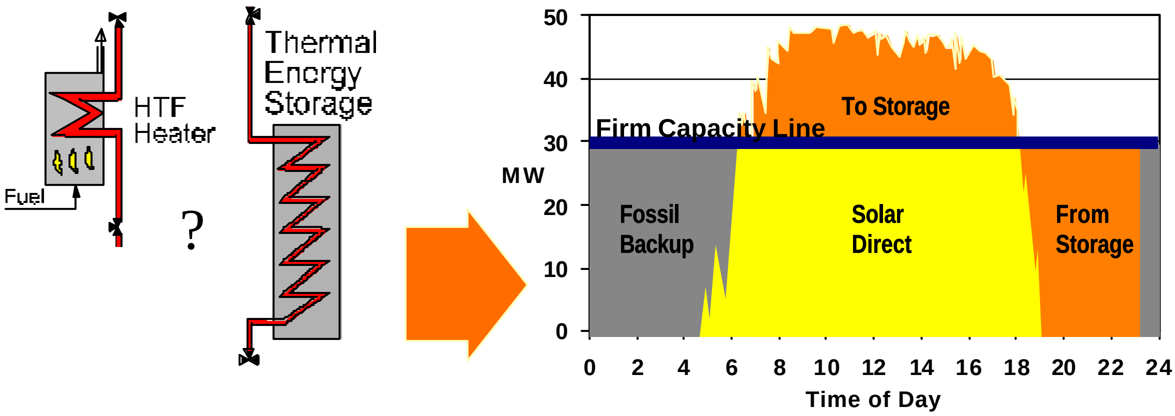


Fig. 2.1 With minimum fossil backup firing and/or thermal energy storage, the solar capacity is transformed into firm capacity

With a small amount of supplementary energy from natural gas or any other fossil fuel, the solar thermal plants can supply electric power on a firm, secure basis. This is possible because the solar thermal concepts provide the unique capability to internally complement the fluctuating solar burner output with thermal storage or a fossil backup heater. With this feature, solar thermal systems are the only renewable power plants that will neither cause grid perturbations nor disturb the operation of the other existing fossil plants in the rest of the power park. These features make CSP technologies a likely candidate for large-scale emission reduction at a reasonable cost.

2.3 Trough Power Plants

With 354 MW of solar electric generating system (SEGS) parabolic-trough power plants connected to the grid in Southern California since the mid-1980s, parabolic troughs represent the most mature CSP technology. To date, there are more than 100 plant-years of experience from the nine operating plants, which range in size from 14 MW to 80 MW. The drop in fuel prices led to a 40% reduction in revenues from electricity sales in the late 1980s. This resulted in new trough projects no longer being competitive in California. However, the nine existing SEGS units continue to generate electricity, demonstrating the reliability of this technology. Up to now, 9 TWh of solar electrical energy has been fed into the Californian grid, resulting in sales revenues of over US$1000 million.

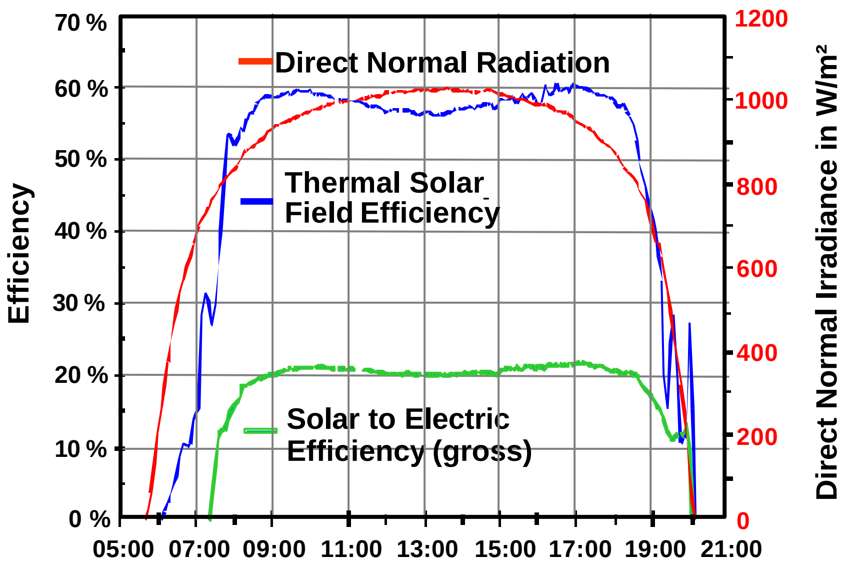


Fig. 2.2 Solar Efficiencies measured at SEGS VI on July 1997 by the KJC Operating Company

The performance of these power plants has continued to improve over their operational lifetime. The Kramer Junction site has achieved a 30% reduction in operation and maintenance (O&M) costs during the last five years, while increasing plant daily summer peak efficiencies to close to 20%. Although higher thermodynamic efficiencies are being predicted for the higher concentrating power towers, none of the many power tower demonstration plants can yet come close to the annual performance and efficiency of the commercially operating parabolic trough plants, falling short of the predictions.

This success is the result of major collector design and O&M procedure improvement programs, jointly carried out by the Kramer Junction Operating Company and Sandia National Laboratories (Albuquerque). Furthermore, key trough-component manufacturing companies have also made advances. For example, Flabeg Solar International has developed improved process know-how and system integration and is working on initiating projects in the world’s sunbelt. Firms like Abengoa and Gamesa in Spain,

Solel in Israel or Bechtel and Duke Solar in the USA have developed capabilities which allow them to become turnkey suppliers. It is estimated that new plants, using current technology with these proven enhancements, could produce clean solar power today for about 12 to 20 US¢/kWh.

Within the DISS (Direct Solar Steam) project, the oil heat transfer medium will be replaced by water that is evaporated and overheated to temperatures of 400°C at a pressure of up to 100 bar directly in the solar field. This steam can be fed directly into a steam turbine, making a heat exchanger and oil unnecessary, thereby reducing costs and increasing annual efficiency. Further cost reduction and better efficiency will result from the EUROTrough project's improved collector structure. Numerous industrial partners are involved in these projects. Prototypes of both project developments have been set-up and are being tested at the Plataforma Solar de Almería.

Fig.2.3 Aerial view of the five 30 MW_e parabolic trough plants at Kramer Junction, California (Courtesy of KJC)

2.4 Power Tower Plants

In more than 15 years of experiments around the world, power tower plants have proven to be technically feasible in projects using different heat-transfer media (steam, air, sodium, and molten salts) in the thermal cycle and with different heliostat designs. U.S. and European industries (including Abengoa, Ghersa, Bechtel, Boeing and Steinmüller) have expressed interest in commercializing second-generation power tower technology and have recently built and operated demonstration power plants.

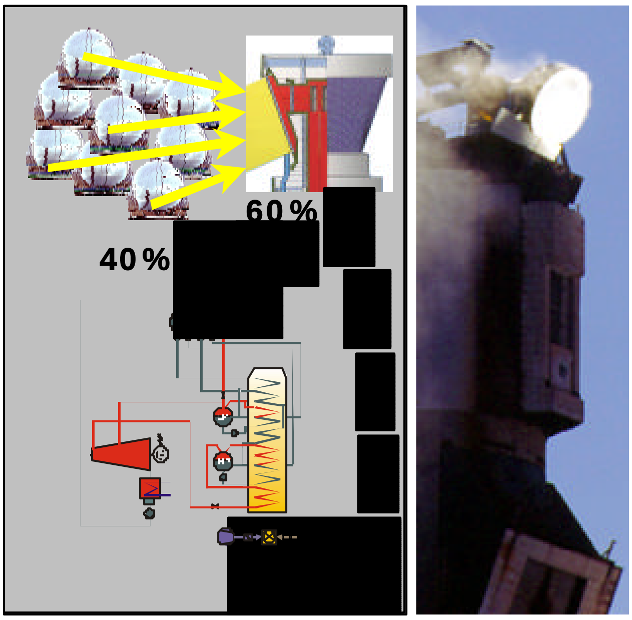
At Barstow, California, a 10 MW pilot plant (Solar One) operated with steam from 1982 through 1988. It recently operated as Solar Two, with molten salt as the heat-transfer and energy-storage medium, after modification of the complete plant in 1996. Before shutting down in April, 1999, the system had accumulated a few thousand hours of experience and was delivering

power to the grid on a regular basis. Solar Two has demonstrated the feasibility of delivering utility-scale solar power from storage to the grid 24 hours a day, if so required.

(Courtesy of SunLAB)

Fig. 2.4 10 MW_e Solar Two power tower demonstration facility with molten salt receiver and storage at Barstow, California (USA)

Meanwhile, in Europe, the volumetric air receiver concept, by which the solar energy is absorbed on fine-mesh screens and immediately transferred to air as the working fluid, has been demonstrated. This concept was extensively validated in the 2.5 MW_{th} Phoebus Technology Program Solar Air Receiver (TSA) tests conducted over the past few years in Almería, Spain.



(Courtesy of Ciemat and DLR)

Fig. 2.5 Phoebus power tower concept with volumetric air receiver and TSA receiver testing at the Plataforma Solar de Almería, Spain

2.5 Market Aspects

With the advent of independent power producers (IPPs) and deregulation of the electricity sector, there is intense competition for market within the power industry. Profit margins on power projects are small, and consequently, IPPs are hesitant to take risks on new technology like CSP plants. As a result, it is very difficult to introduce a new technology on the marketplace.

The market success of CSP plants will depend heavily on the choices made between environmental protection and the lowest possible electricity cost. As these are in many ways mutually exclusive, the final outcome will depend on both energy policy decisions and international support for responsible environmental action in a climate of scarce resources.

The international community is concerned about climate change and environmental damages. The “Intergovernmental Panel for Climate Change” (IPCC) is demanding drastic reductions in greenhouse gas emissions in order to avoid global warming and the collapse of the world climate. In Kyoto, 1998, the nations agreed to compel themselves to CO_2 reduction quotas; Japan committed itself to 6%, the US to 7% and the European Union to an 8% reduction in CO_2 from 1990 levels by 2012.

To achieve this goal, the European Commission wants to increase the renewable share of its annual primary energy consumption from 6% today to 12% in 2010. This was announced for the first time in the 1996 Madrid Declaration, was further specified in the 1998 Energy White Paper and is now supported under the 5th Framework Program. More important, however, is the intention of the European Union to require its member states to set a quota or harmonized premiums for renewable technologies in order to accelerate their market introduction. This includes the introduction of cost-covering compensation tariffs and purchase obliga-

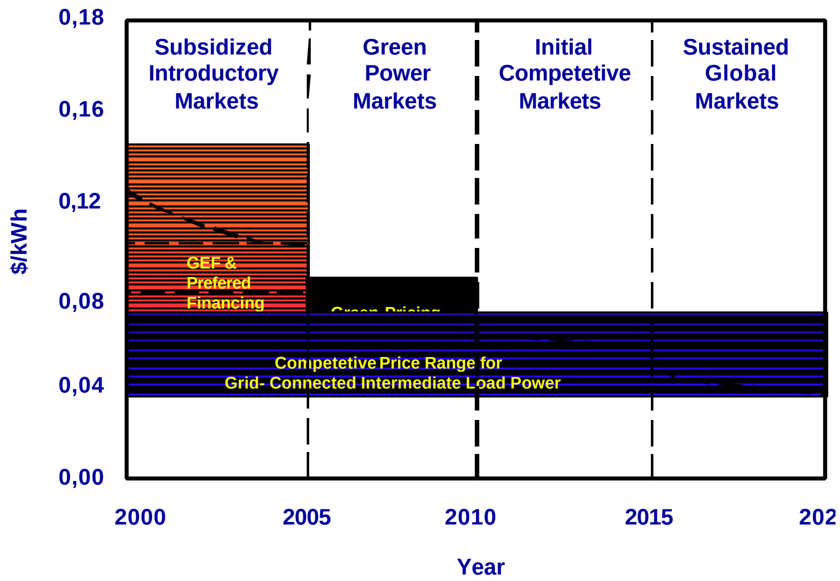


Fig.2.6 Market introduction of CSP technologies with initial subsidies and green power tariffs (Source: SunLAB, USA)

tions for renewable power throughout Europe. Together with liberalization and deregulation of the European electricity sector this will create new market rules and private investment opportunities, since each investor in renewable power will be allowed to produce clean electricity at the sites with best renewable resources and sell them on the markets where revenues are highest.

Also some of the main sponsors of energy investments in the developing world, i.e. the World Bank Group, the Kreditanstalt für Wiederaufbau (KfW) and the European Investment Bank (EIB) have recently been convinced of the environmental promises and the economic perspectives of CSP technologies: Only in spring of this year, the Board of the Global Environmental Facility (GEF) approved grants for first solar thermal projects in Egypt, India, Mexico and Morocco for a total of approx. US$ 200 million.

The dramatic worldwide decrease in interest rates and capital costs has significantly increased the attractiveness of investments in capital-intensive renewable projects, including CSP. Private venture capital for CSP project development and green power investment funds are now becoming available in Europe.

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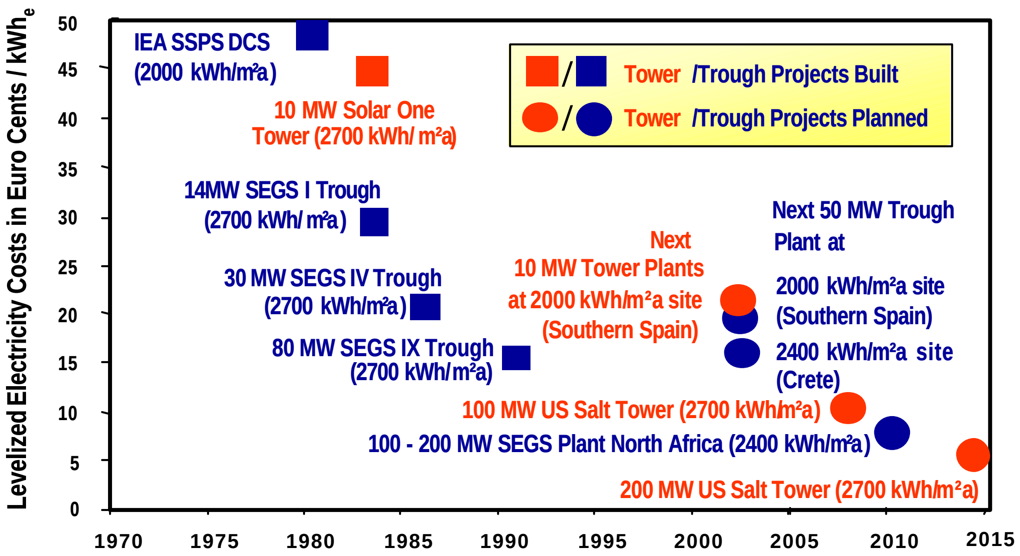


(Source: DLR-Almería)

Fig. 2.7 Evolution of levelized electricity costs for solar thermal power plants referred to solar-only production for sites with different direct normal irradiation

Fig. 2.7 shows the reduction of the levelized electricity cost that has been achieved within the last years and the expected reduction due to the increasing market penetration.

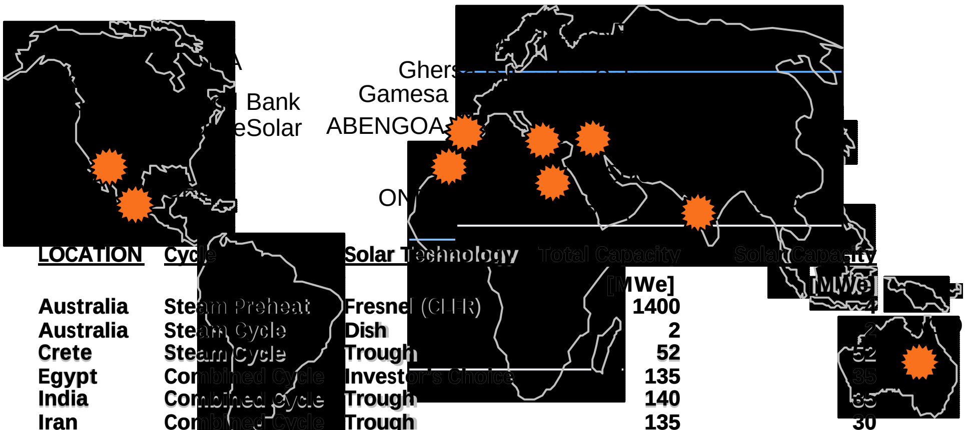
Against this background, project developers suggest a market entry strategy for CSP technologies in three phases:

1. Solar Field Additions: To respond to present market needs and reduce the amount of buy-down necessary to make CSP immediately competitive, small solar fields can be integrated into combined cycle and coal- or fuel-oil fired power plants. The additional investment required will be as litte as US$400 to 1500/kW installed, achieving a modest solar share of up to 10% in base load operation

2. Increased Solar Share: With increasing fossil fuel prices, compensation premiums for CO_2 avoidance and solar field cost reductions, solar shares can be increased to about 50 % and more when they are integrated into conventional, coal- or fuel oil-fired power stations. Here, the potential is greatest for the largest emission reduction.

3. Thermal Energy Storage: With further rising fuel price levels, thermal energy storage will be able to further substitute for the need of a fossil back-up fuel source. In the long run, base-load operated solar thermal power plants without any fossil fuel addition are in principle possible.

2.6 CSP Projects Underway



LOCATION	Cycle	Solar Technology	Total Capacity [MWe]	Solar Capacity [MWe]
Australia	Steam Preheat	Fresnel (CLFR)	1400	4
Australia	Steam Cycle	Dish	2	2
Crete	Steam Cycle	Trough	52	52
Egypt	Combined Cycle	Investor's Choice	135	35
India	Combined Cycle	Trough	140	35
Iran	Combined Cycle	Trough	135	30
Mexico	Combined Cycle	Investor's Choice	310	40
Morocco	Combined Cycle	Investor's Choice	150	30-50
Spain	Steam Cycle	Trough	50	50
Spain	Steam Cycle	Tower (*PS10*)	10	10
Spain	Steam Cycle	Tower (*Solar Tres*)	10	10
US, Nevada	Steam Cycle	Trough	30	30

Fig. 2.8 CSP projects currently underway

In this context, various commercial CSP projects are currently underway:

Australia — Under the Australian Greenhouse Office (AGO) Renewable Energy Showcase Programme, a 13 MW_t Compact Linear Fresnel Reflector (CLFR) demonstration unit will be installed late in the year 2000, retrofitted to an existing 1400 MW_e coal-fired plant in Queensland. A regulatory context for promoting solar energy was en-

acted on December 8, 2000 by the Australian Parliament. Australian legislation requires that the renewable energy content of electricity be raised from the 1997 level of 10.5% to 12.5% by 2010.

Germany In December 2000, the German parliament forced allocation of 20 Million budget DM for a 3-year market introduction effort of CSP technologies, that shall be administered by the German Minister for Environment.

Greece On the island of Crete, the private venture capital fund Solar Millennium, together with strong Greek and European industrial partners has established the first solar thermal project company, THESEUS S.A. and submitted their application for licensing a 52-MW solar thermal power plant with a 300 000-m² parabolic-trough solar field, which will supply solar-only electricity to the island grid on Crete.

Italy In December 2000, the Italian Parliament approved allocation of 110 Million Euro for an intensive 3-year RD&D effort to establish and demonstrate CSP in Italy.

Spain On December 21st in 2000, the Spanish congress approved the proposal of the Government to modify as of January 1, 2001 Law 54/1997 of November 27, 1997 on the Deregulation of the Electricity sector as follows: "The Government is authorized to implement higher premiums for installations that use solar energy as primary energy". Before this modification, the law originally only allowed implementation of premiums over a certain ceiling for photovoltaic systems. The Spanish Government is now preparing a special premium for CSP projects. The prospect of new incentive premiums for the generation of renewable electricity in 1999 has initiated various private solar project developments, with both parabolic trough and power tower technologies. Such prominent Spanish companies as Abengoa, Gamesa and Ghersa with international partners have engaged in solar thermal technologies in three ongoing projects:

- The 10-MWe PS10 solar-only power tower plant project in Sanlúcar near Seville, promoted by the Spanish Abengoa Group with partners, incorporates the Steinmüller volumetric air receiver/energy storage technology (see Fig. 2.5).
- The 15-MWe Solar Tres solar-only power tower plant project in Cordoba promoted by the Spanish Ghersa and Bechtel/Boeing uses US molten-salt technologies for receiver and energy storage (see Fig. 2.4).

The 30-50-MWe AndaSol parabolic-trough solar power plant promoted by the German developer Solar Millennium AG and the Spanish Gamesa in the region

of Andalusia will have a 200,000-400,000-m² EUROTrough solar collector field.

USA Soaring electricity prices and rolling blackouts in California and renewable portfolio policies of various states have revived the chances of long-term power purchase agreements covering the costs of CSP generation. US industry has joined forces in "CSP-Inc" to convince policymakers of the opportunities of CSP in the US.

In the framework of Operational Program No. 7 of the Global Environmental Facility (GEF), which has the objective of reducing anthropogenic greenhouse gas (GHG) emissions by increasing the market share of those low GHG energy technologies for specific applications which are not yet widespread least-cost alternatives in the recipient countries, the governments of the following countries have applied for the financial support of CSP projects:

Egypt has applied to the GEF for support for the addition of a 200,000-to-500,000-m² parabolic trough field to a new natural-gas-fired combined-cycle project in Kuraymat. Lahmeyer was contracted in 1999 to review the previous prefeasibility studies and assist the NREA/EEA in the call for pre-qualification. A pre-bid conference was held in Cairo in January 2000. Over 20 international prequalification statements of interest in financing and operating the first hybrid fossil-solar power plant in Kuraymat, Egypt were received in May 2000. A call for bids for the second phase of consulting for preparation of the Request for Proposals (RFP) was issued in September, 2000.

India has applied to the GEF for support for the addition of a 200,000-m² parabolic-trough field to a 140-MWe naphtha-fired combined-cycle power project in Mathania, Rajasthan. The German KfW has offered a US$150 million soft loan for this project, for which the GEF has also allocated a US$45 million grant. Fichtner and DLR were contracted in the summer of 2000 to assist the Rajasthan State Power Corporation (RSPCL) in the preparation of the Requests for Qualifications (RFQ) and the RFP. The RFQ was issued in November 2000. Over a half a dozen international statements of prequalification were received in January, 2001. A pre-bid conference took place in November, 2000 in Jaipur. The draft RFP is due in the second half of 2001.

Iran has employed own national funds to complete a feasibility study for a 100-MW natural-gas-fired combined-cycle plant with an approximately 366,000-m² parabolic-trough field in the desert of Yazd. In December 2000, the Government of Iran approached the GEF for aid for the project.

Mexico has applied to the GEF for support of the addition of a 100 000 to 500 000-m² parabolic-trough field to a new natural gas-fired combined-cycle project in the desert

areas of northern Mexico, that will be offered to private investors for bidding as an independent power project. The preparation of the terms of reference is to be done by CFE of Mexico.

Morocco has applied to the GEF for support of an addition of a 100,000- to 500,000-m² parabolic-trough field to a new natural-gas-fired combined-cycle close to the new gas pipeline from Algeria to Spain, that will be tendered to private investors as a merchant power project. Fichtner and DLR were contracted in November, 2000 to assist the Moroccan National Electric Utility ONE in preparing the RFQ and the RFP. The draft RFP is due before the end of the year 2001.

S. Africa Eskom is evaluating the potential of commercial development of CSP across southern Africa. The Eskom study investigates a wide range of CSP technology options, coupled with an initial feasibility assessment of the most interesting designs. Initial results are expected in early 2001.

The GEF and other organizations recognize that it is worth developing clean, sustainable CSP and are offering significant economic incentives, such as grant funding, to deploy initial plants. What appeals to these organizations is that the embodied energy of a CSP plant is recovered after less than 1.5 years of plant operation and the power plant produces orders of magnitude less carbon dioxide per GWh on a life-cycle basis than competing fossil-fired plants. Construction of CSP plants, with GEF grant funding, could thus help sunbelt countries meet the carbon dioxide reduction goals established at the 1997 Kyoto Climate Change Convention to reduce global warming.

The *“Cost Reduction Study for Solar Thermal Power Plants“* "(Ref. [1.16] in Part 1 of this report) prepared for The World Bank in early 1999 concludes that the market for CSP is large and could attain an annual installation rate of 2000 MW. The best regions for CSP are southern Africa, the Mediterranean countries (including North Africa, Middle East and Southern Europe), India, parts of South America, southwest U.S./northern Mexico and Australia where CSP operating characteristics match the intermediate and peak electricity load requirements relatively well.

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

Operating Agent:
Craig Tyner
Sandia National Laboratories

3 Task I: Solar Thermal Electric Systems

3.1 Goals, Objectives, and Deliverables

Task I addresses the design, testing, demonstration, evaluation, and application of concentrating solar power (also known as solar thermal electric) systems, including parabolic troughs, power towers, and dish/engine systems. The focus of our efforts is on ultimate application of complete systems and the needs associated with getting them to the marketplace. The component and research efforts of Task III (see Part 5 of this report) will logically feed this Task as new components are merged into systems, while the results of this Task 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. Each sector is coordinated by a Sector Leader appointed by the OA. 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. This sector is currently led by CIEMAT.

I.2. Distributed Generation Systems, including activities associated with dish/engine and other systems capable of providing power on a distributed basis. The Australian solar thermal consortium currently leads this sector.

I.3. START Missions, implementing SolarPACES's Solar Thermal Analysis, Review, and Training Missions to evaluate the needs of potential user countries and help them initiate activities to implement the technology. This activity also provides technical support to the World Bank and GEF on con-

centrating solar power activities. Sandia National Laboratories currently leads this activity in cooperation with the OA and the ExCo.

I.4. Market Barriers and Opportunities, addressing financial, environmental, regulatory, and marketing issues. The National Renewable Energy Laboratory (NREL) is the lead in this activity.

Task activities are either cost-shared, task-shared (either through SolarPACES or between SolarPACES participants), 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.

Creation of a Task activity is based on the request of one or more participants, with approval of the OA. Each activity has a lead individual designated by the Participants of that activity. The lead individual is responsible for coordination of SolarPACES involvement, as well as regular reporting to the Task.

Deliverables: The OA is responsible for general Task I reporting, including preparation of input to the IEA/SolarPACES Annual Report, and for maintenance of a Program of Work describing ongoing and anticipated activities. Participants are responsible for detailed reporting on their 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 any proprietary information. The activity lead assures input is available to the OA for general reporting requirements. The OA is responsible for organizing one to two meetings per year to discuss activity status and progress. Two Task I meetings were held in 2000, one in March in Australia, and one in September in Egypt.

3.2 Development Status of Technology

Concentrating solar power is represented by three technologies: parabolic troughs, power towers, and dish/engine systems. Only parabolic troughs have been commercialized (via nine SEGS plants totaling 354 MW, built by Luz in California in the 1980s and 1990s), although no new plants are currently being built. Nonetheless, each of the technologies has been developed to the point that early commercial installations could be built within the next few years. Concentrating solar power offers the lowest cost option for solar energy today, perhaps 1/3 the cost of photovoltaics. The new SolarPACES paper ***Concentrating Solar***

Power in 2001 provides a thorough summary of the status of the technology.

A number of parabolic trough suppliers are available and pursuing opportunities to build plants similar to the California SEGS plants using existing technology, with various hybridization options including combined-cycle systems. Early costs are expected to be similar to those of the final SEGS plants, 10-15¢/kWh, and technological risks are expected to be low. Because of the long-term successful operation of the SEGS plants, World Bank/GEF funding has tentatively been approved to buy down the cost of early plants in four developing countries: India, Egypt, Morocco, and Mexico. Advanced technologies, such as direct steam generation, may be available within a few years to help reduce costs still further.

Power tower development status is similar, although no large-scale (greater than 10-MW) plants have been built. This situation seems to be changing, however, based on recent opportunities in Spain, where previous legal restrictions to premium payments for CSP of up to 0.18 EURO/kWh (about 17¢/kWh) over market price were removed in December 2000. Based on this premium, the Solar Tres consortium (a partnership between the Spanish company Ghersa and the U. S. company Nexant, a Bechtel subsidiary) is planning a 15-MW molten salt power tower plant, utilizing the technology successfully proven at Solar Two. Similarly, the Spanish company ABENGOA is planning to build a volumetric air receiver-based system based on the successful PHOEBUS/TSA testing of all key components. Opportunities in Egypt, Morocco, Italy, and the U. S. are also being pursued. Early plants will be comparable in price to the trough plants.

Finally, several dish/engine systems are close to commercialization. Schlaich Bergermann and Partners have extensively tested 9-10 kW systems (based on a stretched-membrane dish and the Solo 161 kinematic Stirling engine) in Almería and follow-up activities based on the EuroDish design are being pursued. Science Applications International Corp. and Stirling Thermal Motors are currently building a second-generation 25-kW system based on the STM 4-120 Gen III engine, while Boeing and Stirling Energy Systems continue development of the 25-kW MDAC system originally tested in the 1980s. WG Associates and Sandia have demonstrated a 9-kW remote power system utilizing an advanced dish design and the Solo Stirling engine. These systems should be available for commercial introduction within a few years. Initial costs will be higher than troughs and power towers, although these systems, because of their modular nature, are targeted toward much higher-value markets. As with the other technologies, numerous opportunities for performance and cost improvements exist

3.3 Program of Work in 2000

Activities within Task I are organized by Sector and summarized in **Table 3.1**. The focus of our efforts is on ultimate application of complete systems and the needs associated with getting them to the marketplace. Activities listed in the table below (with contact person) are currently part of our Program of Work (extensively updated in 1999, with modifications in 2000 to reflect additions and deletions). 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.

Sectors and Activities	Contact	*Sharing*			
		I	M	T	C
Sector 1. Central Generation Systems	**Romero, CIEMAT**				
DIrect Solar Steam (DISS)	Zarza		x		
THESEUS Project	Kistner		x		
EUROTrough	Lüpfert		x		x
USA Trough	Price				
Solar Two Final Evaluation/Solar Tres	Pacheco	x			
10-MW Solar Thermal Power Plant for Southern Spain (PS10)	Romero		x		x
New Solar Thermal Projects in Australia	Meike	x			
Solar Gas Turbine with Tower Reflector (CONSOLAR Project)	Epstein		x		
SOLGATE Project (proposed for inclusion in 2001)	Buck		x		x
Sector 2. Distributed Generation Systems	**Meike, NTCR**				
SAIC USJV Project	Mancini	x			
Dish Engine Critical Components Projects	Mancini	x			
Remote Dish/Stirling Water Pumping System Development	Diver			x	
EuroDish	Heller		x		
Dish/Brayton Project	Mancini			x	
Small Dish Systems	Mehos	x			
Reliability Database	Mehos		x		
Sector 3. START Missions	**Mancini, Sandia**				
START Missions	Mancini			x	x
Egypt/WB Support	Geyer			x	
Brazil/GEF Support	Cordeiro			x	
Sector 4. Market Barriers and Opportunities	**Williams, NREL**				
Identification and Evaluation of Market Barriers	Williams			x	
Developing Projects – India, Egypt, Morocco, Mexico, S. Africa	Williams	x			x
Database of Project and Market Opportunities	Williams			x	
Technology Roadmapping	Price		x		
STEPS - Expert System for Solar Thermal Power Stations	Trieb	x			
RENIP Plan	Kistner	x			

Table 3.1 Summarized Task I activities organized by Sector

3.4 Participation and National Contributions

The Task is open to all IEA/SolarPACES members, subject to approval of the Operating Agent. Participation requires active involvement in at least one of the Task's activities. Currently, all IEA/SolarPACES member countries except Switzerland participate in Task I.

Australia:	Power and Water Authority Pacific Power	ANUTech NT Universities
Brazil:	CEPEL	
Egypt	NREA	
European Commission	DG Research DG Energy	
France:	CNRS	
Germany:	Fichtner Development Engineering Flabeg Solar International MERO Raumsysteme Schlaich Bergermann und Partner Schott Rohrglas	Siemens SOLO Kleinmotoren GmbH Steinmüller GmbH ZSW DLR/Köln, Stuttgart, and PSA
Israel:	Consolar Jacob Blaustein Institute for Desert Research (BIDR) MLM/Israeli Aircraft Industries Ormat Industries Rotem Industries	Silver Arrow Solel Ben Gurion University of the Negev Tel Aviv University WIS
Mexico	IIE	
Russia:	SPO Astrophysica	IVTAN
South Africa	Eskom	
Spain:	ENDESA EUCOMSA GAMESA INABENSA GHERSA IAER Iberdrola	IBERESE INITEC SERLED Unión Eléctrica Fenosa CIEMAT Plataforma Solar de Almería
United Kingdom	Avantica Technologies	SolarGen
United States:	Arizona Public Service Boeing California Energy Commission Duke Solar Electric Power Research Institute FPL Energy Industrial Solar Technology Kearney & Associates KJC Operating Company MWE Nexant (Bechtel Corp.)	Reflective Energies Salt River Project Science Applications International Corp. (SAIC) Southern California Edison STM, Inc. Stirling Energy Systems SunLab (Sandia National Labs and the National Renewable Energy Lab) SunRay Energy, Inc. U.S. Dept. of Energy
Other:	CONOPHOEBUS (Italy) ENEL, Rome (Italy)	INETI (Portugal) Organization for Development of Western Crete (OADYK), Crete (Greece)

Table 3.2: Current participants listed alphabetically by country

3.5 Cooperation with Industry

Not surprisingly, because of the system-level nature of Task I, industry and utilities are involved to some extent in nearly all our 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. (Although not "industry," university and laboratory participants are included at the end of each country's listing for completeness.)

3.6 Summary of Achievements in 2000

Achievements within Task I activities are summarized below by activity within each Sector. Details on activity objectives, key activities, participants, schedules, and expected results are summarized elsewhere in the 1999 Program of Work for Task I (Ref. [1.03] in Part 1 of this report).

3.6.1 Sector I.1. Central Generation Systems

Central Generation Systems include large-scale parabolic trough and power tower systems Manuel Romero, CIEMAT, is the Sector Leader.

DIrect Solar Steam (DISS)

The PSA DISS test facility was operated for more than 1450 hours in 2000 and 188 tests investigating the Direct Steam Generation (DSG) process were performed. Preliminary test results have proven that the DSG process is feasible with horizontal parabolic trough collectors. Temperature gradients measured in the absorber pipes are similar to simulation model predictions at the beginning of the project, while the pressure drop in the solar field is much lower than predicted by the models. Another important conclusion is that a very low water recirculation rate (about 20%) is enough to assure process stability and control in long solar transients. So far, the recirculation option with water injection in the superheating steam part of the solar field seems to be the most suitable option for a commercial DSG plant. Nevertheless, we must wait until the completion of the DSG test plan to arrive at any final conclusion, because only the recirculation and once-through processes have been tested so far.

THESEUS Project

The objective of the THESEUS project is the implementation (by Greek and European industrial partners and the private venture capital fund Solar Millennium) of the first commercial European parabolic-trough power plant, with a 52-MWe capacity produced by a 300,000-m² solar field, on the island of Crete. A detailed design of the solar field and power block has been completed, and a local project company, THESEUS S.A., has been

founded. However, difficulties in reserving land required the THESEUS project development team to look for an alternative site. Screening and negotiation for reservation of a site are ongoing. Issues regarding establishment of the new Greek deregulation authority and definition of power purchase conditions for solar thermal power in a privatized Greek power market are also of concern.

EUROTrough

The EUROTrough I collector prototype was installed in 2000 at the Plataforma Solar de Almería. This parabolic trough collector was designed and qualified by a dedicated consortium of INABENSA and CIEMAT (Spain), SBP, FLABEG, FICHTNER and DLR (Germany), and CRES (Greece) for solar thermal power generation, process heat and desalination. The design will be available for licensing to interested project promoters and has already been considered for several solar thermal projects. The Spanish Gamesa Group plans to use the EUROTrough technology in a 30-50-MW solar trough power plant (LucaSol) in the province of Almería.

USA Trough

Four of five contracts awarded in 1999 were completed in 2000. These included analysis of thermal storage for troughs and optimization of ISCCS plant configurations by Bechtel/Nexant and Flabeg Solar International, analysis of 10 MWe trough ORC power plant concept by Reflective Energies, analysis of several advanced trough concentrator design concepts by Duke Solar, and analysis of the SEECOT trough combined cycle integration concept by IST. A fifth contract that assesses failure mechanisms of trough mirrors and receiver tubes by MWE & Associates is still in progress. In addition, six new USA Trough Contracts were awarded during 2000 and should be completed during 2001. These include follow-on efforts by Duke Solar on the development of a new trough concentrator structure and secondary reflector, and completing an optimized 10-MWe Trough/ORC plant design. New awards were made to Kearney & Associates to evaluate the use of molten-salt as the heat transfer fluid in a trough collector field, IST to modify their trough concentrator to reduce cost and improve the high temperature performance, Augustyn & Associates to develop an improved low-cost DNI measurement system, and SUNI Albany to develop their high resolution satellite DNI mapping technique for the Southwestern U.S.

Solar Two Final Evaluation/Solar Tres

Major Solar Two evaluations have been completed and are being published. The lessons learned from Solar Two are being applied to the first commercial molten-salt power, Solar Tres, planned for deployment in Spain. Solar Tres is a 15-MW solar tower project based on Solar Two molten salt technology with a large solar multiple of 2.6, allowing for 24-hour solar operation. The project is a cooperative activity of the Solar Tres consortium formed by the companies GHERSA and Nexant. During 2000, the technical and economical feasibility of the project was assessed and detailed engineering, permitting and civil works will be started early in 2001.

10-MW Solar Thermal Power Plant for Southern Spain (PS10)

The PS10 10-MW volumetric air power tower plant project to be built at Sanlúcar near Seville has suffered almost a year's delay in the original schedule. Part of the delay was caused by the long time it took to obtain the European Commission contract subsidizing the project with 5 million Euro, which was finally signed in June, 2000, when it was originally expected in January. 2000. The basic engineering was completed by June, 2000, and operating strategies have since been defined. Beginning in June, most of the tasks (with the exception of those related to site characterization, evaluation of the solar resource, and some parts of the detailed engineering) were put on standby by the project Coordinator, waiting for above-market solar electricity rates to be clarified by the Spanish Government. The amendment to Law 54/1997 was finally approved and published on December 30, 2000, so the project is now completely feasible, and as such was restarted in January, 2001.

New Solar Thermal Projects in Australia

For the big dish (later version called the Power Dish) project, after original project definition, ANUTech and Transfield were asked by the power producer to provide 20-year guarantees for operation (power and availability), which effectively doubled costs to a level that was no longer feasible. They are now assessing options, including forming a start-up company. In the mean time, progress is on hold, pending evaluation of options.

With respect to markets, an extra 2% of energy generated from renewables will be required in Australia, brought online in a staggered fashion between 2000 and 2010. The Renewable Remote Power Generation Program (RRPGP) is underway for 4-6 years to include $40-60M (Aus)/yr to fund remote, diesel-displacing renewable power projects in non-grid locations in the north of Australia. There are good options for mine sites for CSP (5-20 MW).

Solar Gas Turbine with Tower Reflector (CONSOLAR Project)

The CONSOLAR Project demonstrating the tower reflector concept is financed by the Israeli Ministry of Industry and Commerce MAGNET program (see cover photo of this report). Participants include Ormat Ind., Rotem Ind., and WIS. Construction of the full experimental setup was completed in 2000. The optical part includes, in addition to the heliostat field, a hyperboloid tower reflector that directs the solar radiation onto a large, vertical-axis CPC (2.2-meter entrance diameter, 0.46-m exit diameter and 5.0 m long). Tower reflector performance was carefully measured using a CCD camera and image processing of the flux profile on a 2.5-x-2.5-m white target in the CPC entrance. Radiation sensors scattered over the target measured absolute flux levels. The results show excellent compliance with the calculations and proof that the reflector facet adjustment method was successful. The 500-kWth receiver was also installed, including the entire instrumentation and control system. Commissioning, cold static-pressure testing, and flow tests were completed successfully. Hot tests started with low power to verify that all measuring sensors were functioning. All emergency scenarios were simulated, and preparation for hot tests with full power was completed. Hot tests are planned for the first half of 2001.

3.6.2 Sector I.2. Distributed Generation Systems

Sector 2 activities are associated with dish/engine and other systems capable of providing power on a distributed basis. Wolfgang Meike, NT Universities, is the Sector Leader.

SAIC USJV Project

In 1999, SAIC installed three hybrid 22-kW dish/Stirling systems at utility sites located in or near Phoenix, Arizona, USA. This year SAIC successfully operated all three systems, achieving a peak 28-day solar availability of 80%, well above prior years. The systems achieved over 2800 hours of combined solar and hybrid operation, generating 32,500 kWh in solar mode and 2200 kWh under gas-fired operation. Hybrid operation included natural gas, landfill gas, and hydrogen as fuel sources. Reliability data has been entered into a SunLab-developed reliability database for all three systems, which will allow us to estimate the current reliability, as well as project future reliability growth for the SAIC design.

Dish Engine Critical Components Project (DECC)

During 2000, the SES/Boeing dish/Stirling development team fielded a second dish/Stirling system at its Huntington Beach, CA,

test site. They continue to operate the two systems and to do extended test cell operation of an engine at Kokums in Malmo, Sweden. Since April, 1998, the start of the DECC Project, a total of 9536 hours of test-cell operation of engines and 8149 hours of on-sun operation of dish Stirling systems have been accumulated. Peak power from the on-sun engines has been 24.3 kW, and the average daily on-sun energy production in Huntington Beach has been 9.9 kWh/m² of collector area.

Remote Dish/Stirling Water Pumping System Development

In 2000, the first-generation (Mod 1) grid-connected remote power system was operated at the National Solar Thermal Test Facility (NSTTF) in Albuquerque, NM. During the year, it accumulated over 1900 on-sun hours and generated over 9 MWh of grid-quality electricity. The design for a second-generation (Mod 2) stand-alone water-pumping system was also developed and hardware fabrication initiated. The SOLO 161 power conversion unit (PCU) for the Mod 2 system and the water pump power management system were independently tested, and the PCU was delivered to Sandia. Cooperative agreements for field-testing a system were reached with four American Indian tribes, and familiarization training on the Mod 1 system was completed with these groups.

EuroDish

Pre-qualification of the PSA DISTAL II facility components was successfully completed and many of the results integrated into the new EuroDish design. The site for the two new EuroDish systems was prepared by dismantling two of the DISTAL I units. After the new foundations had been made, the first concentrator was erected by gluing the single glass fiber facets together to form the shell. The control system is ready for the first test runs. A flux mapping system will assess the quality of the concentrator in January, 2001, and after that the Stirling engine will be mounted.

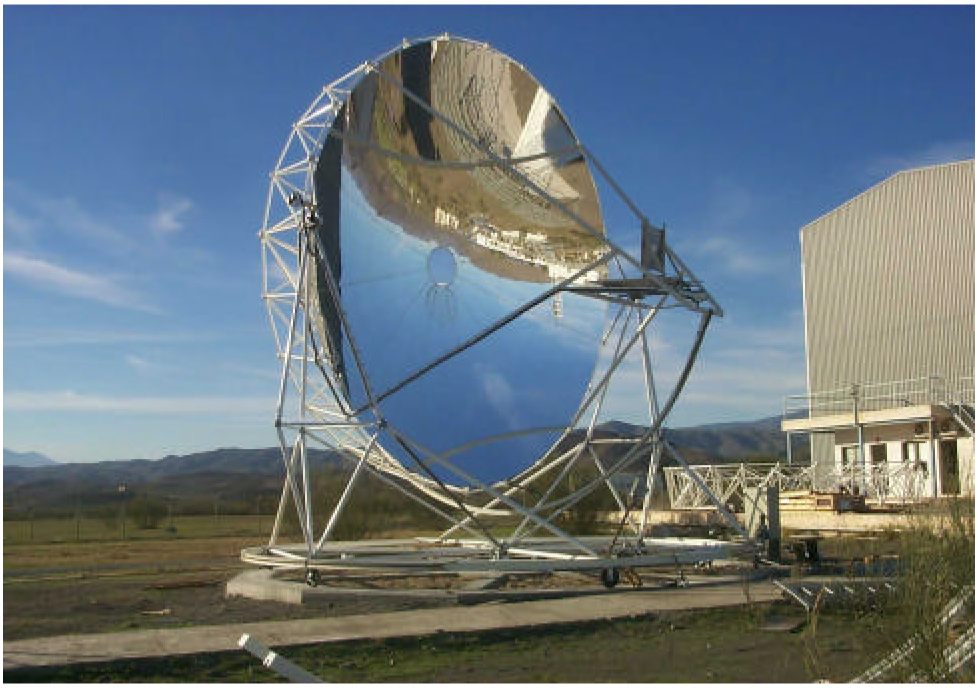


Fig. 3.1 First EuroDish concentrator

Small Dish Systems

SunLab initiated an effort to investigate the technical feasibility of small dish/converter systems after a 1999 market analysis indicated that significant markets might exist for concentrating systems in the 1-3 kW size range. Subcontracts were awarded to four companies for development of small dish systems and components, including a fully autonomous 2.5-kW concentrating PV system, a solarized 2-kW free-piston Stirling engine, and two low-cost 2-axis drives and controls systems designed for tracking small (<10 m^2) concentrators. All of the prototype hardware systems will be tested in 2001 to determine their performance and reliability.

Reliability Database

A web-based reliability database system to track and analyze dish/Stirling system performance was completed near the end of 1999. Access to the Internet is all that is required to enter data into the web-based system once a user profile is set up for a project. Since the system became operational, several hundred incidents representing operation of four dish/Stirling systems have been entered into the database. Software has been developed that allows users to analyze data queried from the database. The MS-Windows-based software allows users to estimate cumulative and instantaneous mean time between failure (MTBF) for the system, project future growth in reliability based on current trends in the data, and calculate MTBFs for individual system components, i.e. concentrator, receiver, converter, controls, etc.

3.6.3 Sector I.3. START Missions

START Missions support implementation of concentrating solar power technology in developing countries. Tom Mancini, Sandia, is the sector leader, having replaced Greg Kolb in September.

START Missions

SolarPACES START activities for calendar year 2000 involved two outreach meetings and updating of our briefing materials. The first START meeting was the ENERGEX Conference in Las Vegas, Nevada, USA, in July. The second meeting was an initial contact meeting in Lebanon in September. Lastly, we updated the START meeting briefing packages to more correctly reflect the solar thermal technologies and activities of the SolarPACES member countries.

Egypt/WB Support

The SolarPACES ExCo and Operating Agents were invited to the investors' conference that took place in Cairo in early January, 2000. (For more details, see Section 1.5.4 under "October" in Part 1, and Section 3.6.4 below.)

Brazil/GEF Support

Brazil received approval from the GEF for a PDF-B grant in March 1998, and the Ministry of Mines and Energy (MME) signed the terms of reference for the study in April, 2000. According to Alcides Codeceira Neto (CHESF), who attended the SolarPACES ExCo meeting in Cairo, work will probably start early next year (not in May, 2000 as was originally expected). MME will be the contact for the study. They are especially interested in irrigation applications in the northeast (where 4 to 7.5 GW are needed). SolarPACES will provide technical support for the study upon request.

3.6.4. Sector I.4. Market Barriers and Opportunities

Market Barriers and Opportunities addresses systems-level and commercialization needs beyond those associated with the technology. Tom Williams, NREL is the Sector Leader.

Developing Projects – Egypt, India, Mexico, Morocco, Iran, South Africa

Egypt has applied to the GEF for support for the addition of a 200,000-to-500,000-m^2 parabolic trough field to a new natural-gas-fired combined-cycle project in Kuraymat. An international consultant was contracted in 1999 to review the previous pre-feasibility studies and to assist the NREA/EEA in the call for pre-qualification. A pre-bid conference was held in Cairo in January

2000. The SolarPACES ExCo and Operating Agents were invited to the investors' conference that took place in Cairo in early January 2000. The conference was opened by the Ministers of Planning and International Cooperation and of Electricity and Energy, who confirmed to the 102 international participants the firm intent of the Government of Egypt to bring the first 120-140-MW hybrid solar thermal plant with private participation to grid by 2003. In addition, the World Bank (represented by the deputy resident in Cairo) confirmed the decision of the GEF counsel to support the project with a $49 million grant and to provide support with their standard project financing instrument currently in the pre-qualification process. Over 20 international pre-qualification statements of interest in financing and operating the first Hybrid Fossil-Solar Power Plant at Kuraymat, Egypt were received in May 2000. A call for bids for the second phase of consulting for preparation of the Request for Proposals (RFP) was issued in September, 2000 and is now being evaluated.

India has applied to the GEF for support for the addition of a 200,000-m² parabolic-trough field to a 140-MWe naphtha-fired combined-cycle power project in Mathania, Rajasthan. The German KfW has offered a $150 million soft loan for this project, for which the GEF has also allocated a $45 million grant. An international consultant was contracted in the summer of 2000, to assist the Rajasthan State Power Corporation (RSPCL) in the preparation of the Requests for Qualifications (RFQ) and the RFP. The RFQ was issued in November, 2000. Over a half a dozen international statements of pre-qualification were received in January, 2001. A pre-bid conference took place in November, 2000 in Jaipur. The RFP is expected in the second half of 2001.

Mexico has applied to the GEF for support of an addition of a 100,000- to 500,000-m² parabolic-trough field to a new natural-gas-fired combined-cycle project in the northern Mexican desert, that will be tendered to private investors as an independent power project. The preparation of the terms of reference for the project has been contracted.

Morocco has applied to the GEF for support of an addition of a 100,000- to 500,000-m² parabolic-trough field to a new natural-gas-fired combined-cycle close to the new gas pipeline from Algeria to Spain, that will be tendered to private investors as an independent power project. An international consultant was contracted in November, 2000 to assist the Moroccan National Electric Utility ONE in preparing the RFQ and the RFP. The RFP is expected before the end of the year 2001.

Iran has employed their own funds to complete a feasibility study for a 100-MW natural-gas-fired combined-cycle plant with an approximately 366,000-m² parabolic-trough field in the desert of Yazd. In December, 2000, the Government of Iran ap-

proached the GEF for aid for the project. Further action is expected in 2001.

In **South Africa**, Eskom is evaluating the potential of commercial development of CSP across southern Africa. The Eskom study investigates a wide range of CSP technology options, coupled with an initial feasibility assessment of the most interesting designs. Initial results are expected in early 2001.

Identification and Evaluation of Market Barriers

Legislation Creates Expanded Opportunities in Spain and Australia. On December 21, 2000, the Spanish congress approved the proposal of the Government to modify Spanish National Law 54/1997 on the Deregulation of the Electricity sector to allow for higher premiums for installations that use solar energy as primary energy. This modification extended solar premiums to solar thermal systems, in addition to photovoltaic systems that were covered by the Royal Decree 2818 of 1999. Developers have the option of choosing between a fixed rate of up to 36 Pts/kWh (approximately $0.21/kWh), or 30 Pts/kWh added to current market rates. Rates will be in effect for at least 5 years, though experience with similar legislation in the wind industry makes the industry confident that premiums will be extended beyond that time. The announcement gave an immediate boost to the development of several commercial projects that include power towers, trough, and dish technologies. Expectations from industry are that 250-400 MW of solar thermal electric capacity could be added in Spain within the next five years.

An alternative approach for promoting solar energy was enacted on December 8, 2000 by the Australian Parliament. Australian legislation requires that the renewable energy content of electricity be raised from the 1997 level of 10.5% to 12.5% by 2010. Factoring in expected load growth, this goal will require 9500 GWh/yr of additional renewable energy by 2010, a 60% increase in renewable energy generation in Australia. The legislation will achieve its objectives by creating a market in tradable Renewable Energy Certificates (RECs). Any wholesale purchasers of power (including electricity wholesalers, retailers, large industrial users) are required to hold RECs, each of which is equivalent to 1 MWh of renewable electricity production. The RECs can be obtained by generating renewable energy from an accredited system, or by buying certificates at market-based prices. Penalties will be levied on purchasers who do not adequately support the goal by having RECs proportional to their net energy purchases.

California Energy Nightmares Create Opportunity for CSP. In the United States, California led the way for deregulation of the utility industry in 1996, a move that promised customer choice of electricity providers and lower electricity rates

through expanded market competition. Results to date have culminated in what most observers term a “disaster”. Average California wholesale electricity prices have climbed to 33¢/kWh, approximately 11 times the rate a year ago. Price caps on utility customer tariffs have pushed California’s two largest utilities, Southern California Edison and Pacific Gas and Electric, to the brink of bankruptcy. And lack of capacity has led to a growing series of power emergencies within the state, recently culminating in rolling blackouts. These events have created a greatly improved business environment for CSP plants because of the higher prices for energy, increased awareness of the need for new power plants, and CSP freedom from price volatility due to fossil fuel costs.

Database of Project and Market Opportunities

Recent years have seen rapid growth in the number of potential commercial CSP projects. Industry, researchers, financial and governmental organizations are all interested in tacking the status of these projects, but maintaining current information has proven to be difficult and time consuming. During 2000, SolarPACES members successfully implemented a project database that allows public access to up-to-date information on projects. The database is currently tracking the status of thirteen active commercial CSP projects around the globe.

Technology Roadmapping

SunLab hosted a second road-mapping workshop with U.S. dish industry and is currently developing a draft dish roadmap document based on the results from the workshop. Distributed Utility Associates facilitated the meeting and is working with SunLab to generate the dish roadmap. SunLab is also working with Bechtel/Nexant to develop a roadmap for molten-salt tower technology.

STEPS - Expert System for Solar Thermal Power Stations

STEPS is an expert system being developed for solar power plant site assessment. A STEPS analysis was performed for Morocco, including a very high-resolution atlas and site-specific time series of direct normal irradiation based on hourly values. In addition, site qualification with respect to land cover, land use, slope, etc. was performed revealing suitable sites for solar power plant erection with a 1x1 km resolution. STEPS material is available at http://www.dlr.de/steps.

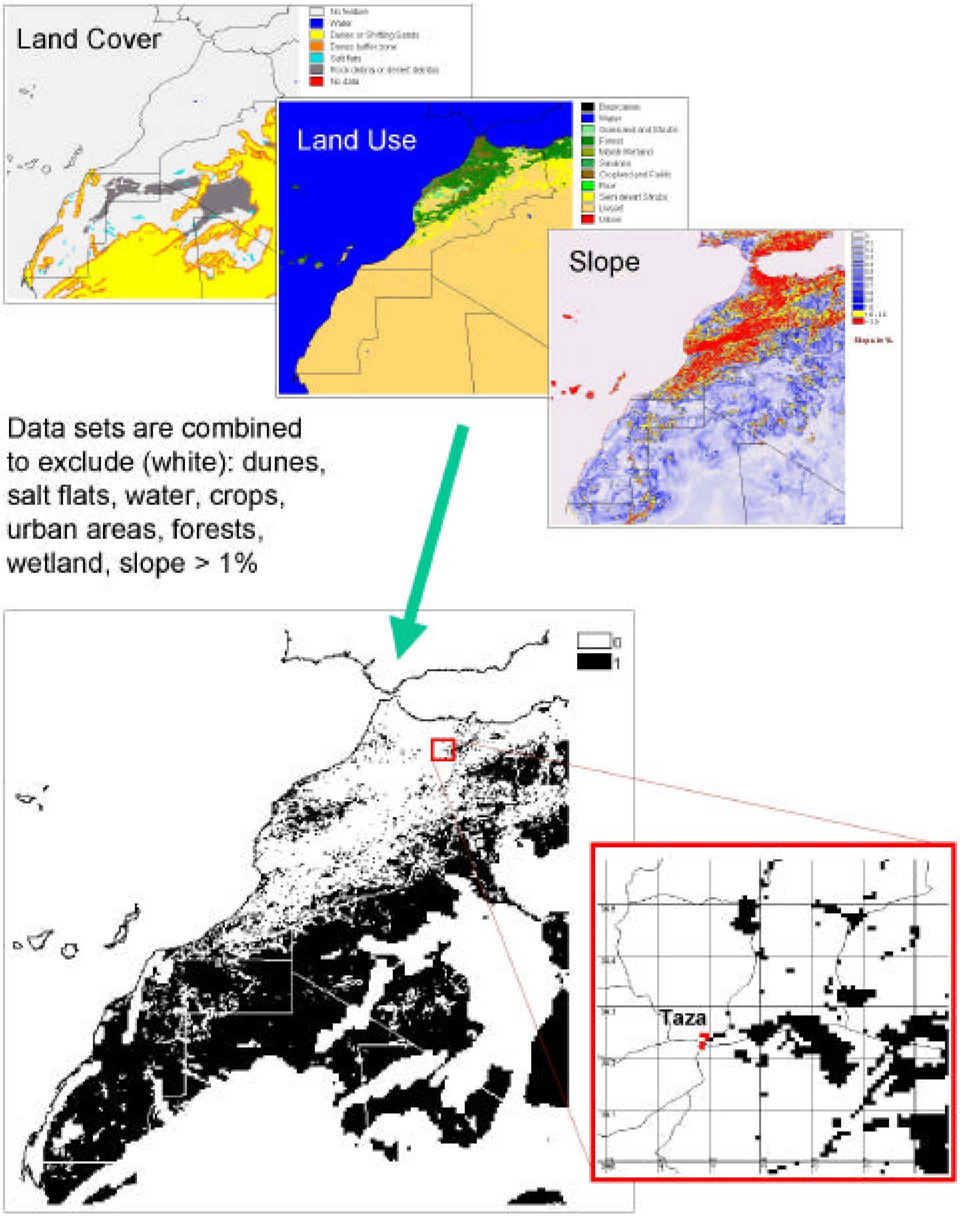


Fig. 3.2 STEPS of site qualification for solar power plants in North-Western Africa

RENIPplan

The objective of the RENIPplan is the development of a user-friendly and fast software tool for a technical and economic simulation of renewable power projects. The official EC project ended at the end of 2000, and a first demo-version of the software will be available in January 2001. This version will allow the simulation of the following renewable technologies: parabolic trough plants, dish/Stirling systems, wind parks and grid-connected photovoltaic systems. Further developments depend on additional funding.

3.7 Outlook 2001-2005

The next few years promise to be very exciting for Task I. With trough, power tower, and dish/Stirling technologies all approaching readiness for the market, a number of commercialization opportunities are beginning to appear. Power towers and trough plants are being planned under the premium payments for solar energy in Spain, and numerous potential GEF and other projects in developing countries throughout the world's sunbelt are being pursued by an active industry. Opportunities for green energy production in countries such as Australia and the United States are also expanding.

Because these projects will be demonstrating relatively new technology, demonstrations and other systems-level testing to prove performance and validate cost projections will be required in support of the commercialization activities. While the commercial projects will be competitively pursued by our industry partners, there are many activities appropriate for collaboration by Task I participants that will support all our efforts and move the technology as a whole forward. Not the least important of these will be addressing the non-technical barriers and market opportunities described above.

Others include cooperative support of the GEF project participants and sponsors, developers, and activities in other countries where CSP opportunities exist; joint testing of advanced systems hardware; and joint development of advanced systems analysis tools.

Success in these efforts will help us achieve the IEA/SolarPACES vision of concentrating solar power technologies making a significant contribution to the delivery of clean, sustainable energy services in the world's sunbelt by 2010.

3.8 Meetings, Reports, Publications

3.8.1 Meetings

Two Task I meetings were held during 2000, one at the University of Sydney, Sydney, Australia on March 15, and one at the NREA Wind Test Facility in Hurghada, Egypt on September 23.

3.8.2 SolarPACES Reports

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[3.02] IEA/SolarPACES Task I: Electric Power Systems, *Task Meeting Summary for Sydney, Australia (3/2000)*, C. E. Tyner, 4/2000.

[3.03] IEA/SolarPACES Task I: Electric Power Systems and Task III: Solar Technology and Applications, *Task Meeting Summaries for Hurghada, Egypt (9/2000),* C. E. Tyner and R. Pitz-Paal, 2/2001.

[3.04] Price, H and Kearney, D., Parabolic Trough Technology Roadmap: A Pathway for Sustained Commercial Development and Deployment of Parabolic Trough Technology, January, 1999 (available at http://www.eren.doe.gov/sunlab/Documents.htm).

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3.8.3 Related Reports

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[3.11] Garg, S., Mathania Integrated Combined Cycle Project (Status Note on the 140 MW First ISCC Project), in *Proceedings of the 10th SolarPACES International Symposium on Solar Thermal Concentrating Technologies*, Sydney, Australia, Mar 8-10, 2000.

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Part 4: Status Report Task II: Solar Chemistry

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4 Task II: Solar Chemistry

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4.1 Nature of Work & Objectives

The Solar Chemistry Annex encompasses activities that deal with solar-driven thermochemical and photochemical processes for:

?? the production of energy carriers
?? the processing of chemical commodities
?? the detoxification and recycling of waste materials.

Solar energy can be converted into chemical fuels which can be stored long-term and transported long distances. Solar energy can also assist in the processing of energy-intensive and high-temperature materials, for treating polluted air, water, and soil, and for recycling waste materials. These are examples of future applications of solar chemistry for addressing the energy and environmental problems facing the world.

The Solar Chemistry Annex aims at coordinating international efforts towards research, development and demonstration of solar chemical technologies through cost, task and information-sharing activities. This goal is being achieved by making use of an efficient network, through the National Coordinators, for the rapid exchange of technical and scientific information.

On February 3-4, 2000, solar chemists met in St. Avold, France, for the "Journées Chimie, Soleil, Energie, Environnement". The proceedings of this event, organized by the Laboratoire de Chimie Industrielle and the CNRS-Laboratoire des Sciences du Génie Chimique, France, were published in a special issue of «Entropie». The Solar Chemistry Annex's Annual Meeting (held in Sydney, March 23, 2000) provided a forum for presenting and discussing the current projects.

4.2 Status of Technology

Systematic development of three solar concentrating optical configurations, trough, tower, and dish, has led to the ability to harness concentrated solar energy efficiently, producing fuels and chemicals for the power, transportation and chemical sectors of the world energy economy. Non-concentrating solar technologies may also be applied advantageously to photochemistry. The subjects being investigated are classified according to their Objectives - nto three domains (sub-tasks):

Task II.1. SOLAR PRODUCTION OF CHEMICAL ENERGY CARRIERS: Solar reforming of natural gas; solar reduction of metal oxides; solar conversion of carbonaceous materials; solar cracking of hydrocarbons; solar chemical heat pipes.

Task 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.

Task 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.

The most important achievements in 2000 are summarized below, with up-to-date information about project participation, objectives, status, and relevant publications.

4.2.1 Solar Production of Energy Carriers

SOLASYS - Solar Upgrading of Fossil Fuels

Participants - DLR (Germany), WIS, ORMAT (Israel), ECN, STORK (Netherlands)

Contact - R. Buck, reiner.buck@dlr.de, M. Epstein, jhlang@wisemail.weizmann.ac.il

Funding - EC funded project, cost shared.

Duration - 3 years.

Objectives - (1) Demonstrate the process of steam reforming of methane with the aid of solar energy to produce hydrogen-rich synthesis gas as a gas turbine fuel. (2) Demonstrate solar reformer interfacing of gas turbine and electricity generation, including grid connection. (3) Explore the possibility of solar reformer interface with fuel cells.

Achievements in 2000 - Design of the solar receiver-reactor was completed. The components were ordered and the receiver assembled. The self-supporting absorber insert (see **Fig. 4.1**) was mounted in the internally-insulated receiver vessel. A jet pump installed in the receiver outlet enables recirculation of the hot syngas from the outlet back to the receiver inlet. Receiver assembly was completed in December and the unit was shipped to Israel for installation at the WIS solar test facility.

Outlook - Receiver installation is planned for February, 2001. After initial N_2 testing of the receiver, syngas production will begin with the gas turbine producing electricity.

Fig. 4.1 Catalytic Absorber insert before installation in the receiver

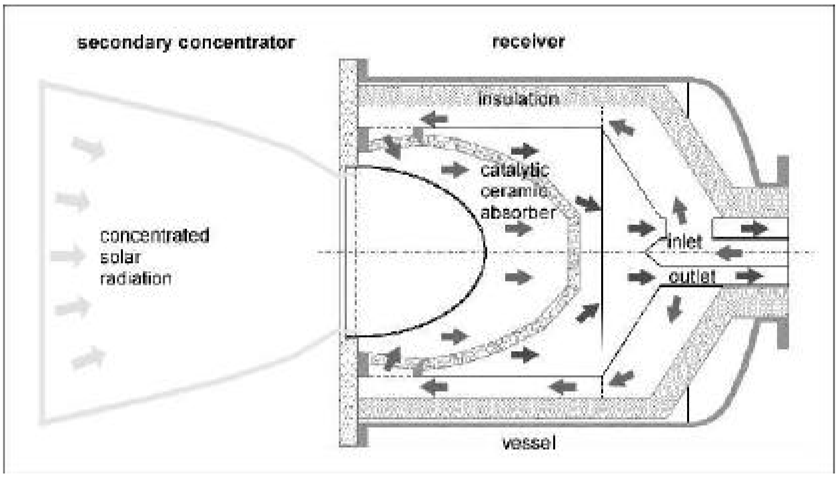

Fig. 4.2 Schematic drawing of the receiver-reactor

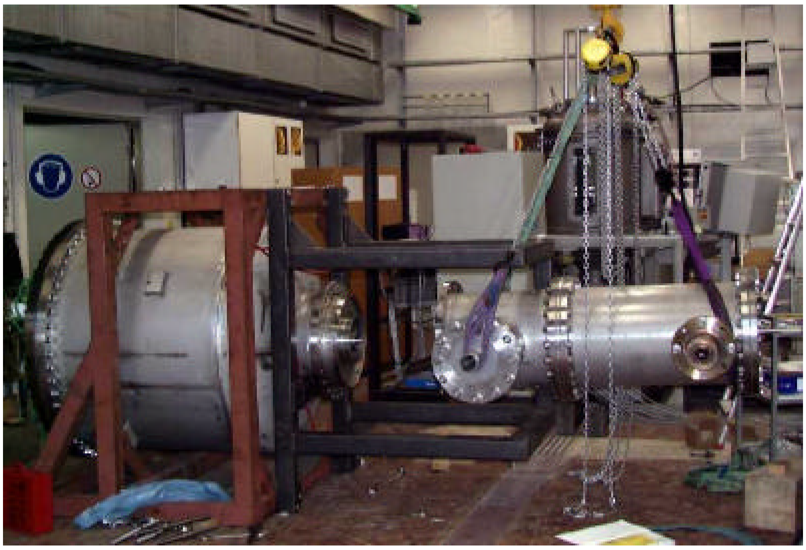

Fig. 4.3 Receiver-Reactor (left) and jet pump (right)

Solar Thermal – Fossil Energy Hybrid Power Generation

Participants - CSIRO

Contact - J. Edwards, jim.edwards@syd.dcet.csirp.au

Funding - CSIRO (AUD 7.5 million)

Duration - 3 years.

Objectives - "Proof-of-concept" demonstration of a solar thermal-fossil energy hybrid concept, applicable to both centralized and distributed power systems, for generating electricity at high thermal efficiency and with potential for greatly reduced CO_2 emissions, featuring: (i) Decarbonization of the fossil energy, using solar thermal energy, to generate a fuel-gas containing hydrogen (H_2) and CO_2. (ii) Recovery of CO_2 from the fuel-gas in a concentrated form, the necessary first step in any subsequent CO_2 disposal/utilization scheme. (iii) Utilization of hydrogen in emerging advanced electricity generation systems such as fuel cells and micro-turbines.

Achievements in 2000 - The demonstration facility is located at Lucas Heights, south of Sydney. The solar-methane reformer has been successfully commissioned with temperatures in the reformer up to 750°C achieved. Under these conditions the chemical reactor has demonstrated good thermal response characteristics with essentially equilibrium methane conversion and product gas composition being obtained. Further work is in progress to refine and optimize the dish tracking/control systems and the heat transfer characteristics of the receiver/reformer. The CO_2-recovery unit has been constructed and commissioning commenced. All vessels for the chemical-absorption CO_2-separation

Fig. 4.4 Solar reactor for CH_4-reforming being tested at CSIRO, Sydney

unit have been constructed and installation will occur in early 2001. Delays have been incurred with the delivery of the 10-kW_e proton exchange membrane fuel-cell system and delivery to the facility is now expected to be in January, 2001. Laboratory-scale fuel-cell support studies in a fully instrumented fuel-cell test station have provided key data on fuel quality and fuel-cell operational issues crucial to the operation of the larger fuel cell in the demonstration facility. A Business Plan covering all major applications of the technology in Australia has been prepared and industrial sponsors for technology commercialization are being sought.

Duration - Three years ending July, 2001.

Publication - Reference [4.01].

Solar Chemical Heat Pipe Using Ammonia

Participants - ANU (Australia); Neu-Technikum Buchs (Switzerland).

Contact - A. Luzzi, luzzi@faceng.anu.edu.au

Funding - US$85,000, Australian Cooperative Research Centre for Renewable Energy (ACRE), Swiss Federal Office of Energy (BFE), German Academic Exchange Service (DAAD), Neu-Technikum Buchs.

Objectives - (i) Demonstrate closed-loop solar operation of a 15-kW_{chem} thermochemical energy storage system based on ammonia dissociation/re-synthesis. (ii) Investigate the performance of key components (with emphasis on reactors) of the ammonia-based thermochemical energy storage system. (iii) Assess scale-up of solar ammonia dissociation to pre-commercial demonstration using ANU's 'big-dish' technology (300 kW_{chem}).

Fig. 4.5 Solar reactor for ammonia dissociation being tested at ANU

Achievements in 2000 - Semi-automated operation of a thermochemical closed-loop ammonia system, featuring a multi-tube solar ammonia dissociation reactor in a cavity receiver and a tube-bundle ammonia-synthesis heat-recovery reactor as the key elements, operated at pressures ranging from 10–20 MPa. Peak solar reactor tube surface temperatures during steady-state operation have been varied between 593°C and 753°C. Heat recovery from the ammonia synthesis reaction was used for the production of hot air, typically between 450° and 500°C. Typical results: Direct beam irradiation, 910 (±25) W/m^2; Intercepted solar radiation at the focal plane, 13.6 (±0.4) kW_{rad}; gross enthalpy converted in reactants at receiver, 39% (±3%); energy losses of water-cooled radiation shield, 38% (±3%); combined reradiation, convection and conduction losses in cavity, 23% (±2%); thermal losses of heat exchanger, 4% (±1%); net solar-to-chemical energy stored by entire system, 35% (±2%). Extensive modeling (TRANSYS) identified operating strategies for maximizing thermal power and exergy output. These models were validated and preliminary system performance results were achieved using real weather data.

Publications - References [4.02]-[4.04].

The Solar Production of Zinc by Thermal Dissociation of ZnO

Participants - PSI (Switzerland), ETH – Institute of Energy Technology (Switzerland), CNRS-LSGC-Laboratoire des Sciences du Génie Chimique (France).

Contact - R. Palumbo: Robert.Palumbo@psi.ch,
J. Lede: Jacques.Lede@ensic.inpl-nancy.fr, I. Alxneit: ivo.alxneit@psi.ch;

Funding - BFE-Swiss Federal Office of Energy (Switzerland); CNRS-ECODEV-LSGC (France).

Background - The goal of the project is to develop the science and technology required to efficiently store sunlight as a fuel in the form of Zn that can be used, for example, to drive a fuel cell. Concentrated solar energy is used to decompose ZnO into its elements and a rapid cooling process is being investigated as the means for separating the Zn from the oxygen. The research emphasizes the kinetics of the condensation of the zinc vapor and its reoxidation (green and red arrows in **Fig. 4.6**) as well as the development of a reactor for the decomposition and product separation steps.

Achievements in 2000 – A new rate expression of the solar thermal decomposition of ZnO was established based on experiments in the PSI solar furnace and the LSGC solar simulator. Sev-

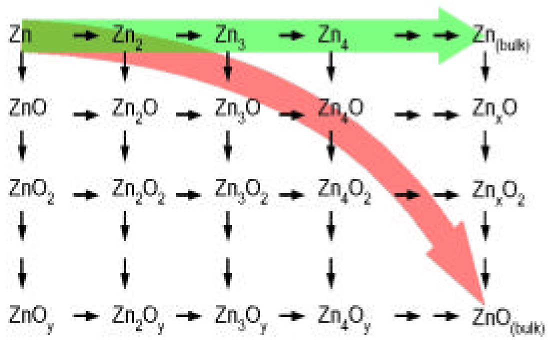

Fig. 4.6 Hypothetical reactions and intermediates involved in the nucleation (green arrow) and reoxidation (red arrow) of zinc vapor.

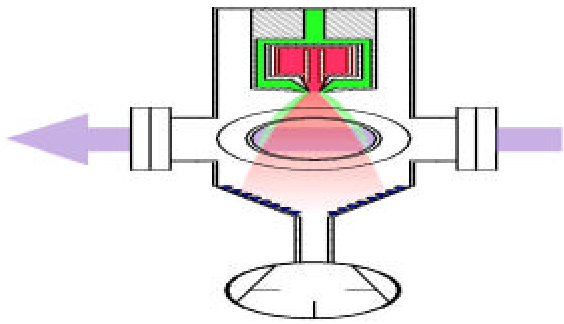

Fig. 4.7 Overview of the experiment being implemented at PSI to study the reoxidation kinetics of zinc vapor.

Several quenching concepts were tested. It was shown that zinc can be recovered by condensation on the cold walls of the quench reactor as well as in the form of aerosol particles formed in the gas phase. An apparatus was designed for studying the kinetics of the reoxidation reaction. The set-up employs a confined coaxial jet in which zinc vapor is picked up in the center of a stream of hot oxygen. The concentration of zinc atoms in the jet will be probed by LIF using a laser sheet to excite zinc atoms and an ICCD camera to detect them.

Outlook - During the coming year, the new rate expression will be used to model the decomposition process for the ROCA reactor. The model will be used to predict reactor temperatures, Zn production rates, and the exergy efficiency. A second important theme for the coming year is to learn how best to obtain high yields of Zn after rapidly cooling the decomposition products.

Publications - References [4.05]-[4.06].

The SynMet-Process – Solar Co-Production of Zinc and Syngas

Participants - ETH/PSI (Switzerland).

Contact - A. Steinfeld: aldo.steinfeld@pre.iet.mavt.ethz.ch; C. Wieckert: christian.wieckert@psi.ch

Funding - BFE-Swiss Federal Office of Energy; Baugarten Foundation.

Background - Zinc and syngas are valuable commodities and attractive energy vectors. However, current industrial zinc and syngas production methods are characterized by their high energy consumption and concomitant environmental pollution. These emissions can be substantially reduced by combining production of both and replacing fossil fuels with concentrated solar energy as the source of high-temperature process heat.

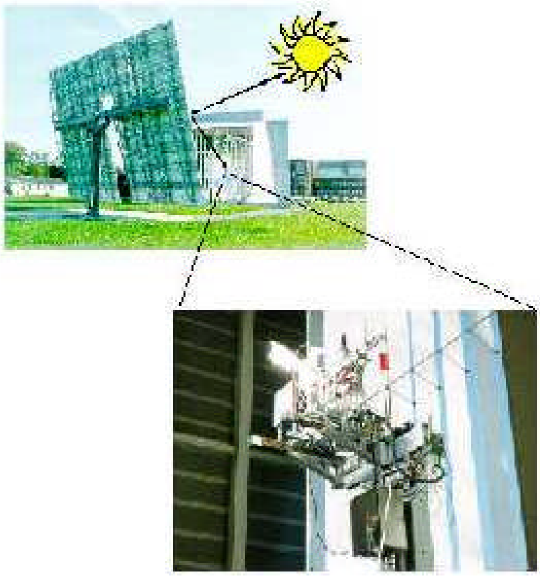

Fig.4.8 SynMet reactor being tested at PSI's solar furnace

Objectives - Development of solar chemical reactor engineering for the co-production of zinc and syngas by combined ZnO-reduction and CH_4-reforming (SynMet process). Investigation of the cyclic electricity generation process.

Achievements in 2000 — The SynMet process was carried out using an improved vortex-flow chemical reactor **(Fig. 4.8).** The reactor operating temperature ranged between 1000-1480 K with solar power input of 2.3-4.6 kW and mean solar flux intensities of 800-1600 kW/m^2. Chemical conversion ranged between 83 and 100%. The thermal efficiency was in the range of 11-28%. A process concept that operates with much less methane (or C) at below 1400ºC was evaluated. Solar fractions of the energy input above 65% are possible. This operating mode is specifically relevant for combination with Zinc-air batteries in order to produce storable "solar electricity".

Publications - References [4.07]-[4.09].

Solar Production of Zinc from Zinc Silicate Ore

Participant - University of Augsburg (Germany)

Contact - A. Weidenkaff, anke.weidenkaff@physik.uni-augsburg.de

Funding - TMR-LFS Program of CNRS-IMP, Odeillo and BFE, Switzerland

Background - The most important zinc ores used for zinc production in the extractive metallurgical industry are smithsonite, $ZnCO_3$, sphalerite, ZnS and the zinc silicates willemite, Zn_2SiO_4

and hemimorphite, $Zn_2SiO_4 \cdot H_2O$. The conventional fossil-fuel-based production of zinc leads to vast emissions of greenhouse gases and pollutants. Alternatively, concentrated solar radiation can be used as a clean, regenerative energy source.

Objectives - Experimental investigation of the thermal reduction of Zn_2SiO_4 using concentrated solar energy.

Achievements in 2000: The experimental set-up in the Odeillo solar furnace is presented in **Fig. 4.9**. The willemite samples investigated in this study came mainly from the Beltana Mine in Puttapu, in South Australia. Condensable products (Zn and ZnO) are deposited on targets with defined surface temperatures, placed on the condenser surface. Quantitative analysis by means of X-ray diffraction and scanning electron microscopy of the condensed product collected from the surface of the condenser confirm that the products of the solar thermal reduction of willemite typically consist of 80% zinc and 20% zinc oxide.

Publications - References [4.10]-[4.12].

Solar Production of Zinc by the reduction of ZnO in the presence of biomass.

Participants - -LSGC-CNRS-ENSIC-Laboratoire des Sciences du Génie Chimique (France)

Contact - J. Lédé, Jacques.Lede@ensic.inpl-nancy.fr

Funding - ADEME, CNRS-ECODEV, LSGC

Objectives - Concentrated radiation can be used for driving thermochemical processes, such as the dissociation of ZnO or the flash pyrolysis of biomass. The purpose of the project is to study each of these processes, showing the feasibility of the dissocia-

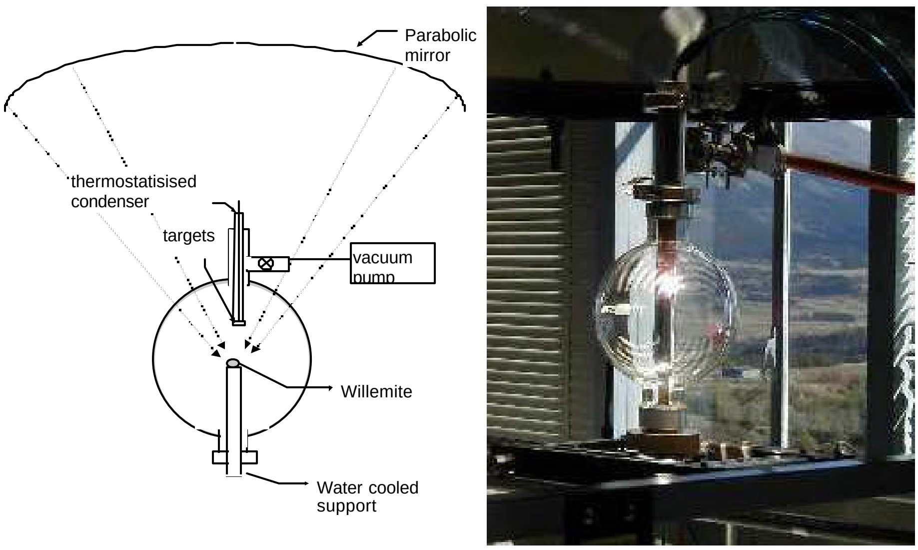

Fig. 4.9 Schematic drawing and photograph of the experimental setup for the thermochemical reduction of willemite in Odeillo, France

tion of ZnO in the presence of biomass. The experiments are performed in the LSGC solar simulator (image furnace).

Achievements in 2000 - Experiments with mixed ZnO and cellulose-powder pellets have been performed under brief, controlled concentrated radiation. The very fast (less than 1 second) reaction occurs at temperatures over 1000 K lower than those observed with pure ZnO. The reaction involves reduction processes with the liquid formed during the thermal depolymerization of the cellulose. The usual carboreduction does not seem to be significant under these severe conditions. Experiments with an electric furnace confirm the very low reaction temperature.

Publication - Reference [4.14-4.17].

Solar thermal reduction of mixed iron oxides

Participant - PSI (Switzerland).

Contact - M. Sturzenegger: m.sturzenegger@psi.ch

Funding - BFE-Swiss Federal Office of Energy.

Background - TREMPER is an experimental reactor for high temperature reactivity studies under concentrated solar radiation. It was employed to evaluate metal oxides for the production of solar fuels. Previous experiments yielded valuable information about equilibrium compositions. However, quantitative reaction kinetics could not be derived from post mortem sample analysis because temporal resolution was insufficient, particularly for the early stage of the experiment.

Objectives - Determine the residence time distribution and employ it to calculate the rate of oxygen release in the sample from on-line gas-phase analysis.

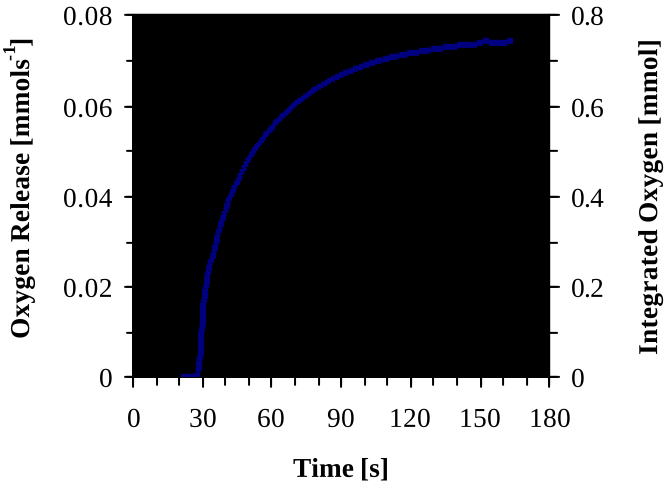

Fig.4.10 Rate of oxygen release and integrated amount of oxygen (blue line) during Mn_3O_4 reduction in the solar furnace. Compositions of the melt calculated from on-line gas phase analysis and post mortem analysis of the solid by thermogravimetry agree well.

Achievements in 2000 - To determine the residence time distribution, a stepped input of oxygen was applied as a tracer. The Oxygen concentration at the reactor outlet was measured by mass spectrometry. The cumulative distribution function *F(t)* was calculated from measured concentrations. The results of experiments with tracer flow rates over 5 $mlmin^{-1}$ are well represented by linear fit on a logarithmic plot. This indicates that TREMPER, even at room temperature, behaves as an ideal stirred tank. Thus the local gas evolution rate can be derived from gas-phase analysis at the outlet of the reactor. Although TREMPER was employed for studying the decomposition of metal oxides, its further use for high-temperature reactivity studies in material science can easily be envisioned.

Publication - Reference [4.18].

Solar Upgrade and Decarbonization of Fossil Fuels - Thermal Dissociation of Methane

Participants - NREL, U. of Colorado at Boulder, BP Amoco (USA); WIS-Weizmann Institute of Science (Israel); ETH-Institute of Energy Technology, PSI (Switzerland).

Contact - A. Lewandowski: allan.lewandowski@nrel.gov;
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Funding - DOE (USA), ETH (CH), WIS (IL)

Background - Two methods for the decarbonization of fossil fuels, i.e., the removal of carbon from fossil fuels prior to their combustion, are shown schematically in **Fig. 4.11**, (1) the solar thermal decomposition of fossil fuels and (2) the steam-reforming/gasification of fossil fuels. These reactions proceed endothermically in the 800-1500 K range. The use of solar energy for process heat has the following advantages: (1) the polluting emissions are avoided; (2) gaseous products are not contaminated; and (3) the calorific value of the fuel is upgraded by adding solar energy in an amount equal to the enthalpy of the reaction. Many fossil fuel reserves exist in regions with high solar insolation. Thermochemical processes that mix fossil fuels with solar energy are important intermediate solutions towards a sustainable energy-supply system.

Objectives - 1) Thermodynamic analysis; 2) Solar reactor design, fabrication, and testing; 3) Process and reactor modeling and validation; 4) economic assessment.

Achievements in 2000 - At NREL, the solar thermal dissociation of methane was carried out using a solar-coupled aerosol reactor. Carbon black was used as a radiation-absorbing target to initiate the pyrolytic reaction. Once started, the carbon produced continued to serve as the radiation absorbing target and no further addition of carbon was required. Preliminary experiments showed high conversion of methane to hydrogen in a reactor not optimized for this process. Economics are highly encouraging. The cost of producing hydrogen is attractive, even without crediting the sale of carbon black. Carbon black can be produced at

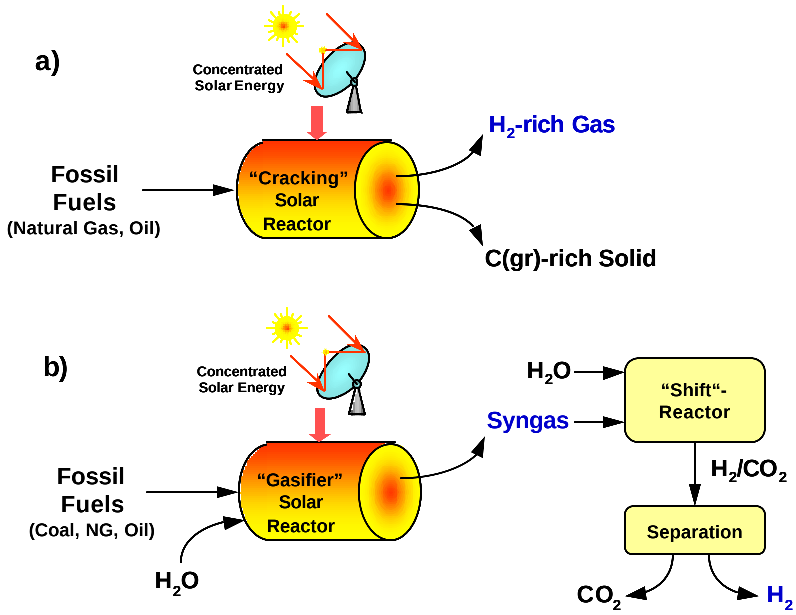


Fig. 4.11 Simplified process flow diagram for the solar thermal decarbonization of foss fuels. The two methods considered are (a) solar thermal decomposition and (b) solar thermal steam-reforming/gasification

less than the current market price without credit for the hydrogen.

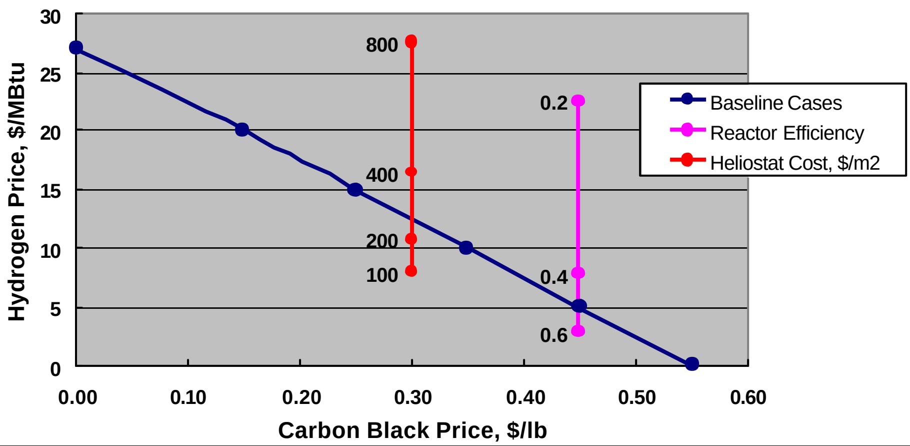
At ETH/PSI/WIS: 2nd law analysis was performed for the process. Four technically viable routes were examined for extracting power from the chemical products of the solar decomposition of CH_4: 1) carbon is sequestered and only H_2 is used in a fuel cell; 2) carbon is used to fuel a conventional Rankine cycle and H_2 is used in a fuel cell; 3) carbon is steam-gasified to syngas in a solar gasification process and the syngas further processed to H_2, which, together with H_2 from the CH_4-decomposition reaction, is used in a fuel cell; and 4) carbon serves as a ZnO reducing agent in a solar carbothermic process producing Zn and CO that are further converted by water-splitting and water-shifting reactions to H_2 for use in a fuel cell.

Publications - References [4.19]-[4.20].

4.2.2 Solar Processing of Chemical Commodities

Large Scale Production of Fullerenes and Nanotubes by Solar Energy

Participants - CNRS-IMP, Université. Montpellier II (France) Tony Guillard, J.F. Robert, B. Rivoire, J Giral



Cash flow assumptions	Base case assumptions
ɜtime: 21 yrs nstruction: 1 yr ɔrking capital: 10% of total capital % depreciation/yr ‹ rate: 28% :: 15%	H_2 production: ~1M scf/day Heliostat cost: $250/m^2 H_2 recycled: 20% Reactor temp: 1600°C Residence time: 1 sec Reactor thermal efficiency: 0.5 Solar capacity factor: 0.28 CH_4 cost: $3/1000scf

Cash flow assumptions *Base case assumptions*

Fig. 4.12 Initial economic results

Contact - G. Flamant, flamant@imp.cnrs.fr, D. Laplaze, laplaze@gdpc.univ-montp2.fr

Funding - CNRS-ECODEV, region Languedoc-Roussillon.

Background - Conventional methods for the synthesis of fullerenes and carbon nanotubes such as laser or electric-arc ablation have failed when the process is scaled up. Our ultimate goal is to scale a solar process up from 2 to 500 kW. The method for this scale-up has been shown to be valid because process performance variables at 50 kW could be predicted from preliminary 2-kW experiments. The key parameters characterizing this process are the carbon-soot mass flow rate and the desired product yield. The carbon-soot production rate is a function of the target temperature that can be predicted from a heat transfer model of the larger system. The yield is a function of specific reactor variables such as patterns of fluid flow, residence times and reaction chemistry. For fullerenes it depends primarily on the concentration of carbon vapor in the carrier gas, the target temperature and the temperature distribution in the cooling zone. Using these parameters, the process was scaled up to 50 kW and the predicted results compared to measured performance. A 6-cm-diameter graphite target was vaporized in an argon atmosphere at a reduced pressure of 120–240 hPa with a solar flux density of 600-900 W/cm^2 (reactor mounted at the focus of the 1000 kW CNRS-Solar Furnace, see **Fig. 4.13**). Vaporization rates of 20 g/h were measured with a fullerene production rate equal to or greater than 1 g/h, i.e. the expected results. Other IMP activities related to solar chemistry concern the development of zirconia-based nanomaterials (contact: Claude Monty, -mail: monty@imp-cnrs.fr)

Publications - References [4.21]-[4.22].

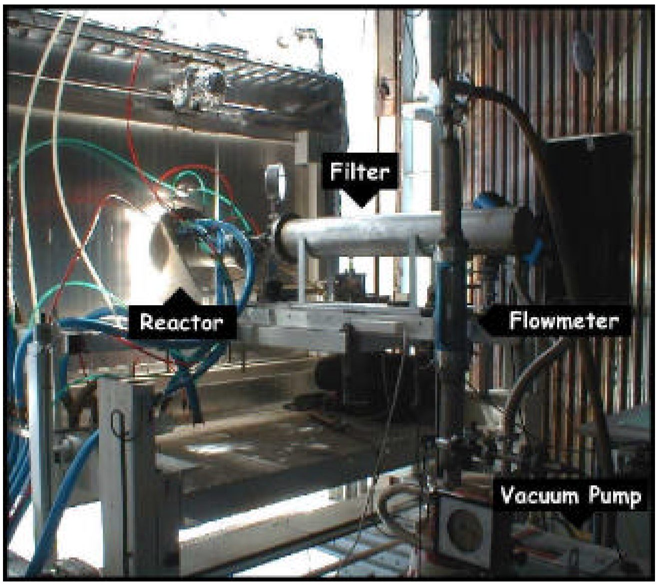


Fig. 4.13 The Experimental System at the Focus of the 1000 kW Odeillo Solar Furnace.

Solar Production of Aluminum: carbothermal reduction route

Participant - Colorado School of Mines (USA).

Contact - Jean Murray murray@imp.cnrs.fr

Funding - National Science Foundation

Background - Aluminum can be reduced from alumina using carbon as the reductant at temperatures in the 2100-2400°C range. Since these temperatures are impossible to produce using combustion energy, commercial research is centered on making an electric furnace feasible for the process. But two commercially-researched processes should be feasible with highly-concentrated solar energy as the process heat source. The first, at temperatures of about 2100°C, uses a mixture of silica, alumina and carbon, and results in an aluminum-silicon alloy which can be purified after its production. Another process with alumina and carbon at temperatures in excess of 2200°C, results in an aluminum-aluminum carbide mixture of varying compositions.

Objective - The objective is to demonstrate that highly-concentrated solar energy is a feasible source of process heat for the carbothermal reduction of alumina and alumina/silica mixtures for ultimate aluminum production.

Achievement in 2000 - The project, which was carried out as part of an NSF-funded Visiting Professorship grant, was not well funded for the research portion of the work. In addition, administrative delays prevented experimental work from starting for a full year. In the short time remaining, we were unable to reach

the high temperatures required for the process. Similar work is continuing under an NSF research grant, with the collaboration of Alcoa Technical Center personnel.

Publication - Reference [4.23].

Solar Thermal Recycling of Secondary Aluminum

Participants - DLR, University Dortmund

Contact - M. Roeb, martin.roeb@dlr.de; M. Sonnenschein, sonnenschein@ct.uni-dortmund.de

Funding - DLR, AG Solar, Ministry of Schools, Education, Science and Research of the Federal State of North Rhine-Westphalia (Germany)

Background - The recycling of aluminum scrap is a process of increasing industrial interest. Along side growing global consumption of aluminum, the increase in recycled aluminum is disproportionate. Economic studies have shown that solar thermal recycling of aluminum scrap has a chance to become a feasible alternative to conventional processes in the mid-term. The design of the reactor system is crucial to the transfer of this melting process into a solar operation.

Objectives - Development of process concepts for the solar thermal recycling of secondary raw materials including feasibility and economic studies as well as the experimental verification of practicability.

Achievements 2000 - Two different types of mini-plant reactors have been developed, modified and used for solar remelting of aluminum: a solar-heated rotary kiln (**Fig. 4.14**) and a closed reactor system (**Fig. 4.15**). The rotary kiln has been redesigned and supplemented with exhaust gas cleaning. Convective heat losses of the closed reactor are greatly reduced compared to an alternative reactor with an open receiver area. The functionality and performance of both reactors have been tested in several ex-

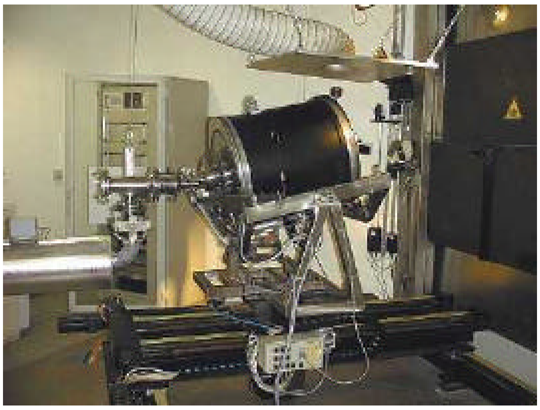


Fig. 4.14 DLR's rotary kiln receiver-reactor

Fig. 4.15 Univ. Dortmund's closed re

periments at the DLR solar furnace. A tri-conical final concentrator as a simple approximation of the CPC, combined with a solar cavity receiver, was developed in Dortmund in order to increase the overall efficiency. Simulation models using the FLUENT code and other mathematical algorithms have been developed to simulate the dynamic behavior of both reactors, and for process design and scale-up considerations.

Solar Production of Lime

Participants - PSI/ETH (Switzerland), QualiCal AG, Lugano (Switzerland)

Contact - A. Meier, anton.meier@psi.ch

Funding - Swiss Federal Energy Office of Energy (BFE)

Duration- September 1, 2000-September 31, 2003

Background - The High Temperature Solar Technology Laboratory at PSI, the Institute of Energy Technology at ETH, and their industrial partner, QualiCal, are jointly exploring the potential of an Industrial Solar Lime Plant. PSI and ETH bring expertise in developing the science and technology of high-temperature solar chemical processes. QualiCal contributes its expertise in developing the technology of the lime industry.

Objectives - The decomposition of limestone (mainly $CaCO_3$) is the main endothermic step in the production of lime (CaO) and cement at 1600 K. The purpose of the project is to substitute concentrated solar energy for carbonaceous fuels as the heat source. The specific purpose of the project is to develop a cost-effective solar reactor technology for a 0.5-MW solar calcination plant.

Achievements in 2000 - (1) Limestone ($CaCO_3$) samples characterized; (2) Calcination tests performed by TG, electric furnace, and the ETH High-Flux Solar Simulator (www.pre.ethz.ch); (3) Solar reactor concept selected.

Solar photochemical processes for bulk/fine chemicals: experimental test and systematic evaluation

Participants - DLR-Köln, Max-Planck-Institut für Strahlenchemie, Univeristät Bielefeld, RWTH Aachen (Germany)

Contact - J. Ortner, juergen.ortner@dlr.de

Funding - DLR, AG Solar-Ministry of Schools, Education, Science and Research of the Federal State of North Rhine-Westphalia (Germany).

Background - During the last decade several solar photochemical methods have been developed and examined worldwide which allow bulk or fine chemicals having quantum yields of ? ?1

to be produced. The focus of such research was the technical feasibility of the approach. Due to the high sales prices of this type of chemicals justifying the use of more expensive solar equipment, up to now the economic efficiency of the production of fine chemicals could only be guessed at. But in a first study on bulk chemicals, the authors concluded the solar alternatives examined are competitive with the corresponding industrial lamp-driven processes.

Objectives - In the field of bulk chemical production, the photonitrozation of cyclohexane is within the scope of interest. A second objective is to compare the use of flat bed reactors with concentrating reactors for the solar fabrication of fine chemicals. Photoacylation and photooxidation reactions were selected as examples. A third objective is to study the long-term stability of holographic concentrators. A study has been carried out comparing investment and production costs of a solar plant for the production of rose oxide with an industrial lamp-driven one and estimate the corresponding costs of a conventional plant producing ?-caprolactam.

Achievements in 2000 - Concept design of an optimized solar process for photonitrozation has been performed and a new process procedure was proven. New flat bed reactors for photochemical synthesis were tested and compared with the PROPHIS plant. The solar process for the production of rose oxide was found to be competitive with the conventional lamp-driven process, with similar investment (approx. US$5 million)€ and production (approx. US$2 million)€ costs for a plant capacity of 100 t/yr.. Compared to conventional caprolactam production, the investment in the solar option is higher, but production costs are 50% lower based on a yearly capacity of 100 000 t. Therefore it makes sense to search for solar photochemical alternatives to other industrial processes.

Publications - References [4.24]-[4.25].

4.2.3 Solar Detoxification and Recycling of Waste Materials

Solar detoxification technology in the treatment of industrial non-biodegradable persistent chlorinated water contaminants (SOLARDETOX).

Participants - CIEMAT-PSA(Coordinator), Hidrocen, Ecosystem S.A., (Spain), AOSOL Ltd., INETI (Portugal), University of Torino, CESI (Italy), Schott–Rohrglas GmbH, DLR (Germany)

Contact - J. Blanco, julian.blanco@psa.es

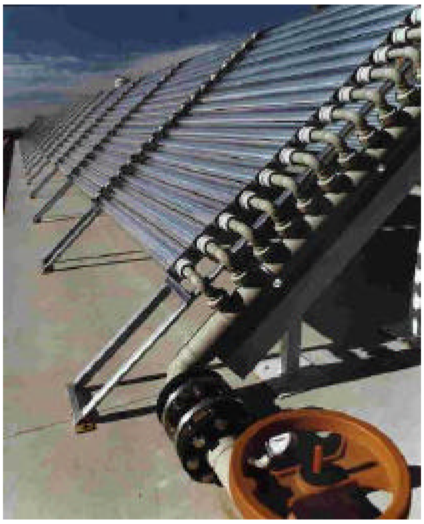
Funding - Total project budget is 1,871,551 EURO, 53% by the EC DG Research (BRITE-EURAM III Program).

Duration- June 1997 - May 2000.

Background - The purposes of the project were to develop a specific CPC-type collector technology for solar detoxification (simple, efficient and low cost) and create an industrial European consortium able to design, construct and install “turnkey” plants. The project was the result of long CIEMAT-PSA experience in solar detoxification system technology development and testing.

Objectives - Scientific and Technological objectives: (1) Assess and define the best working conditions for the catalyst developed compared to the efficiencies of the P25 reference catalyst in the treatment of chlorinated solvent compounds; (2) Assess the degradation mechanisms; (3) Evaluate photonic efficiencies; (4) Determine side-products; (5) Model process kinetics from degradation data; (6) Design a reactor of highly solar-UV-transmissive glass; (7) Design an upgraded solar collector; (8) Upgrade and support the catalyst; (9) Develop highly efficient UV-reflective surfaces; (10) Optimize and standardize system components; (11) Design and erect a full-scale pilot plant; (12) Demonstrate technical and economic feasibility; (13) Assess the destructive capacity. The project formally finished in 2000 with all Objectives - uccessfully achieved.

Achievements in 2000 - A European industrial consortium has been created for the design, manufacture, installation and set-up of turnkey SOLARDETOX? plants for the treatment of hazardous and non-biodegradable water contaminants using solar light. The process is based on the solar photocatalytic mineralization of organic compounds dissolved in water and addresses the treatment of persistent industrial contaminants. This consortium has



6 Views of Hidrocen industrial solar detoxification plant: catalyst separation unit (left) and (right)

performed comprehensive research and development of a state-of-the-art technology, validated by a complete demonstration plant erected in an industrial environment. Initial market analyses show a promising number of possible applications for this remarkable environmental technology that has been validated even where there is not so much sunny weather, such as in west Germany.

These analyses also show that this technology could be fully competitive with conventional wastewater treatment processes. Also during 2000, the design, set-up and testing of the first industrial solar detoxification plant in the world was concluded in Madrid (Spain), (**Fig. 4.16**). The main features of this plant are:

?? 2 parallel rows of 21 31-m long collectors, totaling 100 m^2 of collector aperture area;
?? total circuit volume: 800 L; total plant volume: 2000 L;
?? catalyst configuration: slurry;
?? completely sealed circuit with air injection.

Publications - References [4.26]-[4.31].

Water recovery from olive mill wastewaters after photocatalytic detoxification and disinfection (LAGAR).

Participants - INETI (Portugal), Coordinator, CIEMAT - PSA (Spain), TU Wien (Austria), NAIAS S.A. (Greece), Pereira da Silva Lda. (Portugal)

Contact - S. Malato Rodríguez, sixto.malato@psa.es

Funding - EC DGVI-XII-XIV FAIR PROGRAM. Total project budget: 931,000 EURO (50% financed by EC).

Duration: September 1998 - February, 2001.

Background - Detoxified olive-oil mill wastewater can be used as fertilized irrigation water.

Objectives - The objective is the development of pilot-plant-scale photochemical detoxification for the mineralization of the recalcitrant phenolic contaminants typically found in the soluble organic fraction of the Olive Mill Wastewater (OMW). The detoxification efficiency of 3 different photochemical reactors, using solar irradiation will be compared, in terms of technical and economical aspects. The selected ones will be installed under real working conditions in two industrial factories, one in Portugal and another in Greece. The economics of the treatment systems will be assessed at the end of the project.

Achievements in 2000 - In this part of the project, a Solar Photoreactor (Falling Film Reactor, FFR) designed and erected at the Plataforma Solar de Almería (see SolarPACES Report No. 99) was

Fig. 4.17 Falling Film Reactor at the Plataforma Solar de Almería testing photo-Fenton degradation of olive mill wastewater

tested with different model compounds (phenols) and its efficiency was compared to that of CPCs. The experiments showed that all the chosen phenols are easily degraded even with a rather small amount of iron (chosen in order to obtain more data on the degradation process). The degradation rate is highly dependent on the phenol structure and solubility in water. The FFR was also tested with the photocatalytic system (Photo-Fenton) found to the best of those tested (see SolarPACES Report 99) for the treatment of OMW (**Fig. 4.17**). Its efficiency was compared with that obtained using CPCs. The experiments with the FFR are slower than those with the CPCs, but the overall efficiency is almost the same. The total volume/Illuminated surface ratio has to be minimized for optimizing the treatment times in the FFR.

Publications - References [4.32]-[4.33].

Photocatalytic Disinfection of Air or Water

Participants - NREL, U. of Missouri at Columbia (USA)

Contact - D. Blake, daniel_blake@nrel.gov

Funding - US Dept. Energy Building Energy Technology and International Proliferation Prevention Programs, and Center for Indoor Air Research

Background - This group of projects addresses the application of the photocatalytic chemistry of TiO_2 surfaces to the killing of microbes in air and explores the mechanism of disinfection of water. Ongoing work includes the study of the effect on bacterial and fungal cells and spores.

Objectives - The Objectives - re to 1) understand the range of susceptible microorganisms and the mechanism by which the photocatalytic process kills them, 2) determine the rates at which microorganisms are removed from titanium dioxide surfaces by oxidation, and 3) determine the parameters necessary for the design of solar and lamp-activated devices to apply the phenomenon to the purification of indoor air and drinking water.

Achievements in 2000 - In aqueous suspension, killing of fungal spores represented by *Aspergillus niger* (*A. niger*) was found to be much slower than bacteria such as *Escherichia coli* (*E. coli*). It has also been established that the carbon content of biological molecules such as polysaccharides, proteins, and phospholipids as well as a range of bacteria, bacterial spores, and fungal spores can be quantitatively oxidized to carbon dioxide on TiO_2 surfaces. Bacteria require about a day for total oxidation and fungal spores require about four days. The oxidation is significantly slower and less complete in dry air than at 50% relative humidity. Self-cleaning mesh filters, treated with TiO_2, were fabricated and shown to separate, fix, and destroy the microorganism *E. coli* K12 from an aqueous suspension, and regenerate for further separations. These coated filters could be regenerated simply by irradiating them with a UV-light source. The filters were photocatalytically active for the oxidation of ethanol as well as for the microorganism studied. It oxidized the trapped *E. coli* to CO_2 and water as the final products. *E. coli* separation efficiencies attained were over 90%.

Publication - Reference [4.34].

Solar photocatalytic detoxification of water containing organic pollutants (pesticides and dyes).

Participants - Laboratoire "Photocatalyse, Catalyse et Environnement", IFOS (UMR CNRS 5621), Ecole Centrale de Lyon, (France), Ecole Nationale d'Ingénieurs de Gabès (Tunisie), PSA (Spain), Millennium Inorganic Chemicals, Ahlstrom Paper Group, Domaine Louis Latour

Contact - J. M. Herrmann, jean-marie.herrmann@ec-lyon.fr

Funding - CMCU Franco-tunisien; Millennium

Background - The project concerns the fundamental study of the photocatalytic degradation of pollutants in water and its transfer to solar photoreactors. The reaction pathways, as well as the influence of various basic parameters governing photocatalysis, are determined in the laboratory with artificial light before being adapted to large-scale "helio-photocatalysis".

Objectives - The Objectives - re to develop cheap, efficient solar-driven devices to clean contaminated water for reuse or recy-

cling in semiarid countries. This mainly concerns the elimination of agricultural pesticides and of textile and tannery dyes.

Achievements in 2000 - Various toxic pollutants such as 2,4-D (2,4-dichlorophenoxy-acetic acid, a widely used herbicide), 4-chlorophenol, 2-chlorobenzoic acid, nitrobenzene and malic acid were successfully destroyed. Various dyes were also decolorized and totally mineralized: methylene blue, methyl red, Congo red, and indigo, which is widely used in dyeing cloth, especially denim in Tunisia. In parallel, a new series of Millennium Tiona? -PC industrial photocatalysts were tested and compared to others (Degussa, Hombikat, Tioxide). The same laboratory also carries out research in the characterization of self-cleaning glass, the properties of which arise from a thin TiO_2 coating which is activated when exposed to solar light (contact: pichat@ec-lyon.fr)

Publications - References [4.35]

Solar chemical detoxification of "agricultural" waste waters

Participants - U. of Dortmund, U. of Leipzig, (Germany)

Contact - L. Wimbert wimbert@uni-dortmund.de , T. Ebbinghaus thorsten@analytik.chemie.uni-dortmund.de

Funding - DLR, AG Solar-Ministry of Schools, Education, Science and Research of the Federal State of North Rhine-Westphalia (Germany).

Background - Nitrogen compounds from agriculture and other anthropogenic nitrogen entries, can have a lasting effect on the nutrient balance of natural waters up to eutrophication.

Objectives - Mineralization of pollutants by solar radiation/TiO_2. The work focuses on degradation of amines, pesticides, and antibiotics, development of new TiO_2 catalysts, up-scaling of laboratory experiments, and combination with other processes. Complete degradation of several compounds has been possible in the laboratory, but quantum yields have to be improved.

Achievements in 2000 - The experiments were carried out in the laboratory and in a technical setup using CPC-type reactors. Doped photocatalysts based on TiO_2 were prepared by sol gel methods. The physical (e.g. BET) and photochemical (e.g. FQE) properties for water treatment were tested. Less biodegradable compounds like Primicarb® were mineralized using TiO_2/UV. The degradation intermediates were identified.

Publication - ? Reference [4.36].

Photocatalytic Technologies for selective cleaning and recycling of production waste waters from textile processing - PhoRTex

Participants - DLR, Carl Albani Gardinenfabrik GmbH & Co., EnviroTex GmbH (Germany)

Contact - C. Sattler, christian.sattler@dlr.de

Funding - German Ministry of Education and Science (BMBF)

Background - The textile industry is a main producer of waste water. Such water often contains non-biodegradable organic substances for which standard sewage treatment methods are insufficient. The minimization of the demand for fresh water is a main objective in modern industrial processes. Advanced oxidation technologies, like photocatalysis, are suited in principle to achieving the Objectives - f the treated water can be reused in processes integrated into water recycling.

Objectives - In the project, the photocatalytic water treatment technology will be developed for integration into curtain production. At first, the reaction conditions are determined to determine the optimum treatment of the process water. Then a small-scale bypass plant will be tested under industrial conditions at the curtain company Carl Albani Gardinenfabrik GmbH & Co., Augsburg Germany. The results of these tests will be used to construct a demonstration plant which is integrated into curtain processing to make water recycling possible. The data acquired in the lamp-driven plant will be the basis for transfer of the results to solar applications. Solar treatment of textile waste water would be particularly interesting in the Mediterranean area where the textile industry is an important economic factor.

Achievements in 2000 - The project started in August, 2000. Until now, the curtain production process has been investigated. The most important pollutants have been described and a large amount of laboratory irradiation tests have been carried out to set the parameters for the design of the bypass plant which is to be erected by the end of 2001.

Treatment of Gaseous Emissions by Photocatalysis

Participants - CIEMAT-DER, Madrid, Instituto de Catálisis y Petroleoquímica, ICP-CSIC, Madrid (Spain)

Contact - B. Sánchez (beni@ciemat.es).

Funding - Regional Government of Madrid (CAM) and the Interministerial Commission of Science and Technology (CICYT)

Background - Under the general title of “Treatment of gaseous emissions and photocatalysis” there are three lines of research:

"Optimization of Parabolic Trough Collectors for photocatalytic destruction of VOCs", "Destruction of Polychlorodibenzo-p-dioxins and polychlorinated dibenzofurans" and "Indoor-Air Photocatalytic treatment".

Objectives - The project deals with the design of gas purification units based on solar collectors and/or artificial light and monolithic catalysts with adequate physical-chemical properties and fluid dynamics for industrial application. From the point of view of the catalyst, the aim is the substitution of conventional active carbon beds with a monolithic adsorbent, which appreciably reduces the problems derived from the pressure drop and mechanical resistance generated by the use of conventional fixed beds. From the photonic point of view, the influence of such different parameters as temperature, linear velocity, photonic intensity and others, as well as the capacity for formation of hydroxyl radicals and promotion of redox reactions of solar radiation with TiO_2, to optimize reactors, will be investigated.

Achievements in 2000 - A new flat photoreactor consisting of two parallel Pyrex windows enclosing a rectangular framework holding the photocatalytic monoliths has been erected. One window is orientated toward the sun and the opposite can be covered by an aluminum layer to reflect solar photons or used as a simple Pyrex window permitting the use of UV lamps as a supplementary source of photons if necessary (**Fig. 4.18**).

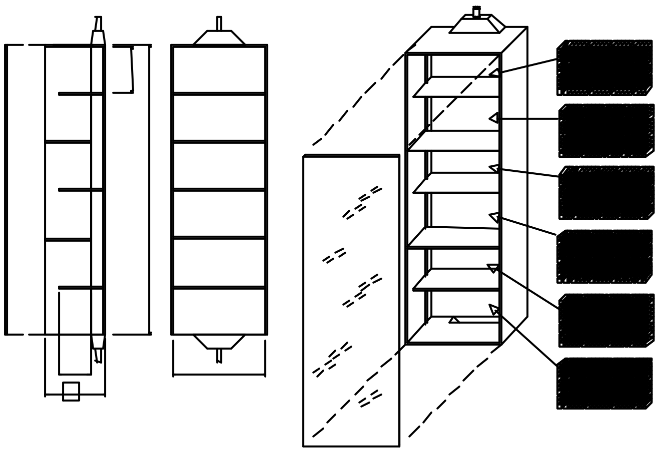


Fig. 4.18 Flat photoreactor to be used with solar photons or artificial lamps

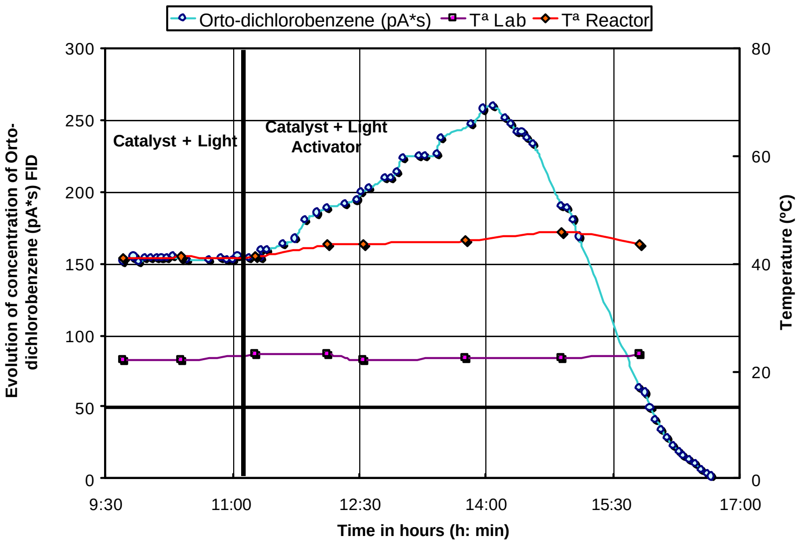


Fig. 4.19 Evolution of Ortho-dichlorobenzene concentration. Before 11:00 Ortho-dichlorobenzene + Catalyst + Light. After 11:00 Ortho-dichlorobenzene + Catalyst + Light + Activator

10% v/v ortho-dichlorobenzene was chosen because of its molecular structure, which is nearly half of the 2,3,7,8,-PCDD target compound. The behavior and initial mechanisms of degradation of this molecule permits the optimization of the process where flow rates, residence times and operational temperatures have been taken into account. Ortho-dichlorobenzene is bubbled into the air stream, passes through the catalyst in the reactor and heat-traced outlet gases are analyzed by on-line sampling using a GC with an FID/TCD detector.

The success and limitations observed in this treatment have been pointed out to assess the performance of AOP decomposition of these types of organic chlorine compounds.

Publications - References [4.37]-[4.39].

Photo-oxidation of Volatile Sulfur Compounds

Participants - CNRS, LCTPCM, UMR 5624, Université de Pau (France), CMAT, Photochimie, Université Catholique de Louvain (Belgique)

Contact - S. Lacombe, sylvie.lacombe@univ-pau.fr

Funding - CNRS, FNRS, NATO

Background - New photosensitizers, different from TiO_2, are elaborated to carry out the oxidation, under visible irradiation, of volatile compounds in a gas-solid photoreactor.

Objectives - Construction of a gas-phase photocatalytic reactor for the treatment of Volatile Organic Compounds and nauseating gas streams.

Achievements in 2000 - When a gaseous stream of a volatile sulfide and oxygen is flowed in the photoreactor, substantial amounts of sulfoxide, adsorbed on the photocatalytic surface, are formed. The gaseous flow only contains unreacted sulfide. The photosensitizer may be regenerated by smooth thermal treatment. A cheap deodorization method, using only oxygen and visible light, is thus available.

Publications - Reference [4.40]

Photo reactors containing Fe/Nafion/glass fibres for solar Fenton processes

Participants - Octav Enea (UMR 6503 CNRS, University of Poitiers (France), (IPC II, EPFL, Lausanne, (Switzerland), Saint-Gobain Recherche, Aubervillies, (France)

Contact - O. Enea: octavian.enea@univ-poitiers.fr

Funding - UMR 6503 CNRS, EPFL, Saint-Gobain Recherche.

Objectives - Aromatic compounds, textile dyes, pesticides and other bio-recalcitrant compounds contained in industrial wastewater are efficiently destroyed by the hydroxyl radicals produced in photo-assisted Fenton advanced oxidation treatments. The Fe-ions can be removed from the solution at the end of the treatment by using Fe-ions clusters encapsulated into Nafion perfluorinated membranes. Nafion thin films are deposited onto high-surface-area fiberglass provided by Saint-Gobain. The morphology of these films containing the encapsulated iron catalyst has been characterized by scanning electron microscopy and iron oxidation level examined by XPS. The repeated decontamination cycles have shown no decrease of the activity of catalysts that can be submitted to long term testing periods corresponding to industrial applications in wastewater decontamination.

Achievements in 2000 - We have designed and satisfactorily tested a small (15-cm) photo-reactor containing Fe/Nafion/glass fiber catalysts subjected to the concentrated (13.5 times) solar light provided by a parabolic solar collector (80 cm). A full size reactor (150 cm) is now under construction. The tests will be performed in June 2001 at the Plataforma Solar de Almería, under the EC DG Research IHP Programme.

Publications - Reference [4.41]

Degradation of dialkylphthalates

Participants - Laboratoire de Photochimie UMR 6505 CNRS Université Blaise Pascal, Clermont-Ferrand (France), Marine Institute of Piran, University of Ljubljana (Slovenia), PSA (Spain)

Contact - Michèle Bolte, Michele.Bolte@univ-bpclermont.fr

Funding - Program MDRI (CNRS) – Slovenian Ministry of Technology, European Community (IHP)

Background - The research covers the whole degradation process, from the primary mechanism to complete mineralization. The analytical approach is systematically combined with the kinetic approach (cf. references). It is worth mentioning that the low iron (III) concentration used in the work (1-3x10^{-4} mol.L^{-1}) not only permits complete mineralization of the pollutants, but is also directly compatible with a safe environment.

Objectives - Quantify the degradation of the pollutant, identify intermediates, quantify their formation and follow the mineralization process under both artificial and solar irradiation.

Achievements in 2000 ? The complete mineralization of butyl and ethylphthalates was obtained at laboratory scale under 365 nm irradiation and solar light. ?OH radicals generated upon irradiation of iron (III) aqua complexes mainly attack the methylene group in ? position of COO^- group in dibutyl phthalates (DBP). The complete mineralization of diethylphthalate was also obtained at larger scale (35 liters) at Plataforma solar de Almería.

Publications - References [4.42]-[4.43].

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

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5 Task III: Solar Technology and Applications

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Jakob Karni, Israel

Carlos Ramos, Mexico

Vladislav Iampolski, Russia

Louis van Herden, South Africa

María Luisa Delgado, Spain

Aldo Steinfeld, Switzerland

Nikki Ranzetta, UK

Thomas R. Mancini, USA

5.1 Objectives and Structure

The objectives of this task deal with the advancement of technical and economic viability for the 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 on how to design, evaluate and use the components and subsystems which concentrate, receive, transfer, store and apply solar thermal energy in an optimized way. In essence, the goals are to investigate innovative multi-discipline advances needed for the further development of concentrating solar thermal systems. This concerns, among others, also 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 effort covering R&D-oriented activities with clearly defined technical objectives, time schedule and expected results.

For structuring purposes, each of the 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

Several kinds of activities are coordinated in these sectors:

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

Participation in SolarPACES Task III include the following benefits:

1. Exchange of information on R&D projects among the different research groups as well as on industrial involvement
2. Dissemination of innovation among potential users
3. Critical review by experts
4. More efficient use of R&D resources by task and cost sharing activities
5. Access to SolarPACES tools and test programs

Examples of these benefits with regard to activities in the year 2000 are:

- SolarPACES study on integration concepts for parabolic Troughs into Power Plants (TIPP; benefits 2,3,4, for details see page 5.17)
- SolarPACES Simulation and Software Workshop (benefits 1, 2 & 4 for details see page 5.19)
- SolarPACES software library (TRNSYS-STEC, benefits 4 & 5; for details see page 5.18)
- SolarPACES Flux Measurement Intercomparison Campaign 2000 (benefits 3 & 4, page 5.21)
- SolarPACES Project Proposal to the European Commission on Accelerated Integration and Standardization of Concentrated Solar Power in Europe (benefit 2 & 4, for details see page 5.21)
- SolarPACES Outdoor Weathering Program of Reflector Materials (benefits 2, 3,4 & 5; for details see page 5.28)
- SolarPACES Working Group Meetings in Australia and Egypt (benefit 1 & 2)

5.2 Status of Technology

5.2.1 Components and Subsystems

The actual market of components and subsystems for solar thermal power plants is small, because neither large-scale nor numerous solar systems have been built in the last 10 years. Since this technology is at the beginning of its commercialization, the cost reduction potential to be achieved by competition and mass production is expected to be quite high. In spite of this, the number of potential suppliers today remains small.

In general, experience in this technology is limited, so that today it is difficult to decide which is the most promising solar thermal technology for the future. This results in both intensive basic and industrial R&D, mostly conducted with the support of public research entities, to improve performance, cost and reliability of solar thermal systems. The present focus in troughs as well as central receiver systems is on concentrator and receiver development. Hybrid options combining solar heat and fossil fuel input are investigated as well.

5.2.2 Tools and Test Facilities

Solar thermal test facilities are available around the world in different scales and technologies. They are mainly operated by public R&D institutions and most provide access opportunities for external users. The major focus today is on the improvement of solar concentrated radiation and temperature measurement. Since these systems are very specific to this technology, for

which they represent a basic requirement, several options are available at those centers. A commercial market for these systems does not yet exist.

Another aspect deals with the design of computer tools for all kinds of solar thermal system optimization. The progress in software and hardware capabilities presently allows the generation of the comprehensive, yet easy-to-use tools, which are becoming an essential requirement of commercial solar thermal system offers. Most of these developments originate in the public R&D sector and are distributed as public-domain software.

5.2.3 Technologies and Applications

New technologies, especially for the manufacture of long-term durable reflective surfaces, anti-reflective coatings and selective absorber surfaces are key points of industrial interest in this field. This includes the development of accelerated weathering options that enable long-term durability estimates.

Industrial process heat became a new focus in the field of applications. Reliable low-cost parabolic trough collectors available on the market show substantial benefits compared to flat-plate or evacuated-tube collectors at temperatures above 80°C. Several demonstration projects are currently underway.

5.3 Updated Program of Work for 2000

Activities which currently form part of our Program of Work are organized within Task III by sectors as summarized in Table 1. For a detailed description please refer to the Program of Work (PoW) (also accessible at http://www.eren.doe.gov/sunlab/).

Activities which are marked I or M in the list are mainly for purposes of information exchange or dissemination. Several of those listed in 1999 have been completed or reporting has stopped so that they no longer appear in the table for 2000. Some new activities of this kind have also been added to the list, like the BioDish, Solar Thermoelectric Power Generator, MDF Flux Measurement System, High Flux Simulator, Infrastructure Network, Access to Large Scale Facilities and Hybrid Solar Biomass Concept. Due to lack of information, resources spent for such Task III projects cannot be precisely reported, however, the Operating Agent estimates them to be between 4 and 5 MEuro for the year 2000.

With regard to activities generated or coordinated through SolarPACES (labeled T and C) the following changes must be noted:

- Heliostat Data collection (1999 activity) is complete and a report has been released

- The Evaluation Standardization Task has been ended due to lack of progress. A new, somewhat differently focused attempt has been initiated with the preparation of a funding proposal to the EC related to non-discriminating integration and standardization of Concentrated Solar Power
- A new flux measurement campaign was performed in 2000 (continuation of 99 activity)
- The SolarPACES TRNSYS STEC Software Library activity continues preparation of a new version for release
- The DELSOL Code Software Review (1999 activity) was extended to other codes (now entitled Review and Exchange of Simulation Software)
- The Outdoor Exposure Program for reflectors continues (now including Russian participation)
- The Process Heat Exploration Program continues

Resources spent for these projects are estimated at between 8 and 12 person/years in 2000.

Sectors and Activities	Contact	Sharing			
		I	M	T	C
Sector 1. Components and Subsystems	**T. Mancini, SunLab**				
Atmospheric Volumetric Receiver	Hoffschmidt		x		
Pressurized Volumetric Receiver	Buck		x		
BioDish	Heller		x		
Autonomous Heliostat	Garcia	x			
Heliostat San Lucar 90	Romero	x			
Solar Thermoelectric Power Generator	Neumann	x			
Sector 2. Supporting Tools and Test Facilities	**D. Martínez, CIEMAT**				
Trough Integration into Power Plants	Geyer			x	
TRNSYS Software Library STEC	Schwarzbözl			x	
Review and Exchange of Simulation Software	Pitz-Paal			x	x
Non-discriminating Integration/ Standardization	Pitz-Paal			x	
Infrastructure Network	Martínez		x		
Flux Meter Intercomparison Campaign 2000	Neumann			x	
Sunshape Measurements	Neumann			x	
MDF Flux Measurement System	Balestrin	x			
High Flux Solar Simulator	Steinfeld	x			
Access to Large Scale Facilities	Martínez		x		
Sector 3. Advanced Technologies and Applications	**K. Hennecke, DLR**				
Outdoor Exposure of Reflectors	Jorgensen			x	
Process Heat Applications	Hennecke			x	
Coatings	Zarza	x			
Hybrid Solar Thermal- Biomass Concept	Romero	x			

C = SolarPACES cost-shared activities

T= SolarPACES task-shared activities

M = member country task-shared activities of interest to SolarPACES

I = individual member country activities of interest to SolarPACES

Table 5.1: List of activities performed in 2000

5.4 Participation and National Contributions

In 2000 the following organizations were involved in Task III activities:

ANU, Canberra	Australia
DG Research and TREN	European Commission
NREA	Egypt
CNRS-IMP, Odeillo	France
DLR, Cologne, Stuttgart and Almería	Germany
Weizmann Institute, Rehovot	Israel
IIE Cuernavaca	Mexico
CIEMAT, Madrid and Almería	Spain
PSI, Villigen	Switzerland
NREL, Denver	USA
Sandia, Albuquerque	USA

5.5 Cooperation with Industry

SolarPACES Research activities aim at industrial application. However, in the early commercial stage of this technology, much of the momentum of innovation is generated at research institutes. Cooperation with industry is essential to ensure a clear path to the commercialization of new products and to cost reduction of the technology . Major industrial partners involved in Task III are:

Germany	Alanodl Babcock Borsig Power DENARO Fichtner Solar Flabeg Solar International G+H Saint-Gobain Industriekeramik SIAMANT Schlaich, Bergermann and Partner Schott Rohrglas
Israel	Ormat Turbines Rotem Industries SOLEL
Spain	Cajamar ENDESA GHERSA IBERDROLA IBRESE SERLED Sistemas de Calor Inabensa
USA	Bechtel Corp. KJC Operating Company Kearney & Associates Industrial Solar Technology

Table 5.2 List of major industrial partners involved in Task III

5.6 *Summary of Achievements*

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

This sector covers activities in the field of

- Receivers
- Dish Systems
- Heliostats
- Others

Receivers

Atmospheric Volumetric Receivers

Participants ?
Member Countries: DLR (D), CIEMAT , INABENSA, IBERESE (E),
Non-Member Countries: Helotech (DK), Forth-CEPRI (GR)

Contact ? B. Hoffschmidt, DLR

Funding ? 50% EC DG Research; total cost MEuro 3

The objective of this activity is to develop and demonstrate a new volumetric air receiver technology which is based on ce-ramic volumetric absorber modules, resulting in improved reliability and performance with reduced component costs for the next generation of solar power tower plants.

The HITREC II project continues testing of the modular ceramic receiver concept, providing valuable information for the design and optimization of the subsequent SOLAIR receivers.

The SOLAIR project consists of two consecutive phases. During the first phase, the design, manufacturing, treatment and assembly of the ceramic absorber modules will be optimized according to specified cost and performance requirements. The absorber module will be qualified in small-scale pre-tests. Steel structure supporting the absorber, warm air return system and passive control elements to homogenize the outlet air temperature will be developed. The qualified components will be assembled and tested at the 200 kW_{th} receiver test bed at the Plataforma Solar de Almería. Research on degradation of absorber materials will be performed for exposed elements to estimate lifetime expectations of these new elements.

The second phase will provide the necessary intermediate step in the scale-up to large-scale application, to reduce technical and commercial risk. A scaled up 3-MW_{th} receiver will be designed, manufactured and tested in the existing 3-MW volumet-

ric air receiver solar test bed at the Plataforma Solar de Almería. In order to minimize testing cost, a modular design representing a typical section of the prototype power plant will be tested, to demonstrate specified performance and reliability criteria, and to gain operation and maintenance experience. In parallel, detailed optimization of power plant cycles will be analyzed to fully exploit the expected benefits of this advanced receiver system.

Fig. 5.1 HITREC

Work on SOLAIR is progressing with only slight delays in the schedule as presented in the PoW. Based on experiments in the DLR solar furnace (Cologne) and laboratory research, the material most suitable for the receiver modules was selected and the module was designed. SOLAIR receiver modules will be square, and larger in size to reduce the number of modules required for a future commercial receiver, however, to reduce development risks, modules similar in size to the hexagonal HITREC modules (**Fig. 5.1**) will be tested first. In a second step, the size will be increased. A 200-kW$_{th}$ receiver design to be completed early in 2001 will allow simultaneous testing of both sizes. Testing is scheduled to start in May, 2001. The tests carried out on the HITREC II receiver confirmed the advantages of the double-membrane design to hold the receiver modules in place.

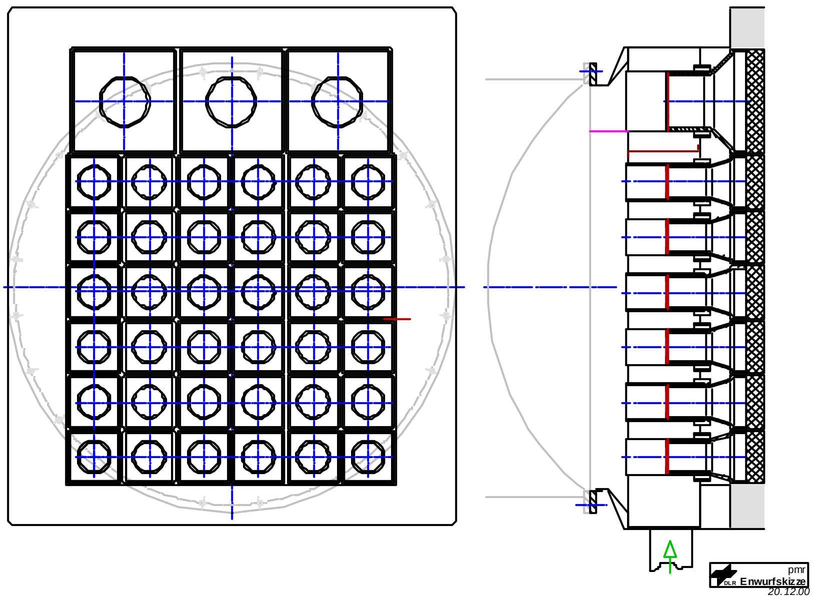

Fig. 5.2 SOLAIR 200-kW$_{th}$ receivrer concept

Pressurized Volumetric Receivers

<u>Participants:</u> DLR, G+H (D); CIEMAT (E)

<u>Contact</u> R. Buck, DLR

<u>Funding:</u> National Programs, total cost of MEuro 3 for 2.5 years

The objective of the "REFOS" receiver technology is the direct integration of solar energy into gas turbines or combined cycle systems (by solar preheating of air or solar reforming of natural gas). A single receiver module (consisting of the receiver and the secondary concentrator) is installed in the CESA-I tower at the Plataforma Solar de Almería (PSA).

The REFOS-2 project was begun in January, 2000, with the major goals of demonstrating a cluster of three receiver modules operating with air at 15 bar and up to 800°C, in a closed pressurized test loop. The total absorbed power will achieve 1 MW_{th}.

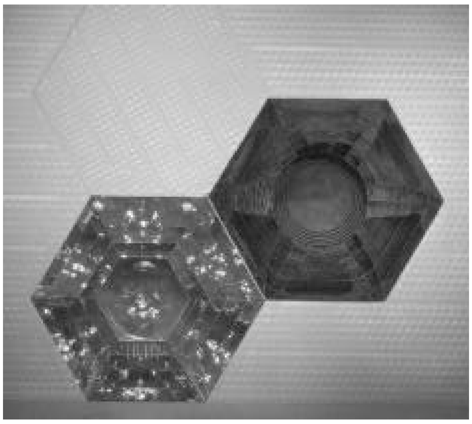

Fig. 5.3: Old and new secondary concentrator at PSA

Significant conductive heat loss had been detected in the receiver during the previous test phase and so the internal insulation of the pressure vessel was disassembled and examined. A new, improved insulation structure was manufactured and installed. Following this, solar operation was resumed to increase operating experience.

The new secondary concentrator was installed next to the old version (see **Fig. 5.3**). Solar power throughput was measured with a cold water calorimeter at the outlet of the secondary. The results confirmed the predicted gain in efficiency of about 10%. This gain is mainly achieved by an improved geometry of the secondary. In addition, a new manufacturing technique, which produced significant reductions in weight and cost, was successfully proven during the tests. Design and manufacture of two new receiver modules was initiated and is now underway.

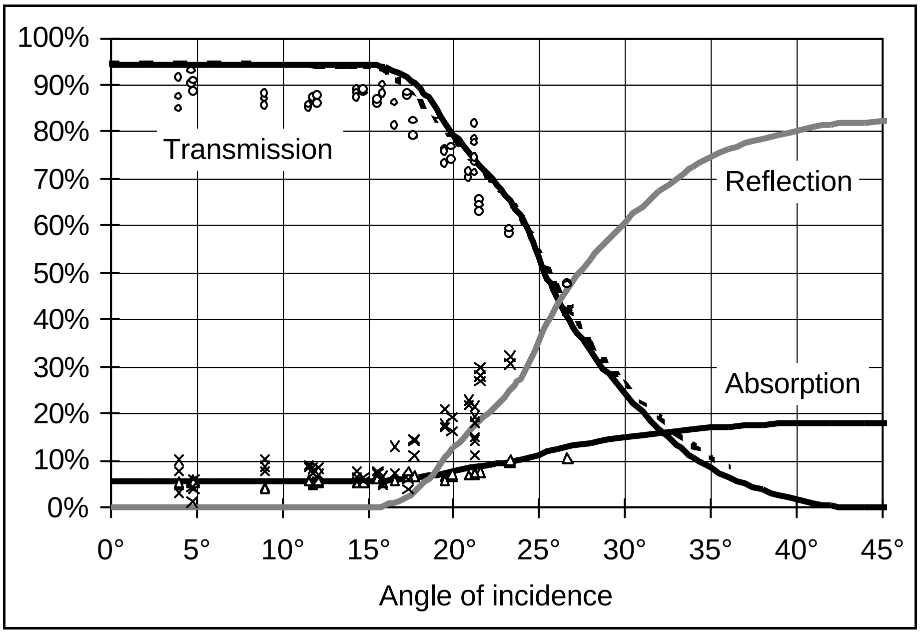

Fig. 5.4 New Secondary concentrator performance vs. incidence angle (curves: predicted; symbols: measured)

Dish Systems

BioDish

Participants ? DENARO, DLR SIAMANT (D), Sistemas de Calor, Caja Rural (E)

Contact ? P. Heller, DLR

Funding ? Co-funded by the EC, total cost Meuro 1.5

This project focuses on the development of a ceramic hybrid receiver for biogas-fired dish/Stirling systems for electric power supply

During the first year, the design of the hybrid receiver, including the fossil burner and packaging, was finished and the mold for manufacture of the receiver was prepared. At the test site at the PSA, in Spain, a flux measurement campaign was conducted in order to predict flux distribution on the receiver surface. With this input, flux at the domed absorber was simulated with Circe2 and the geometry of the absorber optimized.

Heliostat Development

Autonomous heliostat

Participants ? Sevillana, Ghersa, CIEMAT (E)

Contact ? G. García, CIEMAT

Funding ? National Program, total cost of MEuro 0.85

The wireless autonomous heliostat prototype already described in 1999 has completed the extensive test campaign by June 2000, confirming its robustness and reliability regarding radio communications, PV power supply and low electrical consumption. The operational experience accumulated after 1.5 years of continuous testing has revealed neither failures nor power supply shortages. The second phase of the project was initiated in September 2000. The objective of this phase is to implement the wireless concept and to validate communication protocols for a small field of 20 heliostats. The MBB-heliostat field at the PSA is being adapted for this purpose. During 2000 the MBB field has been prepared and new local controls have been developed. The field is expected in operation and controlled by radio in July 2001.

Heliostat Sanlúcar-90

Participants ? IAER, INABENSA, CIEMAT (E)

Contact ? M. Romero, CIEMAT

Funding ? Co-funded by EU FEDER, total cost MEuro 1.3

Two prototypes of the Sanlúcar-90 heliostat have been developed and installed at the Plataforma Solar de Almería for testing. The heliostats were developed by the Spanish company INABENSA in collaboration with CIEMAT for future application in

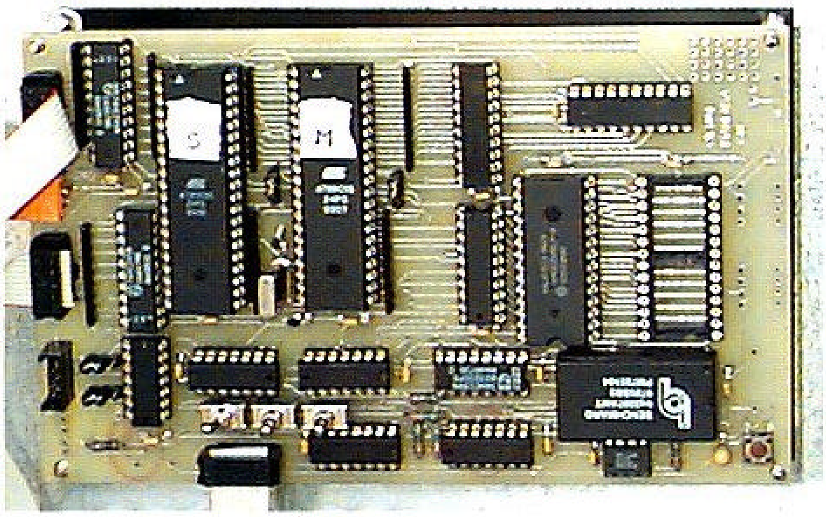

Fig. 5.5 Sanlúcar-90 local control card

the PS10 solar thermal power project. The Sanlúcar-90 heliostat is a mature glass-metal design making use of the structural solutions, facets and local control previously proven in the GM-100 and COLON prototypes. The Sanlúcar-90 local control is a simplified version of the former GA2696A. The new approach is based on the use of two micro-controllers using the master/slave concept, much reducing the complexity of the PCB design and the size of the control card while maintaining performance.

Fig. 5.6 Rear view of the hydraulic Sanlúcar-90 heliostat at the Plataforma Solar de Almería.

The heliostat is 9.57 m high by 9.67 m wide and consists of 21 4.33-m^2 facets. The net reflective surface is 91 m^2 and mirror reflectivity is 92%. It is held in place by four trusses, torque and concrete pedestal. The total weight without foundations is 3 500 kg The first prototype installed and tested had a Peerless-Winsmith worm-gear drive and supplied a beam quality of 2.4 mrad. As shown in **Fig. 5.6**, the second prototype has a hydraulic mechanism. The hydraulic prototype is to be evaluated early in 2001 after the local control has been adapted for the new drive. The Sanlúcar-90 heliostat evolved from the experience in glass-metal technology accumulated at PSA in the last 10 years. The cost projection is for $125/$m^2$ for 1 000 units.

Others

Development of a Solar Thermoelectric Power Generator

Participants ? DLR (D)

Contact ? A. Neumann, DLR

Funding ? National project, total cost N/A

The direct conversion of heat energy into electricity is possible through the Seebeck effect in thermoelectric converters (TEC). Such converters may be fabricated from commercially available materials and, although nominal efficiencies are only 5%, which

is quite low compared to other systems using generators coupled to thermodynamic engines, they have no moving parts and are consequently very reliable.

Compared to photovoltaic converters for terrestrial solar energy applications, the advantage of the TEC is the possibility of being connected to thermal energy storage. The latter combination may be more cost-effective than a battery storage system.

We have developed a TEC coupled to a solar energy receiver. The receiver was designed for the 1 kW DLR DISKUS dish concentrator. A first approach was the construction of a solar TEC based on Bismuth Telluride modules. The receiver temperature has to be limited to 300 C to avoid deteriorating the TEC materials. Furthermore, the receiver design must guarantee homogeneous temperature distribution over the hot TEC junctions. Testing of a receiver design not optimized for low thermal loss had a direct normal irradiance to electric efficiency on the order of 3.5%.

Further investigation with TEC modules using SiGe semiconducting material showed a high ZT and best efficiencies in the range of 400-800ºC, which is better suited to a solar concentrator like the DLR 1-kW dish. Future plans involve combination with a different type of module to increase the efficiency.

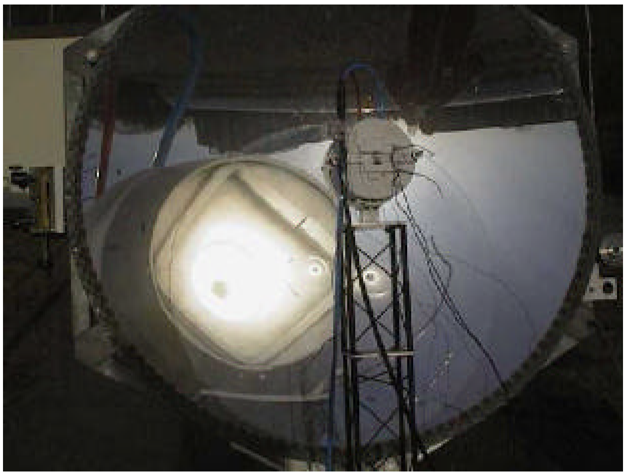

Fig. 5.7 View of the thermoelectric converter mounted in the focus of the 1.5-m concentrator Diskus. The front side with the receiver aperture is seen as a magnified image

5.6.2 Sector III.2: Supporting Tools and Test Facilities

This sector covers the following activities:

- Simulation and Software Activities
- Networking / Standardization
- Flux Measurement and Sunshape
- Test facilities

Simulation and Software Activities

Trough Integration into Power Plant (TIPP)

Participants ? DLR, Flabeg (D), Sandia, NREL, Bechtel (USA)

Contact ? M. Geyer, DLR

Funding ? SolarPACES task-shared activity ; estimated total costs: 1-2 person-years in 2000

The TIPP activity was launched to investigate optimized cycles for integrated solar combined cycle power plants (ISCC). These plants consist of a gas turbine with heat recovery steam generator and a field of parabolic troughs which are used to generate additional steam for an oversized steam turbine (compared to a CC plant).

If these plants are to deliver design power even when there is no insolation, they must have a supplementary firing system, which has a lower efficiency than a conventional CC power plant. If the design is careless, an ISCC with supplementary firing may have higher fuel consumption than a CC plant with the same electricity output. Another ISCC plant option is thermal storage of the solar heat to minimize the use of supplementary firing.

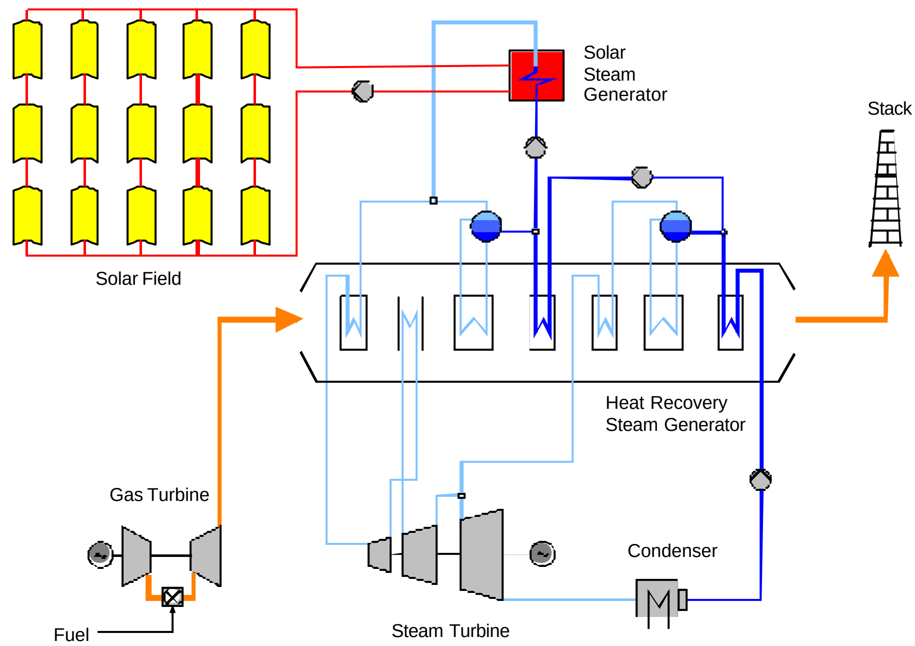

Fig. 5.8 Scheme of an ISCC power plant

Two different approaches have been investigated in detail, a low-impact and a high-impact ISCC. The first one, with two 157-MW$_e$ output gas turbines and a thermal input of 83.4 MW from the solar field, has a total electricity output of 525 MW$_e$ at design point. The low-impact ISCC has only one gas turbine with 157 MW$_e$ and a thermal input of 139 MW from the solar field for a total electricity output of 296 MW. Based on the total thermal

input (solar heat/[solar heat+fuel mass flow*LHV]) the design solar fraction is 9% for the low impact ISCC and about 24% for the high impact ISCC. Three pressure HRSG were used and the steam generated from the solar heat was added to the high pressure line for both cycles.

Several ways to balance cycles have been calculated in order to acquire sufficient input data for annual performance calculations. Cycle runs for different ambient temperatures, different solar heat input, different supplementary firing capacities and different solar steam temperatures were carried out. Three-pressure CC cycles with the same gas turbines were used as reference cycles.

Results of the calculations are:

- The cycle efficiency of the ISCC plants without solar input is almost the same as for the CC reference plants.
- Replacing the whole solar heat input with supplementary firing gives an efficiency penalty of 0.7% for the high-impact ISCC and 0.1% for the low impact ISCC.
- Boiler design for the low-impact ISCC is rather simple whereas the high-impact ISCC needs unconventional solutions like bypassing of super heaters for full supplementary firing.

Results from these cycle calculations will now be used for annual performance calculations and finally an economic evaluation of the different configurations will be carried out.

TRNSYS Software Library STEC

Participants ? ANU (AUS); DLR (D) ; CIEMAT (E) ; SunLab (USA) ,

Contact ? P. Schwarzbözl, DLR

Funding ? SolarPACES task-shared activity ; estimated cost: 1-2 person-years in 2000

The TRNSYS model library for simulation of Solar Thermal Electric Components (STEC, see SolarPACES Technical Report No. III – 4/98), which is distributed free to all interested SolarPACES members, is continually used, improved and extended in numerous projects and feasibility studies on solar thermal technology. A main focus in 2000 was the continued validation of the STEC models against measured data from the 30 MW_e SEGS VI plant which was started in 1999. Better agreement with measured data was obtained through improved modeling of startup and shutdown operation of this huge technical system. New models for parabolic trough systems and plant control result from this activity. **Fig. 5.9** shows the comparison of simulation with measured data for a clear summer day as an example.

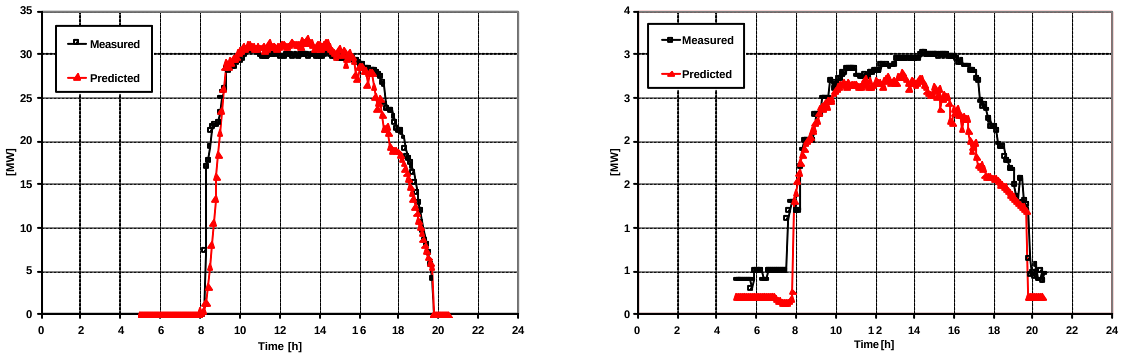

Fig. 5.9 Measured and predicted gross output and useof parasitic power on a clear summer day

Moreover, new models were created and validated for a closed-loop ammonia thermochemical system by ANU, Australia. These are ammonia reactor, solar dish concentrator, receiver and heat exchanger for fluids with changing heat capacities. These components calculate steady state performances. Transient characteristics are yet to be added. Preliminary system simulation results were achieved for a small-scale, energy-input only, part of the closed-loop ammonia based thermochemical system.

Review and Exchange of Simulation Software

<u>Participants</u> ? ANU (Aus); PSI (CH); DLR, ZSW (D); CIEMAT (E); IEE (Mex); SunLab (USA)

<u>Contact</u> ? R. Pitz-Paal, DLR

<u>Funding</u> ? SolarPACES task-shared activity; estimated cost: 1.5 person-years in 2000; Simulation Workshop cost shared by Solar-PACES

The exchange of software developments among SolarPACES members to check installation, documentation and functioning of these codes has started with the testing of TRNSYS STEC by CIEMAT and WDELSOL by DLR, Cologne. Experiences were documented in software review reports. It was agreed at the Simulation Workshop in Cologne in 2000, to extend this activity to all codes developed. Therefore a Software Volunteer List was created to coordinate the exchange between developers and testers. Software testers must return a detailed report about their experiences within 8 weeks of having received the software.

The above mentioned workshop on Simulation of Solar Thermal Power Systems was held at DLR, Cologne in September 2000 (see SolarPACES Technical Report No. III – 3/00).

In addition to TRNSYS STEC, many other software developments for solar thermal power systems were presented:

- Optical performance calculation codes
- Performance prediction tools and applications

- Commercial software for power cycle analysis
- Fully dynamic simulation tools
- Meteo data bases
- Integrated planning tools

Networking and Standardization

Infrastructure Cooperation Network 'EuroCARE'

Participants – Member Countries: CIEMAT (E), CNRS (F); Cardif University (UK)
Non-Member Countries – ENEL (I); IFRF (NL)

Contact – E. Zarza, CIEMAT

Funding – EC-DG Research under the 'Improving Human Potential Programme'. Total cost approx. 1.5 person-years in 2000

The main task concept is to foster cooperation amongst all the members of the network, transferring good practice, improving and developing access to facilities, creation of a distributed network via development of Internet use. The various study panels are designed to develop these concepts in detail in various important and relevant areas.

The Infrastructure Network is being developed in a number of different ways in order to meet the objectives via:

- a yearly general meeting, which receives reports from each infrastructure operator, feedback and reports from the users, updated by the coordinator on EU programs and policy, and tours of the facility where the meeting is being held.
- a second yearly meeting, whereby more specific study group reports and activities are discussed and revised. This includes Exploratory Research Infrastructure Workshops, and the preparation of RTD proposals
- enhancement of the existing distributed/virtual infrastructure, e.g., web sites, e-mail, etc.
- proposals for high-level scientific conferences, viz., Euro-conferences, Euro- courses and non-traditional conferences.
- transfer of good practice such that the quality and standard of access can be improved within large-scale facilities.

In 2000, the yearly general meeting was held on the IMP-CNRS premises in Odeillo (France) on May 16th and 17th. There the membership of three study panels was arranged and their activities were scheduled. The three study panels are:

Study Panel 1	High Temperature Characterization and Materials
Study Panel 2	Future Research Requirements
Study Panel 3	Industrial Training in the Context of Large Scale Facilities

An additional meeting at Strasbourg (France) was held on September 19th and 20th, to coincide with the 'Conference on Research Infrastructures' organized and hosted by the European Commission DG Research. There the current status of the study panel activities was reviewed and objec-

tives were set for the next meeting to be held at Livorno (Italy) in March, 2001.

EU Proposal related to Non-Discriminating Integration and Standardisation of CSP Technology

Participants – Member Countries: ETH (CH), DLR , FLABEG; Fichtner (D); CIEMAT (E) OME (F); GEF (US)
Non-Member Countries ; CRES (GR) CESI (I), IST (P)

Contact – R. Pitz-Paal

Funding – Application submitted to the EC 5th Framework, MEuro 1.2 requested

The main objective of the proposal is to clear the path for successful, time-efficient implementation of CSP projects in Europe, so that the currently blocked CSP project developments, THESEUS, PS10, Solar Tres and Lucasol, can finally be resumed and be successfully replicated for the benefit of the European environment.

It is the objective of this project to provide the member states with the required definitions, mechanisms and rules for non-discriminative integration of CSP generators in order to remove these barriers.

Detailed objectives are:

- Identification of barriers in licensing procedures and grid integration for CSP in European Mediterranean countries Portugal, Spain, France, Italy and Greece
- A non-discriminative certification/green-labeling of CSP
- Identification of standardization requirements
- Analysis of the regulatory discrimination leading to the prohibitive delay of the two European CSP Demonstration projects in Greece and Spain

The monitoring of the ongoing permitting and implementation process of the CSP projects in Egypt, India, Mexico and Morocco in cooperation with the United Nation Environmental Program (UNEP) and the Global Environmental Facility (GEF).

The proposal coordinates such CSP integration through the European Secretariat of the International Energy Agency (IEA) SolarPACES Implementing Agreement to feed the results back to the IEA Ministerial Board and G8 energy policies.

Flux Measurement and Sunshape

Flux Measurement Intercomparison Campaign 2000

Participants – DLR (D), CIEMAT (E), CNRS (F), WIS (IL),

Contact – A. Neumann

Funding – SolarPACES task-shared activity , co-sponsored by the regional ministry of Northrhein-Westfalia, total cost estimate: 2 person-years

The International Radiometer Intercomparison Campaign InterComp 2000 was held from August 21st to September 8, 2000 in the DLR Solar Furnace. The operation of the solar furnace and the hosting of the guest scientists received funding from the Solar Energy Association NRW (AG-Solar). The project was managed by the DLR Solar Furnace group.

11 radiometers from four different institutes were compared. Due to the different measurement ranges of the instruments, the campaign was divided into two parts, one for high flux and one for low flux instruments. The threshold was set to a flux value of 1500 kW/m² as determined by the operating ranges of the instruments:

- High-flux instruments are used in high concentrating solar facilities like solar furnaces or dishes with concentration ratios up to 15 000 suns (15 MW/m² flux density).
- Low-flux instruments are typically used in solar power tower systems where solar radiation is concentrated to ratios of about 1500 (flux density: 1500 kW/m²).

While the former comparison campaigns focused on all kinds of currently used radiometers, the Cologne campaign compared non-commercial radiometers that had been developed at the solar facilities. The development of radiometers is an important task due to the fact that there is no really reliable radiometer on the market at the moment.

Three of the 11 radiometers were real non-commercial instruments: the IMP-CNRS ASTERIX, the Weizmann Institute's radiometer and the DLR SunCatch. They are under continual development and require that their performance be tested. In the first part of the campaign, the high-flux instruments were tested (August 21st to August 31st) by the teams from DLR and IMP-CNRS. The instruments were changed on September 1st with the arrival of the scientists from WIS and PSA. **Fig. 5.10** shows the mounting plate carrying all the participating instruments. The plate is positioned in the focus of the DLR Solar Furnace. The cylindrical instrument along side of the plate is the DLR SunCatch.

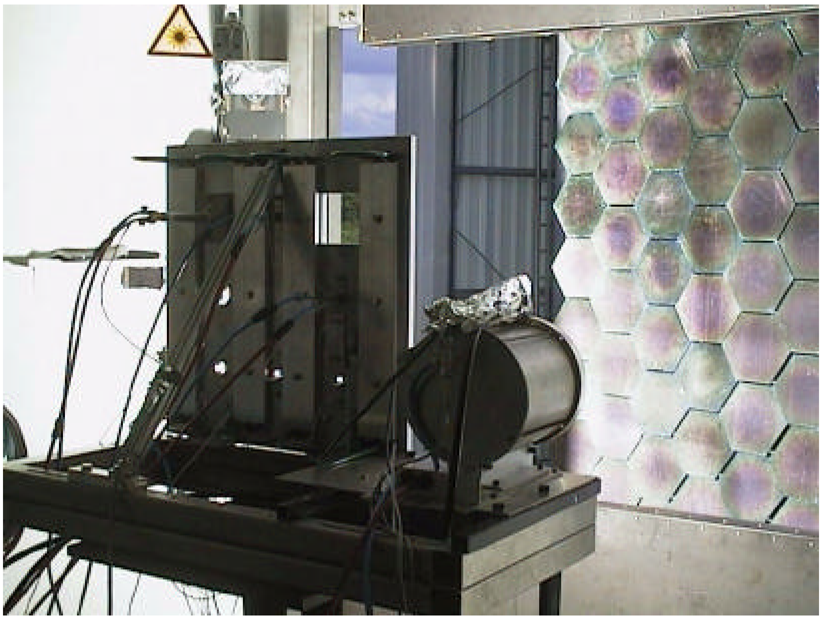

Fig. 5.10 View of the mounting plate in the focus of the DLR Solar Furnace. The cylindrical instrument on the right side of the plate is the DLR SunCatch.

Sunshape Measurement

Participants: DLR (D), Sandia (USA)

Contact – A. Neumann

Funding – Task shared activity through SolarPACES. Total cost estimated as 1 person-year.

The effect of atmospheric scattering leads to an aureole around the solar disk. The spreadout solar disk is called sunshape and can be modelled by the circumsolar ratio CSR (Neumann and Witzke, 1999).

Within a collaboration between DLR Cologne (A. Neumann, A. Witzke) and Sandia National Laboratories (S. Jones) a study was initiated on the impact of the variability of sunshape profiles on solar tower plant performance. For this purpose measured solar brightness profiles taken under different conditions and at different locations were introduced into the DELSOL computer code. Low, medium, and high CSR conditions, corresponding to a clear, moderately hazy, and hazy skies were used. The first series of model runs revealed a drop of several percent of annual plant performance in case of hazy sky conditions. **Fig. 5.11** shows the results under the assumptions of a yearly constant CSR.

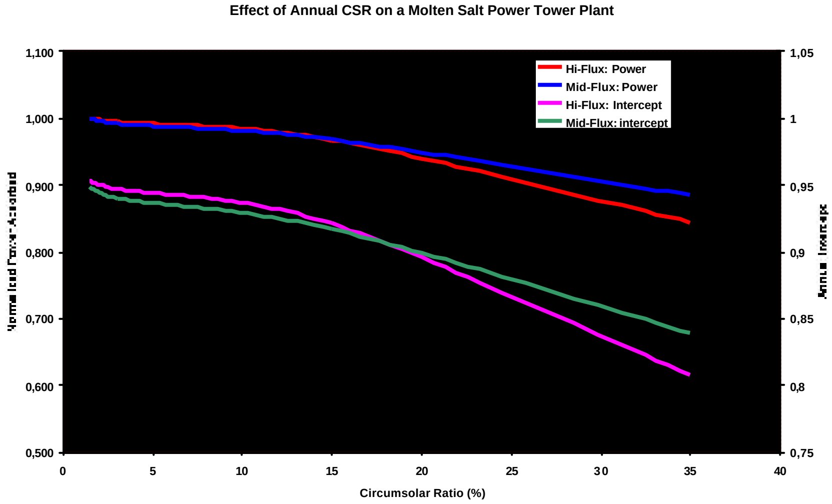

Fig. 5.11 Variation of the annual intercept factor and absorbed power with the circumsolar ratio CSR.

MDF- Direct Flux Measurement System

<u>Contact</u> – J. Ballestrín, CIEMAT

<u>Participants</u> – CIEMAT (E)

<u>Funding</u> – National program; total costs N/A

A direct flux measurement system, MDF, has been designed, fabricated and mounted on top of the SSPS-CRS tower at the PSA in addition to the indirect flux measurement system (CCD camera). It is one of the main objectives of this initiative to compare both measurements, increasing the confidence in the estimate of high flux values by a more accurate analysis of error propagation. The MDF system represents a substantial advance versus previous direct measurement systems like HFD and MFV. A new type of calorimeters with response times in microseconds makes it possible to think of instantaneous direct flux measurement. Based on this principle, a moving bar with several of these sensors has been built. The moving bar passes in front of the receiver aperture in a parallel plane pivoting on a fixed point under the receiver aperture, in a vertical line from the center. Using a fast acquisition system for the calorimeters and an appropriate moving bar speed, the flux distribution can be measured instantaneously without cooling. The bar with calorimeters and the lambertian plates used with the indirect method with CCD camera are mounted together on the same plane. This represents a good opportunity to compare the results.

Fig. 5.12 Heat Flux Microsensor (HFM)

The calorimeter selected is the Vatell Heat Flux Microsensors (HFM) that are made using thin film processes. Thin film construction gives the sensors many unique advantages, like fast response time, high accuracy operating at high temperatures and others.

Two measurements are made with the HFM: The first is a temperature measurement obtained from a resistance temperature sensing element (Resistance Temperature Sensor, RTS) which consists of a pure platinum thin film deposited in a loop pattern around the outer edge of the sensor face. The second is a heat flux measurement obtained from a thermopile heat flux sensor (HFS) that occupies most of the surface.

The MDF system is mainly a data acquisition system consisting of a moving bar with eight HFM calorimeters, an acquisition card with 32 differential 3-?V highest-resolution channels and acquisition and evaluation software. The global error estimated for the MDF system is ? ? 6%.

Test Facilities

The ETH High-Flux Solar Simulator for High-Temperature Solar Thermal and Thermochemical Application R&D

Participants –Swiss Federal Institute of Technology (ETH),– Paul Scherrer Institute (PSI) (CH)

Contact – A. Steinfeld, ETH

Funding – The High-Flux Solar Simulator was erected with financial support from the NEFF- Swiss National Energy Research Foundation and the ETH-Project Nr. TH-29/99-4.

The High-Flux Solar Simulator provides a rapid external source of intense thermal radiation that approaches the heat transfer

conditions of high concentration solar systems. The light source is a high-pressure argon arc enclosed in a clear quartz envelope. It delivers up to 100 kW continuous radiative power. The arc envelope is internally cooled by using a swirling film of de-ionized water that rapidly flows between the plasma arc and the clear quartz lamp tube. The arc produces radiation at visible wavelengths with additional power in the infrared and ultraviolet regions of the spectrum. Advanced optical filters can be applied to the tubular quartz envelope for adjusting the spectral distribution of the arc to closely match the suns true output - either to AM0 (space) or AM1.5 (terrestrial) standards. The system was manufactured by Vortek, Canada.

This light source is closed-coupled to precision optical reflectors of elliptical shape to produce an intense beam of concen-

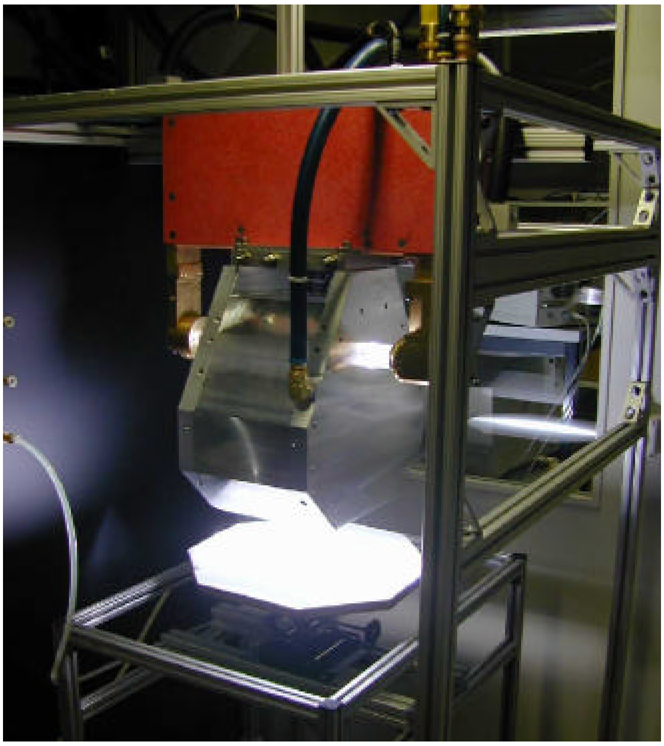

Fig. 5.13 The High-Flux Solar Simulator at ETH. The argon arc lamp is enclosed by an elliptical mirror that redirects the radiant power into the target

trated radiant energy. With this arrangement it is possible to achieve power flux intensity equivalent to 5000 suns (1 sun = 1 kW/m^2) and process temperatures exceeding 3000 K. Power flux intensities and temperatures can be adjusted to meet the specific requirements of the application by simply varying the position of the test target along the axis of the focusing mirrors or by varying the electrical input power to the arc electrodes.

Such a unique research facility is serving as a major experimental platform for investigating high-temperature solar thermochemical processes. It is also a very convenient research tool for studying the properties of advanced ceramics and ultra-high

temperature materials under intense radiation fluxes and controlled atmospheres. The facility is well-equipped with state-of-the-art control and measurement instrumentation.

Access to Large Scale Facilities at Plataforma Solar de Almería

Participants – CIEMAT (E), open to others

Contact – E. Zarza

Funding – 'Improving Human Potential' (IHP) programme of EC-Research, estimated total cost 1 person-year + MEuro 0.5

The broad range of CIEMAT-PSA facilities enables testing in such different areas as solar generation of electricity, photocatalytic detoxification of industrial waste waters, production of fine chemicals, thermal treatment of advanced materials, development of control algorithms for industrial heat transfer processes, desalination of sea water and passive architecture component development. The CIEMAT-PSA opens its doors to research groups or individuals interested in the development of clean industrial applications based on solar thermal energy.

This task is carried out through the EC-DG Research 'Improving Human Potential' (IHP) program. Through it, 156 weeks of access are offered in 8 of the PSA's facilities during the three years of the IHP program (2000-2002). This means that an average of two persons per project will carry out a total of 3808 man/days in 28 projects per year at the PSA.

The research activities at the PSA are organized into four Projects, with a Project Leader for each, who is responsible to the PSA Director for all aspects of project progress. External Users are under the direct responsibility of the Project Leader corresponding to their line of work. This Project Leader requests and coordinates support from other departments and helps the User to design and carry out the experiments so as to take best advantage of the facilities. Project Leaders are also responsible for scheduling their users at the facility as well as keeping the facility in good operating condition during their visit.

In addition, the staff of the 'Training and Access to the PSA' project acts as their host, caring for such details as travel arrangements, transportation to and from Almería, lodging, office availability, any bureaucratic matters and their contact for solving any problem or difficulty.

The logistics necessary for facility operation and user support are provided by an 'Engineering Department', for assistance with instrumentation and measurement systems, civil engineering and drafting; a 'Computer Service'; a 'Facility Operating Team', with experienced personnel specialized in the particularities of solar concentrating systems; an on-site 'Maintenance Team', a 'Reference Library', an 'Administration Department ' and services such

as power supply (including UPS in every facility), telephone, fax, e-mail and several workshops, stores, and a chemical laboratory.

This activity started on February 1, 2000 and 19 User groups have been granted access to the PSA during 2000.

More activity is expected during 2001, starting with a 'Users Workshop' to be held next March.

5.6.3 Sector III.3: Advanced Technologies and Applications

This sector covers the following activities:

- Materials Development and Testing
- Process Heat Applications
- Hybrid Solar Thermal- Biomass Concept

Materials Development and Testing

Outdoor Exposure of Reflector Materials

Participants – DLR; (D), CIEMAT (E); Russia; NREL (US)

Contact – G. Jorgenson, NREL

Funding – SolarPACES task-shared activity , total cost 2-3 person-year in 2000

The primary objective of the Concentrator Reflective Materials Testing project is to provide data on performance losses as a function of exposure time at a number of locations that are attractive to utilities and industrial companies interested in concentrating solar power generation. The sites provide a way for power providers to gain direct experience with materials that may be used in early commercial power plants. Careful planning and proper execution of this research is intended to enable an understanding of why materials degrade differently at geographically diverse test sites.

Candidate reflective materials are identified based on their potential for low cost and optical performance and durability. Reflective constructions are prepared and optically characterized prior to exposure testing. These constructions are then subjected to outdoor weathering at a variety of geographically diverse exposure sites. At each location, radiometric and meteorological monitoring is performed to quantify the important environmental exposure conditions (stresses) experienced by the materials being tested that can affect the material's performance and useful lifetime. Optical performance is periodically remeasured as a function of exposure time (stresses) to assess optical durability.

This collaborative effort was initiated in December, 1994 under the auspices of the SolarPACES Subtask III.3.2 agreement. During the past year, Russia has also joined the collaboration. Six

fully instrumented (in terms of monitoring meteorological conditions and solar irradiance) outdoor exposure sites are presently active in the United States and Europe

Fig. 5.14 New test set-up in Russia

During the past year, durability testing of candidate solar mirrors has continued. A list of what materials are being tested at which sites and a discussion of test results to date for a large number of candidate solar reflector materials is given in [5.8]. Based upon outdoor exposure testing (OET) and accelerated exposure testing (AET), conclusions can be drawn on the optical durability of the following candidate reflector materials tested to date. Thin glass (from Naugatuck, Schlaich, Bergermann und Partner, or Steinmüller), thick glass (from ATS or Flagsol), and two metallized polymers (SA-85, ECP-305+) can be characterized as excellent, although degradation of some thin glass materials adhesively bonded to metal substrates has been observed. The all-polymeric construction, several of the aluminized reflectors (Alanod's improved product, materials from Metalloxyd), and a metallized polymer (ECP-305) can be characterized as intermediate and require further improvement and/or testing and evaluation. A metallized polymer (SS-95), metallized fluoropolymers (until specularity can be sufficiently improved), and constructions in which adhesives are in direct contact with a silver reflective layer can be characterized as poor and do not warrant further consideration for solar applications. Recently, a number of promising constructions have been identified including: several front-surface mirrors under an ongoing NREL subcontract and prepared by NREL staff; a new all-polymeric construction using improved interlayer resins and incorporating UV screens; a newly available commercial solar reflector material called SolarBrite 95;

and a novel commercial laminate construction co-invented by NREL staff and industry collaborators.

A new material, Miro2+, has shown excellent durability at all outdoor test sites [5.6], although accelerated exposure testing has indicated problems with an outdated version of the material.

Outdoor exposure testing of promising candidate solar reflector materials will continue. Problems have been experienced with acquiring meteorological and radiometric data from four of the five operational OET sites in the US. Consequently, US OET network will be consolidated from five to three sites, namely: Golden, CO; Miami, FL; and Phoenix, AZ.

Selective coatings for solar absorbers, anti-reflective films and front surface mirrors

Participants – CIEMAT (E)

Contact – E. Zarza

Funding – National program, total costs N/A

In 2000, CIEMAT continued the development of sol-gel selective coatings. Au/TiO_2 selective absorbers were prepared and characterized with 0.90 solar absorptance and about 0.2 thermal emissivity, with excellent thermal stability and no thermal alteration at 500ºC. Hemispherical reflectance of different thicknesses of a cermet sol-gel absorber deposited over electro-polished aluminum is shown in **Fig. 5.15**. Options for replacing noble metals used so far as infrared reflectors in high temperature absorbers have been investigated also, as well as protective silica layers for metal substrates. So efficient silica layers have been developed to protect aluminum (500ºC), nickel (400ºC) and copper (300ºC).

In addition to the selective coatings for medium temperature applications, CIEMAT has also prepared and characterized CoS/TiO_2-selective solar absorbers for low-temperature applications, thus achieving a 0.95 solar absorptance and 0.3 thermal emittance at 100ºC. The high thermal emissivity was due to the presence of residual organic matter in the absorber coating. Next activities will attempt to reduce this value.

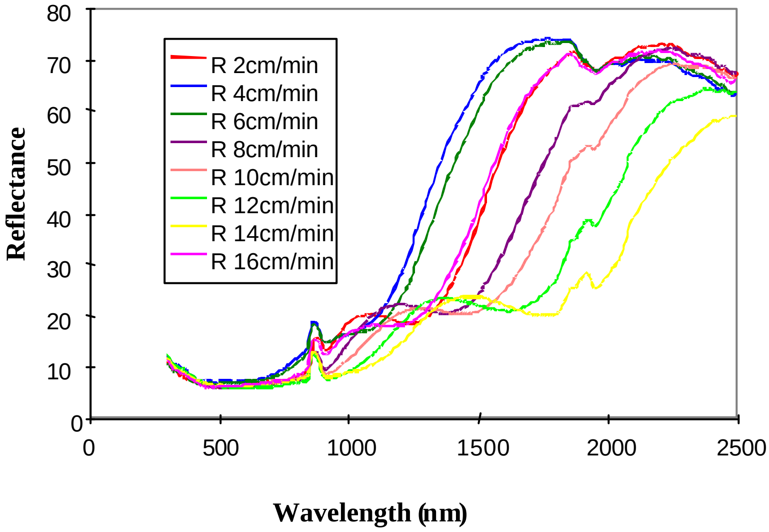

Fig. 5.15 Hemispherical reflectance of different thicknesses of a cermet sol-gel absorber deposited over electro-polished aluminium. A withdrawal-rate (R) increase leads to increase in layer thickness.

In 2000, CIEMAT was able to increase glass transmissivity from 0.92 to 0.96 by means of a silica-based anti-reflectance (AR) coating with good mechanical resistance.

For sol-gel applications, CIEMAT has also developed a new electroless bath for silver film coating, thus enhancing specularity of front-surface reflectors and reducing the silver consumption per square meter.

Process Heat Applications

Exploration of Market Niches for Parabolic Trough Applications

Contact – Klaus Hennecke, DLR

Participants: DLR (D); IST (USA)

Funding – SolarPACES task-shared activity, total costs estimated at 2 person-year in 2000

The objective of this activity is to develop concepts for potential new early commercial plants and to market these concepts to potential developers

Results achieved in 2000 with regard to the work packages defined in the PoW are:

1. System testing and modeling:
The IPH demonstration facility "SOPRAN" at DLR Cologne has been operated to collect reliable efficiency data for the modeling of different applications. Some modifications have been implemented (different reflector material, end reflector to reduce end losses), and their effect on the system performance is under in-

vestigation. In 2001, new absorber tubes with integrated secondary reflector will be installed and evaluated.

2. Demonstration of solar process steam generation

Basic design and operating parameters for process steam generation in small trough systems have been determined in the course of a pre-feasibility study for solar process steam integration at a porous concrete production facility. The experimental validation of these results at the SOPRAN test facility had to be postponed due to lack of funding. It is planned to investigate the potential of solar steam for cooling applications, and to demonstrate a solar steam cooling system at the DLR SOPRAN test facility, subject to availability of funding.

3. Development and demonstration of small roof-mountable trough (RMT)

The RMT has been developed by IST, and a prototype was assembled. 100 m² will be provided for a demonstration project at a hotel in Turkey, to be integrated in a solar assisted air conditioning system. The project is funded from private sources and the state of Nordrhein-Westfalen (Germany). Performance monitoring and scientific evaluation will be carried out by DLR.

4. Concept marketing

Several conceptual design and numerical performance simulation studies were carried out for different applications, including district heating with or without seasonal heat storage, industrial process heat (hot water or steam) and cogeneration. The results were presented in conferences and workshops, leading to an increased visibility of concentrating solar technology, and growing interest of potential users. It is intended to follow-up the most promising contacts with a view to realize one or more demonstration projects.

Advanced Hybrid Plant Concepts

SOLBIO: Solar-Biomass Hybrid Tower Power Plant (Contact: M. Romero, CIEMAT)

Participants: IBERESE, SERLED, INABENSA and CIEMAT (E)

Funding: national program, total costs N/A

A feasibility study on the solar-biomass hybrid tower power plant system has been conducted in Spain. The study included a GIS-driven analysis of solar and biomass resources in Andalusia, with selection of potential sites.

Two kind of solar systems were used for integration with biomass, a PS10-type air-cooled solar tower plant and a COLON-type saturated-steam solar tower plant. For the saturated-steam plant the major issues were the way to achieve a significant solar share and how to solve the solar transients with the relatively

high inertia of the biomass combustor. For this design, the saturated steam produced in the solar receivers was mixed in the boiler of the biomass combustion chamber. Regarding the minimum solar share, a turbine with flow rate regulation was selected, with an operating margin of up to 140% load and two admission valves. With this operating strategy, a 23% annual solar share was estimated.

The second integration with volumetric receiver and PS10 configuration showed fewer restrictions concerning transients and solar share. Steam was produced in a recovery boiler consisting of a water/air heat exchanger. Hot air was the result of mixing outlet air coming from the solar receiver and the biomass gasifier. The design includes two gasifiers able to work in parallel with a technical lower limit of 40% load each. Depending on operational overnight strategies, annual solar shares were between 23 - 33%.

The economic analyses for a 10-MW_e plant with the above mentioned solar shares and power production between 76-110 GWh_e/yr, revealed an LEC of Euro cents 7.5/kWh. The SOLBIO is considered an interesting option in Spain for the PS10-type project at certain sites where biomass prices are competitive (Euro cents 0.5/kWh_{th}).

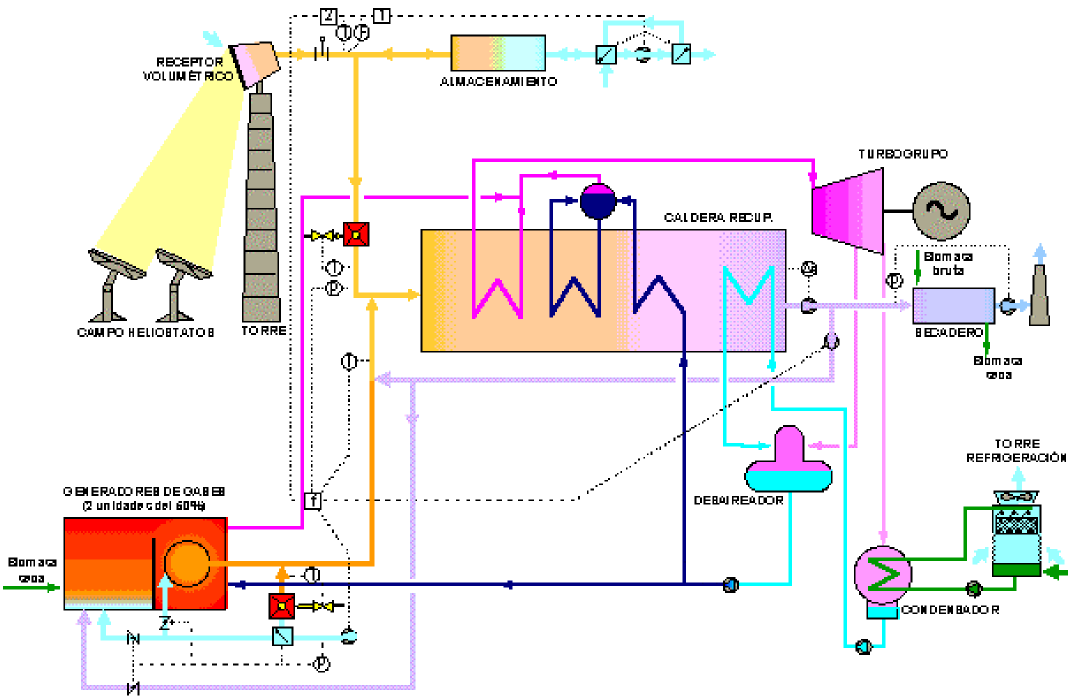

Fig. 5.16 Design concept for a Solar-Biomass Hybrid Tower Power Plant

5.7 Outlook

The next few years will be very exciting for Task III. R&D projects, led by industry and including substantial industrial resources, are currently preparing the next generation technology, needed to significantly lower costs and increase plant output.

Computer tools have come far and are ready to be applied in the scope of the ongoing project development reported under Task I, and will serve to optimize plant design.

Robust measurement systems will be needed based on current lab systems to allow for quality control during construction and start-up of theses new power projects.

A small market for concentrating collectors for process heat application is also about to emerge. Finally, a standardization task is becoming more and important as the projects start to develop.

Technologies which are the key to further cost reduction include:

- New coatings for absorbers and reflectors
- New cycles or media for cycles
- High temperature materials
- Energy storage for sensible and latent heat in the range from 400°C to 1200°C
- Improved remote sensing and evaluation methods for satellite site identification

5.8 Meetings, Reports Publications

5.8.1 Meetings

- On the occasion of the 58th Meeting of the Executive Committee in Sydney, Australia, the 14th Meeting of Task III Working Group took place on March 14th, 2000.
- The 15th Meeting of the Task III Working Group took place jointly with the Task I Working Group Meeting on the occasion of the 59th Meeting of the Executive Committee in Cairo, Egypt, at the NREA Wind Energy Center, Hurghada, Egypt, on September 23, 2000.
- The first SolarPACES Task III Workshop on Simulation of Solar Thermal Power Systems took place in Cologne, Germany, on September 28/29, 2000.

5.8.2 Literature

a) SolarPACES Technical Reports

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[5.03] SolarPACES TR-III-3/00 – R. Pitz-Paal, P. Schwarzbözl (Ed) Proceedings of the SolarPACES Task III Workshop on Simulation of Solar Thermal Power Systems, Cologne September 28/29, 2000

b) other

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[5.05] Buck R., Lüpfert E., Téllez F. (2000): Receiver for Solar-Hybrid Gas Turbine and CC Systems (REFOS), *Proceedings 10th SolarPACES Int. Symposium 'Solar Thermal 2000'*, March 8-10, 2000, Sydney, Australia, pp.95-100

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[5.07] G. García, A. Egea, M. Romero and J.A. Gázquez (2000), " The stand-alone heliostat first operation results". *Proceedings Solar Thermal 2000-Renewable Energy for the New Millennium Conference*, Sydney, Australia, 8-10 March, 2000. Eds: H. Kreetz, K. Lovegrove and W. Meike; Australian and New Zealand Solar Energy Society, Sydney; pp. 165-170.

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