International Energy Agency (IEA)

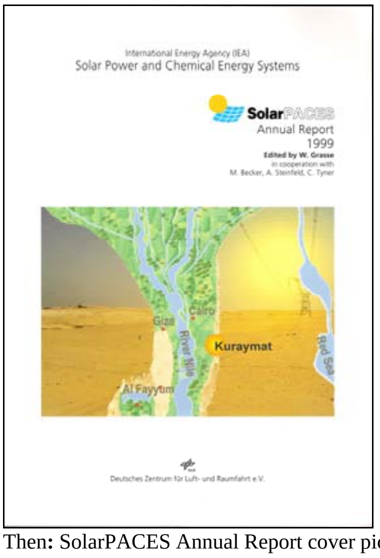
Solar Power and Chemical Energy Systems

SolarPACES

Annual Report 2008

Edited by C. Richter
in cooperation with
J. Blanco, P. Heller, M. Mehos
A. Meier, R. Meyer, W. Weiss

Deutsches Zentrum für Luft- und Raumfahrt e.V.



Then**:** SolarPACES Annual Report cover picture in 1999

Cover picture 2008

Now: The dawning of concentrating solar power in Kuraymat, Egypt. Photo courtesy Solar Millennium AG.

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May, 2009

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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.

Editors

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Foreword

Tom Mancini
Chairman, SolarPACES
Executive Committee

Hello All,

It has been reported that a series of Chinese (or maybe Western European) curses, each more severe than the previous one, reads……

May you live in interesting times.

May you come to the attention of those in authority.

May you find what you are looking for.

From the development of CSP projects and markets over the past year, we might interpret these curses in any number of ways. One way to look at the situation is that the times are indeed interesting – Andasol 1 came on line and more than 12 GWs of CSP capacity are under purchase power agreements around the world but, with the current economic situation, financing is difficult to secure. Those in authority seem to recognize the value of electricity generated by CSP technologies and are trying to place an economic value on the emission of carbon into the atmosphere. We are looking for projects to be financed, break ground, complete construction and start producing carbon-free electrical power. All in all, if we can break the log jam of project finance, this isn't an awful situation at all. In fact, it is an encouraging one.

With the additions of the Republic of Korea, the UAE, and soon Italy and Austria, SolarPACES' membership will grow to 16 countries. At our last Executive Committee meeting, we also authorized the admission of CSP companies as members of Task Working Groups. As an international organization, we are in a unique position to support CSP projects and influence decision makers around the world. Our activities are evolving and we continue to find and support new ones. I invite each of you to become more involved in the organization by participating in our Task Groups and Symposia. Please let us know what we can do to help promote projects and/or provide R&D or test support for the CSP industry.

I want to express my heartfelt thanks to Dr. Michael Geyer for his efforts as SolarPACES Executive Secretary from 2000 through 2008. Michael was instrumental in getting the Global Market Initiative started and represented SolarPACES very effectively at a number of meetings and conferences. He is a special individual and a great friend to us all; he will be missed. Please join me in wishing Michael the best of luck in his new position as Director of International Business Development for Abengoa Solar.

With every rain shower comes the sunshine and rainbow on the other side. We are extremely fortunate to have as our incoming Executive Secretary Dr. Christoph Richter of the DLR. Many of you know Christoph very well and have worked with him over the years in his position as the Operating Agent for Task III. Dr. Richter joined the DLR (German Aerospace Center) at the Plataforma Solar de Almeria after obtaining his Ph. D. in Physical Chemistry at the University of Cologne. Having worked in the areas of photochemical applications of solar energy for water purification and solar thermal power plant operation, Christoph is an experienced researcher. Since July 2001, he has managed the DLR's Solar Research Group at the PSA. My personal experience working with Christoph is totally positive – he is conscientious, forward thinking, and willing to help solve problems and take on assignments. We are very fortunate to have him working with us.

Last, I want to thank the Executive Committee and Operating Agents for your support and good work during this past year.

Best Regards,

SolarPACES Chair

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List of Acronyms

A	Austria
AEE	Arbeitsgemeinschaft Erneuerbare Energie (A)
AICIA.........	Asociación de Investigación y Cooperación Industrial de Andalucia (E)
ALG............	Algeria
ANL............	Argonne National Laboratory (USA)
ANU	Australian National University (AUS)
AOP............	advanced oxidation process
APTL..........	Aerosol and Particle Technology Laboratory (GR)
ARM...........	Atmospheric Radiation Mission (US DOE)
ASES	American Solar Energy Society
ASIC...........	Austria Solar Innovation Center
ASTM.........	American Society for Testing and Materials (USA)
AUS............	Australia
B	Belgium
BEU............	Bonnet (integral cover), one-pass shell, U-tube bundle heat exchanger
BFE.............	Swiss Federal Office of Energy (CH)
BGU............	Ben Gurion Univ. of the Negev (IL)
BMU...........	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (D)
BMZ	Federal Ministry for Technical Cooperation and Development (D)
BSRN..........	Baseline Solar Radiance Network (WMO)
CA...............	California (USA)
CA ISO	California Independent System Operator
CAM...........	Government of the Autonomous Region of Madrid
CanMet	Meteorology Canada
CAS	Chinese Academy of Science
CB...............	carbon black
CDER	Centre de Développement des Energies Renouvelables (MRC)
CEA	Commissariat à l'Energie Atomique (F)
CENER........	Centro Nacional de Energías Renovables (E)
CENIM	Centro Nacional de Investigaciones Metalúrgicas (E)
CERTH........	Centre for Research & Technology Hellas (GR)
CESI	Centro Elettrotecnico Sperimentale Italiano
CFD	computational fluid dynamics
CFE.............	Comisión Federal de Electricidad (MEX)
CH...............	Switzerland
CIE..............	Energy Research Centre, UNAM (MEX)
CIEMAT......	Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (E)
CLFR...........	compact linear Fresnel reflector
CNR............	Consiglio Nazionale delle Ricerche (I)
CNRS...........	Centre National de la Recherche Scientifique (F)
CONACYT..	Centro Nacional de Ciencia y Tecnología (MEX)
COP	coefficient of performance
CPC.............	compound parabolic collector
CPERI..........	Chemical Process Engineering Researc Institute, CERTH (GR)
CPTEC.........	Center of Weather Forecast & Climatic Studies (BRA)
CR5.............	counter rotating ring receiver reactor recuperator
CSIC	Consejo Superior de Investiación Científica (E)
CSIRO	Commonwealth Scientific and Research Organisation (AUS)
CSP.............	concentrating solar power
CST.............	concentrating solar technologies
CT...............	computer tomography

D	Germany
DBU	Deutsche Bundesstiftung Umwelt (D)
DG RDT	Directorate General Research Development and Technology (EC)
DG TREN	Directorate General Transport and Energy (EC)
DISS	Direct Solar Steam
DK	Denmark
DLR	Deutsches Zentrum für Luft- und Raumfahrt e.V. (D)
DLR ISIS	irradiance at the surface derived from ISCCP cloud data
DNI	direct normal irradiation
DOC	dissolved organic carbon
DOE	Department of Energy (USA)
DSG	direct steam generation
E	Spain
EC	European Commission
ECMWF	European Centre for Medium-Range Weather Forecasts
EdM	Ecole des Mines, Armines (F)
EDS	European Desalination Society
EGY	Egypt
EHF	Energy and Seminconductor Research Laboratory (U. Oldenburg)
ENEA	Agency for New Technology, Energy and Environment (I)
ENEL	**E**nte **N**azionale per l'**E**nergia e**L**ettrica (I)
ENTPE	Ecole Nationale des Travaux Publics de l'Etat (F)
EPC	engineering, procurement, construction
ESI	School of Engineering, Univ. Seville (E)
ESTIA	European Solar Thermal Industry Association
ETH	Institute of Energy Technology (CH)
EU	European Union
ExCo	Executive Committee (SolarPACES)
F	France
FP5, FP6, FP7	5th, 6th ,7th Framework Programme (EC DG RDT)
Fhg-ISE	Fraunhofer-Institut für Solare Energiesysteme in Freiburg (D)
FUSP	Fundação de Apoio a Universidade de São Paulo (BRA)
GA	General Atomics (USA)
GAS	GMES Atmosphere Service
GAW	Global Atmosphere Watch (WMO)
GEBA	Global Energy Balance Archive
GEF	Global Environmental Facility
GEOSS	Global Earth Observation System of Systems
GEWEX	Global Energy and Water Cycle Experiment
gge	gasoline gallon equivalent
GHI	global horizontal irradiance
GISS	Goddard Institute for Space Science (US NASA)
GMAO	Global Modeling and Assimilation Office (US NASA)
GMI	Global Market Initiative
GMES	Global Monitoring of Environment and Security
GR	Greece
GSFC	Goddard Space Flight Center (NASA)
GTER	Grupo de Termodinámica y Energías Renovables, AICIA (E)
HCE	heat collection element (parabolic trough)
HFSF	High Flux Solar Furnace
HFSS	High Flux Solar Simulator (PSI)
HHV	higher heating value
HPLC-UV	
HTF	heat transfer fluid
HTF	heliostat test field
HyS	Hybrid sulfur cycle
HPLC-UV	High-Performance Liquid Chromatography with UV Detector:

I.................... Italy
IAP............... International Action Program
IBR .... Immobilized biomass reactor
ICP............... Instituto de Catálisis y Petroleoquímica (E)
ICV .... Instituto de Cerámica y Vidrio (E)
IDAE............ Institute for Energy Diversification and Saving (E)
IDMP .... International Daylight Measurement Program
IEA .... International Energy Agency
IEE............... Institute of Electrical Engineering (PRC)
IEM.............. Molecular Immunology and Embryology Laboratory, CNRS (F)
IIE................ Instituto de Investigaciones Eléctricas (MEX)
IL .... Israel
INCO .... International Cooperation Programme (EC)
INETI........... Instituto Nacional de Engenharia, Tecnologia e Inovação (P)
INTEC .... Institute for Sustainable Technologies, AEE, (A)
IR .... Ireland
IRSA .... Water Research Institute (CNR)
ISCCP .... International Satellite Cloud Climatology Project
ISCCS .... integrated solar combined-cycle system
ISES .... International Solar Energy Society
ISO............... International Standard Organization
ITC............... Instituto Tecnológico de Canarias (E)
ITT............... International Telephone and Telegraph (USA)

J .... Japan
JOR .... Jordan
JRC .... Joint Research Centre (EC)

KAU .... Korea Aerospace University
KEN............. Kenya
KfW .... Kreditanstalt für Wiederaufbau (D)
KIER............ Korea Institute of Energy Research
KJC .... Kramer Junction Company (USA)
KOR............. Korea

LEC.............. levelized electricity cost
LFR.............. linear Fresnel reflector
LHV .... lower heating value

MB............... mean bias
MHI .... Mitsubishi Heavy Industries
MENA .... Middle East and North Africa
MEX .... Mexico
MRC .... Morroco
MWTP .... municipal wastewater treatment plants

N .... Norway
NAC............. new selective absorber coating
NASA .... National Aeronautical and Space Administration
NASA LaRC Langley Research Center (USA)
NASA SSE .. Surface meteorology and Solar Energy
NC................ National Coordinator (Task 2)
NCTR .... non-concentrating tubular receiver
NDFD .... National Digital Forecast Database (USA)
NEAL .... New Energy Algeria
NERC .... National Energy Research Center (JOR)
NL................ Netherlands
NREA .... National Renewable Energy Agency (EGY)
NREL........... National Renewable Energies Laboratory (USA)

NSO .... Nevada Solar One (USA)
NV............... Nevada (USA)

O&M........... operation and maintenance
OA............... Operating Agent (SolarPACES)
OECD .... Organization for Economic Cooperation and Development
ONE .... Office National de l'Etlectricite (MRC)
ORC .... organic Rankine cycle

P .... Portugal
PAPIIT......... Programa de Apoyo a Proyectos de Investigacióne Innovación Tecnológica (UNAM) (MEX)
PCM............ phase change materials
PDVSA .... Petróleos de Venezuela
PE² .... Pinch Energy Efficiency
PET .... polyethylene terephthalate
POL............. Poland
PRC............. People's Republic of China
PROMES ..... Laboratoire Procédés, Matériaux et Energie Solaire, CNRS (F)
PSA .... Plataforma Solar de Almería (E)
PSE .... Projektgesellschaft Solare Energiesysteme GmbH,
PSI............... Paul Scherrer Institute (CH)
PVDSA .... Petróleos de Venezuela, S.A.
PVPS........... Photovoltaic Power Systems Agreement (IEA)
PVSEC......... European Photovoltaic Solar Energy Conference

QC............... quality control

RCSI .... Royal College of Surgeons in Ireland (IR)
REWP .... Renewable Energy Working Party
RFP .... request for proposal
RPC............. reticulate porous ceramic
RMSD.......... Root Mean Square Deviation
RPS .... Renewable Energy Portfolio Standard (Calif., USA)

S .... Sweden
SBP .... Schlaich Bergermann und Partner (D)
SCA............. solar collector assembly
SCC............. solar-driven combined sycle
SD .... standard deviation
SDIC .... Spatial Data Infrastructure Community
SEGS........... Solar Electric Generating Systems
SEIA .... Solar Energy Industries Association (USA)
SEPA........... Solar Electric Power Association
SES .... Stirling Energy Systems, Inc.
SEWPA........ Solar Energy and Water Processes and Applications (Task 6)
SHAP .... Solar Heat And Power S.p.A. (I)
SHC............. Solar Heating and Cooling Implementing Agreement (IEA)
SHIP............ Solar Heat for Industrial Processes
SI................. sulfur-iodine cycle
SME .... small and medium enterprises
SNL............. Sandia National Laboratories (USA)
SOAP .... Simple Object Access Protocol
SODIS.......... Solar Water Disinfection
SolarPACES Solar Power and Chemical Energy Systems
SONDA........ National Network of Environmental Data for Renewable Energy Resource Assessment (BRA)
SPG............. Solar Power Group
SPR .... solid particle receiver
SPWTP .... Solar photocatalytic water treatment plant
SRB............. Surface Radiation Budget
SSE .... Surface Meteorology and Solar Energy dataset (US NASA)
SSPS .... Small Solar Power Systems (IEA)

ST .... solar thermal
START .... Solar Thermal Analysis, Review and Training (SolarPACES)
SUNY .... State Univ. of New York
SWERA .... Solar and Wind Energy Resource Assessment (UNEP)

TCE............. trichloroethylene
TEM............ transmission electron microscope
TEMA.......... Tubular Exchanger Manufacturers Association
TG................ thermogravimeter
TGA............ thermogravimetric analysis
TUN............ Tunisia

UB................ Univ. Bremen (D)
UC................ Univ. Colorado (USA)
UK .... United Kingdom
UNDP .... United Nations Development Program
UNED .... National Univ. Distance Education (E)
UNEP........... United Nations Environment Program
UNIGE......... University of Geneva (CH)
UNLV .... Univ. Nevada Las Vegas (USA)
UPNA .... Public Univ. of Navarra (E)
USA .... United States of America
USACH........ Univ. Santiago de Chile
UTE .... Unión Temporal de Empresas (joint venture) (E)

VOCs .... volatile organic chemicals
VR................ vacuum residue

WGA .... Western Governors Association (USA)
WH .... Westinghouse cycle
WIS............. Weizman Institute of Science (IL)
WMO........... World Meteorological Organization
WRDC .... World Radiation Data Center
WRF .... Weather Research and Forecasting model
WSDL.......... Web Services Description Language

YEM .... Yemen

ZA................ Republic of South Africa
ZAE .... Zentrum für Angewandte Energieforschung e.V.
ZSW............ Zentrum für Sonnenenergie und Wasserstoff-Forschung (D)
ZWE .... Zimbabwe

1 Report of the SolarPACES Executive Committee for 2008

Christoph Richter
IEA SolarPACES
Executive Secretary

Part 1 of this Report, which gives an overview of results and achievements of the SolarPACES Implementing Agreement in 2008, is submitted to the IEA by the SolarPACES Executive Committee.

Part 2 summarizes an overview on the current state and perspectives of Solar Fuel production, on the backdrop of this topic's growing importance in the past few years. The full overview will be available shortly as a SolarPACES brochure on Solar Fuels.

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

As in previous years, it is also the aim of the Annual Report for the year 2008 to inform member country institutions and partners inside and outside the IEA on progress in developing Concentrating Solar Technologies (CST) for near and long-term competitive markets. In this sense, this report exceeds the formal IEA reporting requirements.

1.1 Objectives, Strategy and Scope

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

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

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

Specific examples of expanded outreach and market development are:

- In 2002, SolarPACES joined forces with UNEP, the Global Environmental Facility (GEF) and the Solar Thermal Industry Associations of Europe and the U.S.A. to develop the Concentrating Solar Power (CSP) Global Market Initiative (GMI) to facilitate building 5,000 MW of CSP power plants worldwide over the next ten years. This initiative represents the world's largest coordinated action in history for the deployment of solar electricity.

IEA SolarPACES *VISION*	Our vision is that concentrating solar technologies contribute significantly to the delivery of clean, sustainable energy worldwide
IEA SolarPACES *MISSION*	Our mission is to facilitate technology development, market deployment and energy partnerships for sustainable, reliable, efficient and cost-competitive concentrating solar technologies by providing leadership as the international network of independent experts
IEA SolarPACES *STRATEGY*	Our strategy is to: • coordinate and advance concentrating solar technology research by focusing on the next generation of technologies; • provide information and recommendations to policy makers; • organize international conferences, workshops, reports and task meetings in order to facilitate technology development and market deployment; • provide opportunities for joint projects in order to encourage energy partnerships between countries; • develop guidelines and support standards in order to increase the transparency of the market and reduce risks associated with project development; • manage the undertaking of independent studies of strategic interest; • leverage our activities with other IEA implementing agreements and renewable energy organizations.

- In 2004, the SolarPACES GMI proposal was included in the International Action Program (IAP) of the International Conference for Renewable Energies, held 1-4 June 2004, in Bonn, Germany.
- In 2007, the CSP Global Market Intiative joined forces with the EMPower project, sponsored by the Global Environment Facility (GEF) through the United Nations Environment Programme (UNEP), KfW (the German Development Bank) and the Solar Electric Power Association (SEPA) and the German Ministry for Technical Cooperation and Development (BMZ).
- Reaching out to other IEA Implementing Agreements, SolarPACES has extended its collaboration to the PVPS and SHC implementing agreements on the crosscutting issues of solar resource assessment and the application of CSP technologies for industrial processes.
- Recently, SolarPACES responded to an invitation to participate in the IEA Office for Energy Technology and R&D Gleneagles program of work for the proposed Climate Change, Clean Energy and Sustainable Development Initiative. Of the G8 Plus Five countries, six are active participants in SolarPACES (France, Germany, the United States, Mexico, Italy, and South Africa), and three other countries have participated in the past (Brazil, Great Britain and Russia).

The IEA SolarPACES Vision, Mission and Strategy are described in the IEA SolarPACES Strategic Plan and were updated at the ExCo Meeting in Nov. 2008 in Almería, Spain, as shown in the box above. The IEA SolarPACES vision and mission statements focus on overcoming the technical, non-technical, institutional, and financial barriers to the deployment of CSP technologies.

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

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

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

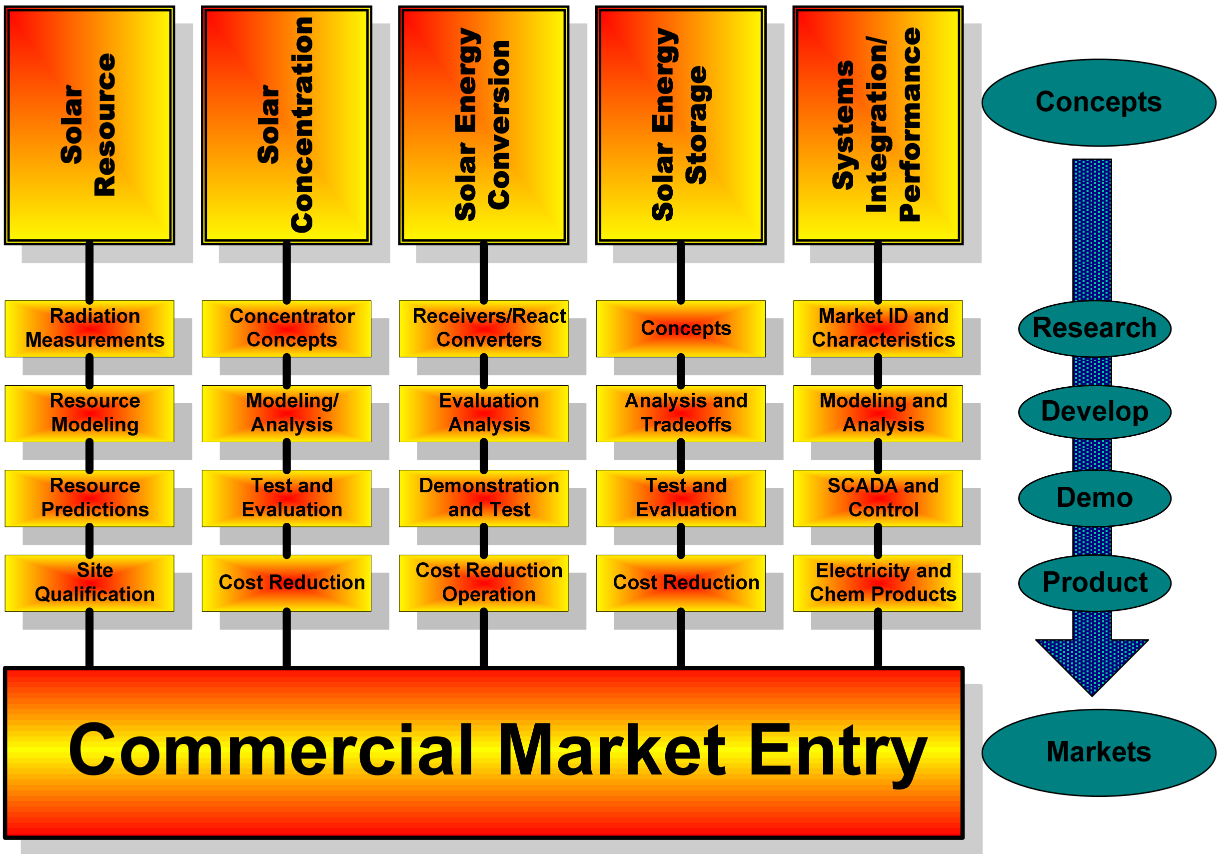


Figure 1.1. Scope of CSP research, development and demonstration work

Table 1.1. SolarPACES Contracting Parties as of December, 2008

Country	Represented by	Govt.	R&D Institute	Industry	Electric Utility	ExCo Member
Algeria	NEAL		X			Badis Djerradi
Australia	Consortium		X			Wesley Stein
Egypt	NREA	X				
European Union	DG-RTD DG-TREN	X				Rolf Ström Pietro Menna
France	CNRS		X			Alain Ferriére
Germany	DLR		X			Robert Pitz-Paal
Israel	WIS		X			Michael Epstein
Mexico	IIE		X			Jorge Huacuz Villamar
Republic of Korea	KEMCO	X				Chang-Hyun Jeong
South Africa	ESKOM				X	Louis van Heerden
Spain	CIEMAT		X			Diego Martínez Plaza
Switzerland	Planair			X		Pierre Renaud
United States of America	Department of Energy	X				Frank Wilkins

A few examples illustrate the range of the work of SolarPACES. Cooperative development and testing of key solar components, including advanced concentrators and receivers, has helped reduce the costs and improve the reliability of concentrating solar technology. System tests of pilot-scale plants, such as the 10-MW Solar Two power tower in the United States and the DISS trough system in Spain have demonstrated the performance and reliability data needed to predict commercial plant performance. Similarly, cooperative action on systems operation and maintenance has led to reduced costs at the commercial Kramer Junction parabolic trough plants in the United States, and will help ensure cost-competitiveness at future concentrating solar power plants. The SolarPACES "START" (Solar Thermal Analysis, Review and Training) team missions have assisted in the introduction of concentrating solar power in developing Sunbelt countries. By sending an international team of experts, independent technical advice has been made available to interested countries including Egypt, Jordan, Brazil, Mexico and Algeria. START missions to Algeria, Egypt, and Mexico have already contributed to the first phase of planning concentrating solar power plants in these countries. In solar chemistry research, where the commercialization goals are more long-term, SolarPACES has succeeded in building and promoting international interest, defining research priorities, and facilitating cooperative international research.

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

As of December 2008, 13 countries, or organizations designated by their governments, participate in IEA SolarPACES as shown in Table 1.1.

The SolarPACES Implementing Agreement has attracted ***non-IEA member countries***, Algeria, Egypt, Israel, Mexico, and South Africa, which possess excellent solar resources for the application of solar concentrating technologies. Task Participation is shown in Table 1.2, where (X) indicates the Operating Agent.

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

Table 1.2. *Task Participation.*

SolarPACES Task	ALG	AUS	EC	EGY	F	D	IL	KOR	MEX	RSA	E	CH	USA
I. CSP Systems	x	x	x	x	x	x	x	x	x	x	x		(X)
II. Solar Chemistry		x	x		x	x	x	x			x	(X)	x
III Technology and Advanced Applications	x	x	x		x	(X)	x		x	x	x	x	x
IV SHIP Solar Heat for Industrial Processes	Task completed 10/2007												
V Solar Resource Knowledge Management	x			x		x			x		x		(X)
VI Solar Energy and Water Processes And Applications	x			x		x	x		x		(X)		

Industry and utility partners are actively participating in the Tasks and their technical meetings and seminars, as reported in detail in the SolarPACES Annual Reports. Since the announcement of renewable electricity incentive programs in the European Union, industry and utility participation in the task meetings has increased sharply. At the last task meetings, over a dozen private firms were represented. At the last biennial Symposia, about half of the 500 participants come from industry and utilities. Industry actively participates in SolarPACES Tasks and other activities as partners. Task I, which focuses on CSP systems and is most closely related to market and near-term demonstration projects, is the most prominent example. Industry is responsible for over 50% of the information sharing projects.

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

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

- Abu Dhabi, which has announced a 500-MW CSP program and is now preparing the construction of the first 100 MW plant, Shams 1.
- Algeria, which has awarded the first BOT Integrated Solar Combined Cycle in North Africa
- China, which has announced the implementation of the first 100 MW of CSP in its current five year plan
- France, which published a solar electricity feed-in tariff in 2006
- Greece, which published a CSP feed-in tariff in 2006
- Italy, which published a feed-in tariff in 2008.
- Morocco, where ONE, the national utility, has awarded a combined cycle plant with integrated CSP in Ain Beni Mathar
- Portugal, where a new CSP feed-in law has been published

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

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

1.3 *The SolarPACES Work Program*

SolarPACES member (contracting party) activities are carried out through cooperative research, technological development and demonstration, and exchange of information and technical personnel. As the nature of electric power technologies would imply, the parties involved comprise governments, public research institutions, industrial suppliers, electric utilities, and international financing entities. They all cooperate by means of information exchange, formal and informal initiation of joint or national activities – task-shared as well as cost-shared – and also by sharing the costs of mutually agreed-upon activities. In the period under review, the work within IEA SolarPACES was structured in the five main Tasks with a number of Subtasks as shown in Figure 1.2. Tasks IV and V are collaborative activities with the Solar Heating and Cooling (SHC) and the Photovoltaic Power Systems (PVPS) Implementing Agreements. Task IV was completed in 10/2007. For detailed information on task organization and results of work please refer to the respective chapters in Parts 3 – 8 of this report.

The collaboration that was earlier focused on Research, Development and Demonstration is now increasingly also emphasizing large-scale worldwide deployment. The new Task VI on "Solar Energy and Water Processes and Applications" will provide the solar energy industry, the water and electricity sectors, governments, renewable energy organizations and related institutions in general with the most suitable and accurate information on the technical possibilities for effectively applying solar radiation to water processes, replacing the use of conventional energies.

1.4 Coordination with Other Bodies

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

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

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

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

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

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

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

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

1.5 Information Dissemination

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

The 14th Symposium, held from March 4 – 7, 2008 in Las Vegas, Nevada, USA, confirmed with about 500 participants, including a growing share of participants

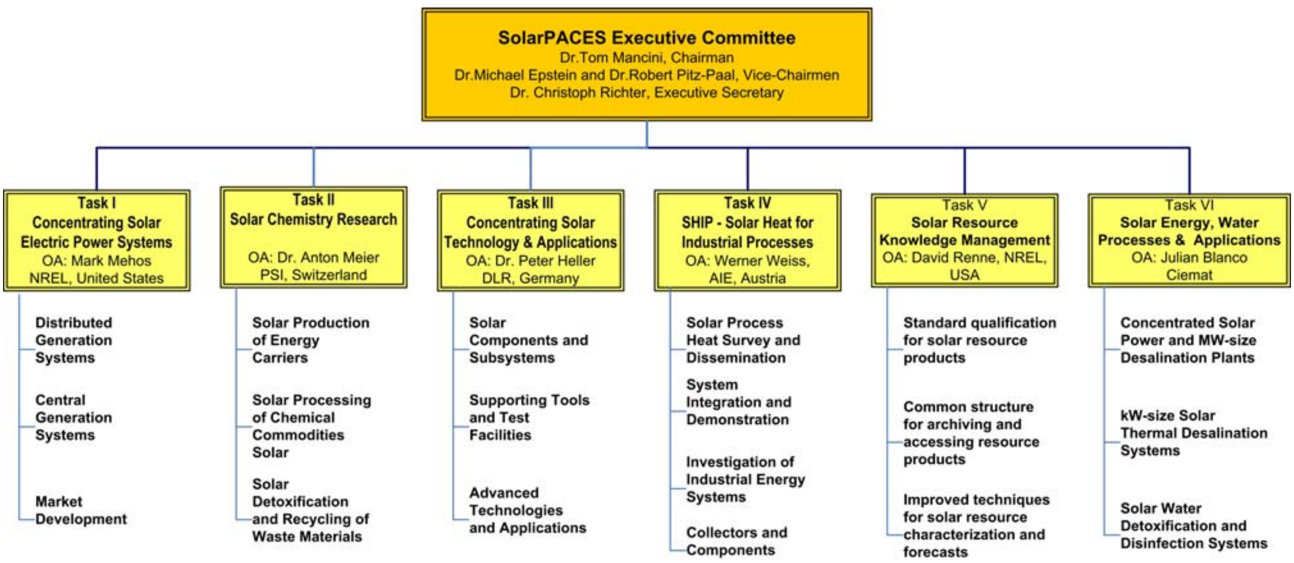


Figure 1.2. Organization of Work within the SolarPACES Task Structure

from industry, the dynamic growth in participation seen in the other recent Symposia, with about 230 in Zurich, Switzerland (2002), 230 in Oaxaca, Mexico (2004), 500+ in Seville, Spain (2006).

The increasing interest of the public and the success of the Symposia contributed to the decision to change to a yearly schedule of Conferences. The next (15th) Conference is planned for 15th – 18th September 2009 in Berlin, Germany (see www.solarpaces2009.org) and the following for autumn 2010 in Perpignan, France.

SolarPACES publications on CST and sharing national CST publications through SolarPACES-wide distribution lists have become another important means of information sharing**.** The ***SolarPACES Annual Report 2007*** was published and distributed to 500-1000 interested experts worldwide, giving detailed literature references and contact addresses to encourage further cooperation.

A ***SolarPACES website*** at **www.solarpaces.org** has been implemented to provide information on the internet. It has had over 300,000 visitors since January 1, 2002. An updated version of this website is currently under preparation.

1.6 Scale of Activities in 2008

The calendar of general SolarPACES-related activities in 2008 is summarized below. For specific task activities please refer to the respective chapters of this report:

February	
5th – 6th	CSP overview presentation and Chairing in Greenpower CSP Conference, Barcelona
March	
3rd	74th ExCo Meeting in Las Vegas, Nevada, including Discussion with Industry on specific interest for further collaboration and SolarPACES activities
4th – 7th	14th SolarPACES Symposium
May	
15th – 18th	Participation in IEA workshop on Roadmap development for Energy technologies
28th – 29th	Participation in IEA workshop on Rural Energization
October	
1st	Participation in Workshop of e-futures Project "Harmonisation and Coordination of European Renewable Electricity Suppor mechanisms), Rome, Italy
2nd – 3rd	Participation in CSP Expo Solar Tech, Rome, Italy
15th – 16th	Participation in Solar Power Conference, San Diego, US
23rd	Conferencia de la Industria Solar, Chairing of CSP Session
November	
4th – 5th	75th ExCo Meeting, Almería, Spain
6th	ExCo Host Country Day, with visit to Andasol 1plant, and Novatec prototype plant
14th	Renewable Energy World Europe Advisory Board meeting, Berlin, Germany

Figure 1.3. 14th Symposium in Las Vegas, Nevada, March 2008

2 Special Report on Solar Fuels

A. Meier, C. Sattler, C. Richter

R&D work on the conversion of solar energy into storable and transportable chemical fuels by high-temperature thermal pathways has gained momentum during recent years. Promising progress has been made, and there has been strong growth in public interest, especially in the sustainable production of hydrogen as a future energy carrier.

Against this background, SolarPACES has edited a brochure on "Solar Fuels from Concentrated Sunlight" to provide an overview of goals, current status, and future perspectives in this emerging field. The following presents a summary of this comprehensive brochure.

The achievements are summarized in Part 4 – Task II: Solar Chemistry Research – of this SolarPACES Annual Report. Special focus was on the solar thermal production of fuels (hydrogen and syngas) and chemicals for the power, transportation and chemical sectors of the world energy economy.

Conversion of solar energy into chemical fuels is an attractive method of solar energy storage (Figure 2.1). Solar fuels, such as hydrogen, can be used for upgrading fossil fuels, burned to generate heat, further processed into electrical or mechanical work by turbines and generators or internal combustion engines, or used directly to generate electricity in fuel cells and batteries to meet energy demands whenever and wherever required by the customers. The challenge is to produce large amounts of chemical fuels directly from sunlight in robust, cost-effective ways while minimizing the adverse effects on the environment.

The success of solar thermal power generation – known as 'concentrating solar power' (CSP) – is already moving towards sustainable, large scale fuel production: concentrating solar radiation with reflecting mirrors provides high temperature process heat for driving efficient thermochemical processes. Although the technical feasibility of various technologies has been demonstrated, marketing these processes has been hindered by their economics.

Nevertheless, solar fuels are among the most promising technologies for curbing the growing demand for fossil fuels and mitigating their effects on climate change. For this, commercial implementation must steadily evolve, starting from the current state-of-the-art fossil fuel production technologies. To facilitate the introduction of new solar fuel production processes, the existing know-how from both the fuel production industry and the CSP research institutes should be merged. At a later stage, the emerging solar fuel technologies will be based on processes that are completely independent of any fossil fuel resources.

The main vector for this transformation is the production of hydrogen, a potentially clean alternative to fossil fuels, especially for use in transport. Today, however, more than 90% of hydrogen is produced by high-temperature processes from fossil resources, mainly natural gas. If hydrogen were generated from solar energy, it would be a completely clean technology. No hazardous waste or climate-changing byproducts are formed, and the only inputs to the process are sunlight and water. This is the vision outlined in the European Commission's 'European hydrogen and fuel cell roadmap', which runs up to 2050 (Figure 2.2).

2.1 *Solar fuel production*

There are basically three routes, singly, or in combination, for producing storable and transportable fuels from solar energy. The *electrochemical* route uses solar electricity made from photovoltaic or concentrating solar thermal systems, followed by an electrolytic process; the *photochemical / photobiological* route makes direct use of solar photon energy for photochemical and photobiological

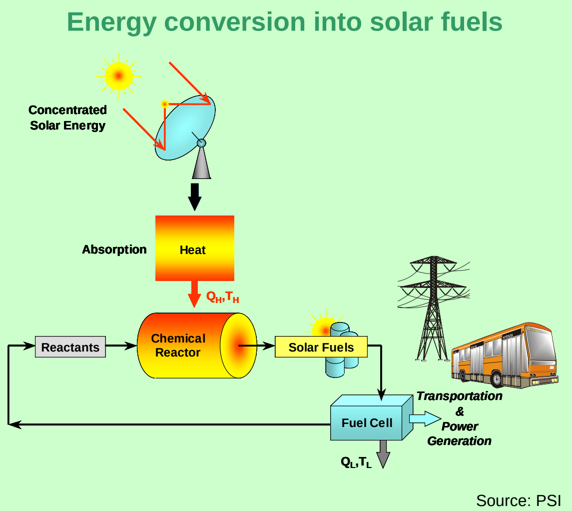


Figure 2.1. Concentrated solar radiation is used as the energy source of high-temperature process heat for driving thermo-chemical reactions towards the production of storable and transportable fuels.

processes; and the *thermochemical* route uses high temperature solar heat followed by an endothermic thermochemical process.

The thermochemical route offers some intriguing thermodynamic advantages with direct economic implications.

2.2 Concentrating solar technologies

The state-of-the-art CSP technology capable of achieving high process temperatures is the 'solar tower' configuration, in which a field of heliostats (tracking mirrors) focuses the Sun's rays onto a solar receiver mounted on top of a centrally located tower. Such solar concentrating systems already operate in large-scale pilot and commercial plants, such as the 11-MW_e PS10 plant near Seville in Spain, which has been delivering solar generated electricity to the grid since 2007. They make use of a heat transfer fluid (air, water, synthetic oil, helium, sodium, or molten salt) that is heated by solar energy and then used in traditional steam or gas turbines. The typical land area required for a 50-MW_{th} plant is about 300,000 m^2.

Solar thermochemical applications, although not as far advanced as solar thermal electricity generation, employ similar solar concentrating technologies. However, high-temperature thermochemical processes require higher solar concentration than CSP plants, which has an impact on heliostat field layout and plant operation (Figure 2.3).

For efficient development of solar fuel production technologies, in particular solar hydrogen, dedicated concentrating research facilities – solar furnaces and solar simulators – are employed. The largest solar furnaces currently operating in France and Uzbekistan have a thermal power of 1 MW.

2.3 Solar hydrogen

Clean hydrogen production will be based on water and energy from renewable sources. Replacing fossil fuels with renewable energy will shift the balance between electricity and fuels. For many applications, electricity will be used instead of fuels, but two major applications will require a massive production of solar hydrogen. Firstly, renewable energy must be stored for balanced use, and secondly, mobility will probably be based on fuels rather than electricity.

The European Union's World Energy Technol-

European hydrogen and fuel cell roadmap – a challenging vision

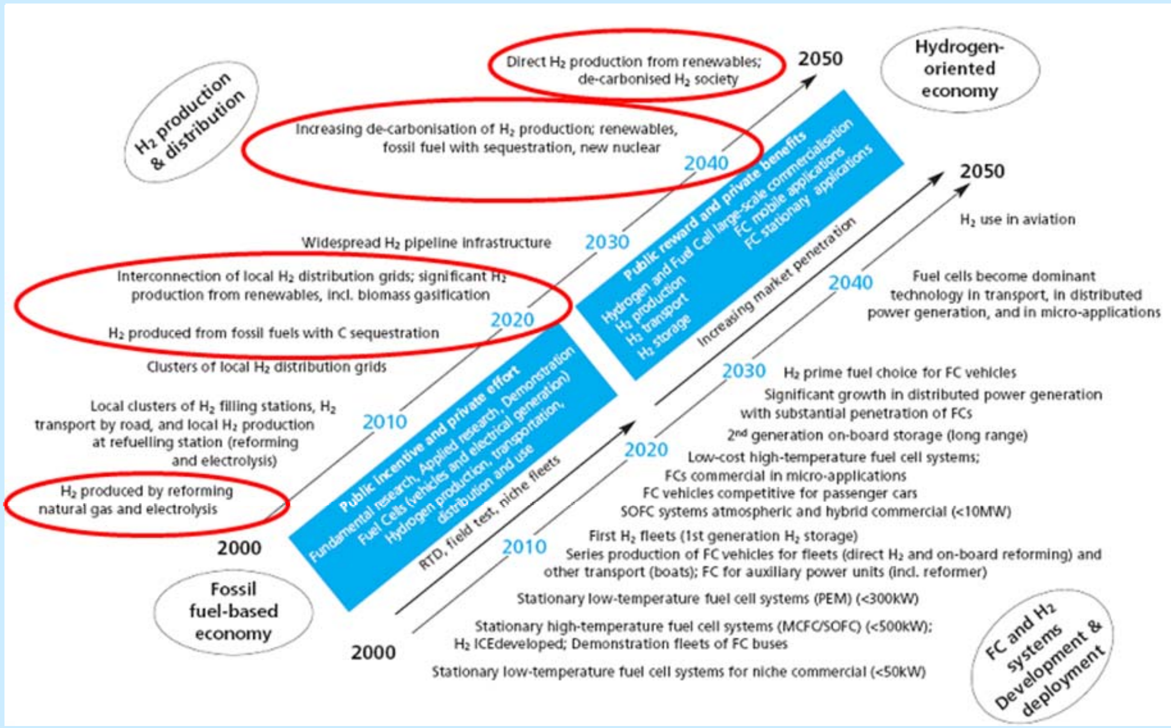
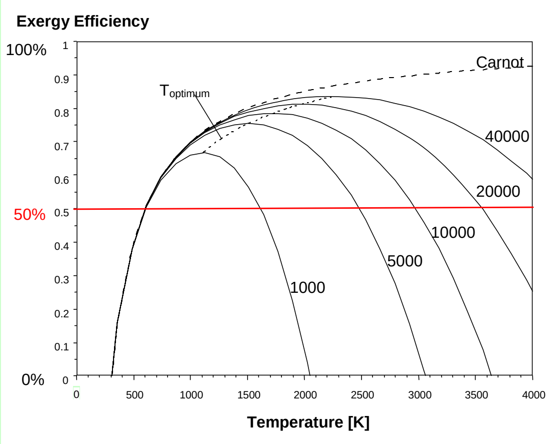


Figure 2.2. *Today, H_2 is produced by reforming of natural gas and electrolysis. In 2020, a significant amount of H_2 will be produced by renewables, and increasing decarbonization of H_2 production is expected for 2040. In a decarbonized H_2 society around 2050, H_2 will be produced directly from renewables.*

Exergy efficiency



Source: Fletcher & Moen, *Science*, 1977

Figure 2.3. Variation of the ideal exergy efficiency as a function of the process operating temperature for a blackbody cavity-receiver converting concentrated solar energy into chemical energy. The mean solar flux concentration is the parameter (given in units of 1 sun = 1 kW/m²): 1000; 5000; …; 40,000 suns. Also plotted are the Carnot efficiencies and the locus of the optimum cavity temperature $T_{optimum}$.

ogy Outlook scenario predicts a hydrogen demand equivalent to about 1 billion tons of oil in 2050.

Solar electricity generated by CSP technology, and followed by electrolysis of water, is a viable technical route for producing hydrogen. It can be considered as a benchmark for other routes, such as solar-driven water-splitting thermochemical cycles that offer the potential of energy efficient large-scale production of hydrogen. The projected costs of hydrogen produced by CSP and electrolysis, assuming solar thermal electricity costs of 0.08 $/kWh$_{el}$, range from 0.15-0.20 $/kWh, or 6-8 $/kg H_2.

There are also a range of thermochemical routes to solar production of hydrogen. All of these involve energy consuming (endothermic) reactions that make use of concentrated solar radiation as the source of high temperature process heat.

2.4 Economic solar hydrogen

The economic competitiveness of solar fuel production is closely related to two factors, the cost of fossil fuels and the need to control the world climate by drastically reducing CO_2 emissions.

Both the US Department of Energy and the European Commission have a clear vision of the hydrogen economy, with firm targets for hydrogen production costs. The US target for 2017 is 3 US$/gge (gasoline gallon equivalent; 1 gge is about 1 kg H_2), and the EU target for 2020 is 3.50 €/kg H_2.

The economics of large-scale solar hydrogen production has been assessed in a number of studies, which indicate that the solar thermochemical production of hydrogen can be more competitive than electrolysis of water using solar-generated electricity. It can even become competitive with conventional fossil-fuel-based processes at current fuel prices, especially if credits for CO_2 mitigation and pollution avoidance are applied.

Further R&D and large-scale demonstrations are therefore justified. This would positively affect achievable efficiencies and lower the cost of investment in materials and components. An important factor will be the mass installation of commercial solar thermal power plants, in particular power towers, since heliostats will be one of the most expensive components of a solar thermal hydrogen production plant.

2.5 Recommended strategy

A range of research activities is already under way for the ultimate goal of developing technically and economically feasible technologies for solar thermochemical processes that can produce solar fuels, particularly hydrogen. Implementation should start immediately to accelerate the transition from today's fossil-fuel-based economy to tomorrow's solar driven hydrogen economy.

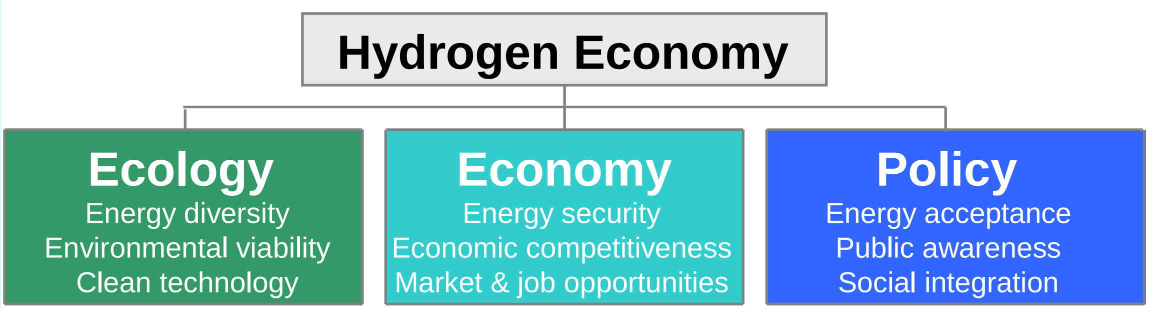
The EU-FP6 project INNOHYP-CA (2004-2006) has already developed a roadmap, showing the way to implementing thermochemical processes for mass hydrogen production.

2.6 The future for solar fuels

Solar energy is free, abundant and inexhaustible, but there at least two steps are crucial to successfully market solar fuels. Firstly, solar chemical production technologies must be further developed and proven to be technically and economically feasible. Secondly, a worldwide consensus needs to be reached on the most promising future energy carriers, both renewable electricity and hydrogen.

The arguments in favor of a future hydrogen economy are excellent, and the political commitment to move in this direction has been manifested in many initiatives (Figure 2.4). What is urgently needed now is a clear decision to start the transition

Benefits of the hydrogen economy



Source: DLR and PSI

Figure 2.4. H_2 is a superb fuel for road transport, distributed heat and power generation, and for energy storage. It is widely considered to have a strong potential for use in future energy systems, meeting climate change, air quality, and resource use goals, and securing energy supply.

from fossil to renewable energies and from gasoline to hydrogen.

We encourage politicians and policymakers, energy officials and regulators, utility companies, development banks and private investors to firmly support the mass production of solar fuels, primarily hydrogen, by taking concrete steps to enable future infrastructure and market development without delay.

The window of opportunity for tackling and solving the critical problems of greenhouse gas emissions and climate change is very short. Solar fuels are part of the solution; they can contribute to the world's energy needs without destroying it.

2.7 References

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Part 3: Task I: Solar Thermal Electric Systems

Operating Agent:
Mark S. Mehos
National Renewable Energy Laboratory

3.1 Nature of Work & Objectives

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

3.2 Organization and structure

The Task I Operating Agent is responsible for organization and reporting of Task I activities. As described in the 2007 annual report for this task, Task I is currently focused on two subtasks, 1) the development and population of an international project database for commercial CSP systems under operation, construction, or development and 2) the development of acceptance test procedures and standards for CSP systems.

3.3 Status of the Technology

Concentrating solar power offers the lowest cost option for solar energy today, with expected production costs of less than 20¢/kWh for early commercial plants sited in locations with premium solar resources. Lower costs are expected where additional incentives for CSP systems are available (e.g. the existing U.S. Federal 30% Investment Tax Credit). As the cost of electricity from conventional generation technologies continues to rise, off-takers are becoming increasingly interested in CSP as a viable alternative to other renewable technology options. Concerns over global warming and the increasing likelihood of a global carbon constrained energy market, has further increased this interest.

Concentrating solar power today is represented by four technologies: parabolic troughs, linear Fresnel reflectors, power towers and dish/engine systems. Of these technologies, parabolic troughs, and more recently towers, have been deployed in commercial plants. Nine SEGS plants totaling 354 MW, originally built and operated by LUZ in California in the 1980s and 1990s, are continuing to operate today with performance of most of the plants improving over time. In 2006, two commercial CSP plants began full-scale operation. Acciona, formerly SolarGenix, completed construction of a 64-MW parabolic trough plant near Las Vegas, Nevada. The 64-MW plant was the first new commercial large-scale parabolic trough plant to begin operation in more than 15 years. Abengoa inaugurated PS10, an 11-MW saturated steam central receiver plant located near Sevilla, Spain. Numerous additional plants continued or began construction in 2008 (see below for list of plants in operation or under construction). Andasol One began start up operations near the end of 2008. Several additional plants, including Andasol Two, PS20, Ibersol, and several Abengoa Solnova plants are anticipated to begin operating in 2009. Many other projects are under various stages of development, primarily in Spain, northern Africa, and the southwest U.S. (see project database task for more information on CSP projects in operation, under construction, or under development).

Parabolic troughs are today considered to be fully mature technology, ready for deployment. Early costs for solar-only plants are expected to be in the range of 0.17-0.20 $/kWh in sunny locations where no incentives are offered to reduce costs. In recent years, the five plants at the Kramer Junction site (SEGS III to VII) achieved a 30% reduction in operation and maintenance costs, record annual plant efficiency of 14%, and a daily solar-to-electric efficiency near 20%, as well as peak efficiencies up to 21.5%. Annual and design point efficiencies for the current generation of parabolic trough plants under construction in the U.S. and Spain are expected to be even higher based on the current generation of heat collection elements being furnished to the plants by both Solel and Schott.

Hybrid solar/fossil plants have received much greater attention in recent years, and several Integrated Solar Combined Cycle (ISCC) projects are now under construction in the Mediterranean region and the U.S. New Energy Algeria (NEAL) selected Abengoa to build the first such project at Hassi-R'mel. The project will consist of a 150MW ISCCS with 30 MW solar capacity. A similar project is under construction in Morocco where again Abengoa has been selected to build the plant. Achimede is another example of an ISCCS project, however the plant's 31,000m^2 parabolic trough solar field will be the first to use a molten salt as a heat transfer fluid.

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

Linear Fresnel systems are conceptually simple, using inexpensive, compact optics, and are being designed to produce saturated or superheated steam. This technology may be suited for integration into combined cycle recovery boilers; i.e., to replace the bled extracted steam in regenerative Rankine power cycles or for saturated steam turbines. Extensive testing experience at a prototype-scale has been underway for several year at the Liddell power station in Australia. Systems are also under development by MAN/SPG (Germany).

Power towers technology, a.k.a. central receiver technology, have completed the proof-of-concept stage of development and, although less mature than parabolic trough technology, are on the verge of commercialization. The most extensive operating experience has been accumulated by several European pilot projects at the Plataforma Solar de Almería in Spain, and the 10-MW Solar One and Solar Two facilities in California.

Construction of PS10, the first commercial power tower, was completed by Solucar at its project site outside of Seville, Spain and has been operating successfully since 2007. The tower system uses a saturated steam receiver to deliver steam to an 11-MW saturated steam turbine. PS20, roughly double the size of PS10, is scheduled to become operational in 2009. Brightsource and ESolar are also developing steam-based receiver designs with the intent of delivering superheated steam at higher temperatures and pressures.

An alternative to steam receiver systems under development by Solucar, Brightsource, and ESolar is the molten salt tower. This approach offers the potential for very low-cost storage that permits dispatch of solar electricity to meet peak demand periods and a high capacity factor (~70%). A molten-salt power tower three times larger than Solar Two is being designed by Sener for southern Spain. This plant, named Germasolar, is a 17-MW molten-salt tower and is projected to start construction in 2010.

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

In Europe, Schlaich Bergermann und Partner have extensively tested several 10-kW systems, based on a structural dish and the Solo 161 kinematic Stirling engine at the Plataforma Solar de Almería. Follow-up activities based on the EuroDish design are being pursued by a European Consortium of SBP, Inabensa, CIEMAT, DLR and others. EuroDish prototype demonstration units are currently being operated in Spain, France, Germany, Italy and India.

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

3.4 Reported Task I activities

The focus of Task I efforts has continued on development of the international project database for CSP systems as well as facilitating discussions related to the development of procedures and test standards for CSP systems. Both efforts are described briefly below.

3.4.1 SolarPACES international Project Database

Description of Project Database Activity

Table 1 provides a listing of operational CSP systems worldwide. Table 2 provides a listing of most of those currently under construction. Data for most of these systems have been provided by the contact points listed and will be made available through a project database located on the SolarPACES website by mid-2009. Examples data provided for some of the systems listed in the table are described in more detail below.

3.4.2 SolarPACES international Standards

Description of Standards Development Activity

A task meeting was held following the 2008 14th Biennial CSP SolarPACES Symposium held in Las Vegas, NV. Those attending the meeting expressed interest in organizing a working group to further define a program for developing procedures and test standards for CSP systems, with an initial emphasis on procedures for acceptance testing of parabolic trough solar fields. It was agreed that a preparatory workshop would be held at NREL in conjunction with Task III. The objective of the preparatory workshop will be to organize and to gather

Table 3.1. CSP Systems in Operation

COMMERCIAL CSP SYSTEMS	CONTACT	Sharing			
		I	M	T	C
Operational Systems					
SEGS I-II	Philip Jones - Cogentrix	x			
SEGS III-IX	Dan Brake – NextEra Energy Resources	x			
Nevada Solar One	Asun Padrós – Acciona Solar Power	x			
Saguaro	Phil Smithers – Arizona Public Service	x			
PS10/PS20	Ana Cabañas – Abengoa Solar	x			
Andasol 1	Manuel Cortés – ACS Cobra	x			
Liddell Power Station	David Mills – Ausra	x			
Kimberlina Power Station	David Mills – Ausra	x			
PE 1	Novatec Biosol				
Jülich Solar Tower					

expert opinions on the subject of testing and standards in preparation for a follow on open workshop coincident with the 2009 SolarPACES Symposium scheduled for September in Berlin.

Table 3.2. CSP Systems Under Construction

COMMERCIAL CSP SYSTEMS	CONTACT	Sharing			
		I	M	T	C
Systems Under Construction					
Manchasol 1	Manuel Cortés – ACS Cobra	x			
La Dehesa	Javier del Pico – Renovables SAMCA	x			
La Florida	Javier del Pico - Renovables SAMCA	x			
Lebrija 1	Carlos Cachadiña – Soleval	x			
Palma Del Rio II	Asun Padrós – Acciona Solar Power	x			
Alvarado 1	Asun Padrós – Acciona Solar Power	x			
Majadas I	Asun Padrós – Acciona Solar Power	x			
Andasol 2	Manuel Cortés – ACS Cobra	x			
Archimede	Massimo Falchetta – NEA	x			
Extresol 1&2	Manuel Cortés – ACS Cobra	x			
Ibersol Cuidad Real		x			
Solnova 1,3&4	Ana Cabañas – Abengoa Solar	x			
Gemasolar Thermosolar Plant		x			

3.5 OPERATIONAL PLANTS

Solar Electric Generating Station VI

The information provided on Solar Electric Generating Station VI, a concentrating solar power (CSP) project, is organized by background, participants, and power plant configuration.

SEGS VI is one of the nine Solar Electric Generating Station plants in California's Mojave Desert. The combined electric generating capacity of these plants, which use parabolic trough technology, is more than 350 megawatts. The plants operate as Qualifying Facility Independent Power Producers under the Public Utility Regulatory Policies Act, with a special Standard Offer 2 type of power purchase agreement to Southern California Edison.

Status Date: April 17, 2009

Project Overview	
Project Name:	Solar Electric Generating Station VI (SEGS VI)
Country:	United States
Location:	Kramer Junction, California
Owner(s):	NextEra
Technology:	Parabolic trough
Turbine Capacity (Gross):	30 MW
Status:	Operational
Start Year:	1989

Background

Solar Resource:	2,725 kWh/m²/yr
Contact(s):	NextEra
Start Production:	February 1, 1989

Participants

Developer:	Luz
Owner(s) (%):	NextEra (41%)
Operator(s):	NextEra
Generation Offtaker(s):	Southern California Edison

Plant Configuration

Solar Field

Solar-Field Aperture Area:	188,000 m²
SCA Manufacturer (Model):	Luz (LS-2)
HCE Manufacturer:	Solel Solar Systems (Solel UVAC)
HCE Type (Length):	Evacuated tube (4 meters)
Heat-Transfer Fluid Type:	Therminol
Solar-Field Outlet Temp.:	390°C

Power Block

Turbine Capacity (Gross):	30 MW
Power Cycle:	MHI regenerative steam turbine, solar preheat and steam generation, natural-gas-fired superheater
Power-Cycle Pressure:	100 bars
Engine/Turbine Efficiency:	37.5% @ full load
Fossil Backup Type:	Natural gas

Thermal Storage

Storage Capacity:	0 hours

Solar Electric Generating Station IX

The information provided on Solar Electric Generating Station IX, a concentrating solar power (CSP) project, is organized by background, participants, and power plant configuration.

SEGS IX is one of the nine Solar Electric Generating Station plants in California's Mojave Desert. The combined electric generating capacity of these plants, which use parabolic trough technology, is more than 350 megawatts. The plants operate as Qualifying Facility Independent Power Producers under the Public Utility Regulatory Policies Act, with a special Standard Offer 2 type of power purchase agreement to Southern California Edison.

Status Date: April 17, 2009

Background

Solar Resource:	2,725 kWh/m²/yr
Contact(s):	NextEra
Start Production:	October 1, 1990

Participants

Developer:	Luz
Owner(s) (%):	NextEra (50%)
Operator(s):	NextEra
Generation Offtaker(s):	Southern California Edison

Plant Configuration

Solar Field

Solar-Field Aperture Area:	483,960 m²
SCA Manufacturer (Model):	Luz (LS-3)
HCE Manufacturer:	Solel Solar Systems (Solel UVAC)
HCE Type (Length):	Evacuated tube (4 meters)
Heat-Transfer Fluid Type:	Therminol
Solar-Field Outlet Temp.:	390°C

Power Block

Turbine Capacity (Gross):	89 MW
Power Cycle:	MHI regenerative steam turbine, solar preheat and steam generation, natural-gas-fired superheater
Power-Cycle Pressure:	100 bars
Engine/Turbine Efficiency:	37.6% @ full load
Fossil Backup Type:	Natural gas

Thermal Storage

Storage Capacity:	0 hours

Project Overview

Project Name:	Solar Electric Generating Station IX (SEGS IX)
Country:	United States
Location:	Harper Dry Lake, California
Owner(s):	NextEra
Technology:	Parabolic trough
Turbine Capacity (Gross):	89 MW
Status:	Operational
Start Year:	1990

Nevada Solar One

The information provided on Nevada Solar One, a concentrating solar power (CSP) project, is organized by background, participants, and power plant configuration.

Acciona Energy's Nevada Solar One is the third largest CSP plant in the world and the first plant built in the United States since 1999. Located in Boulder City, Nevada, about 40 miles southeast of Las Vegas, this parabolic trough system has been operating since June 2007. The US$260 million plant has a nominal production capacity of 64 megawatts with a maximum capacity of 70 megawatts. All of the plant's electricity, which can power more than 14,000 households annually, is being sold to Nevada Energy under a long-term power purchase agreement.

Status Date: April 30, 2009

Background

Lat/Long Location:	35°56'0"N, 114°53'0"W
Land Area:	400 acres
Solar Resource:	2,700 kWh/m²/yr
Electricity Generation:	134,000 MWh/yr
Contact(s):	Asun Padrós , Acciona Energía
Break Ground:	February 11, 2006
Start Production:	June, 2007
Cost:	266,000,000 USD
Annual Net Solar Electric Generation:	2,000 MWh AC (projected)
Construction Job-Years:	350
Annual O&M Jobs:	30

Project Overview	
Project Name:	Nevada Solar One (NSO)
Country:	United States
Location:	Boulder City, Nevada
Owner(s):	Acciona Energy, Solargenix Energy Inc.
Technology:	Parabolic trough
Turbine Capacity (Net):	64 MW
Status:	Operational
Start Year:	2007

Participants

Developer:	Acciona Solar Power
Owner(s) (%):	Acciona Energia (100%)
EPC Contractor(s):	Lauren Engineering
Operator(s):	Acciona Solar Power
Generation Offtaker(s):	Nevada Energy

Plant Configuration

Solar Field

Solar-Field Aperture Area:	357,200 m²
# of SCAs:	760
SCA Manufacturer (Model):	Acciona Solar Power (SGX-2)
SCA Drive Manufacturer(s):	Parker Hannifin, Ansco Machine Company
Mirror Manufacturer (Model):	Flabeg (LS2)
# of Heat Collector Elements (HCEs):	11,136 / 7,104
HCE Manufacturer (Model):	Schott Glass (Schott PTR70) / Solel Solar Systems (Solel UVAC)
HCE Type (Length):	Evacuated tube (4 meters)
Heat-Transfer Fluid Type:	Biphenyl/Diphenyl oxide
Solar-Field Inlet Temp.:	318°C
Solar-Filed Outlet Temp.:	393°C

Power Block

Turbine Capacity (Gross):	70 MW
Turbine Capacity (Net):	64 MW
Turbine Manufacturer:	Siemens (Sweden)
Power Cycle:	Reheat steam Rankine cycle
Power-Cycle Pressure:	100 bars

Cooling Method:	Wet cooling
Engine/Turbine Efficiency:	37.6% @ full load
Fossil Backup Type (%):	Natural gas (2%)

Thermal Storage

Description:	Oversized field piping provides 0.5 hour of storage at full load

Andasol-1

The information provided on Andasol-1, a concentrating solar power (CSP) project, is organized by background, participants, and power plant configuration.

Andasol-1 is the first parabolic trough power plant in Europe. Located in southern Spain, this 300 million Euro power plant has been under construction since June 2006 and began operating in 2008. The nominal production capacity of 50 megawatts is enough electricity for up to 200,000 people. A two-tank indirect thermal storage system holds 28,500 tons of molten salt, and this reservoir can run the turbine for up to 7.5 hours at full load. Andasol-1 and two upcoming companion plants will help the Spanish power grid meet peak summer demand primarily caused by the high energy consumption of air conditioning units.

Status Date: April 27, 2009

Project Overview	
Project Name:	Andasol-1 (AS-1)
Country:	Spain
Location:	Aldiere, Granada
Owner(s):	ACS/Cobra Group, Solar Millennium Group
Technology:	Parabolic trough
Turbine Capacity (Net):	49.9 MW
Status:	Operational
Start Year:	2008

Background

Lat/Long Location:	37°13’50.83”N, 3°4’14.08”W
Land Area:	200 hectares
Solar Resource:	2,136 kWh/m²/yr
Electricity Generation:	158,000 MWh/yr (expected)
Contact(s):	Manuel Cortés, Maria Sanchez, ACS/Cobra Group
Company Web:	www.grupocobra.com, www.grupoacs.com
Break Ground:	July 3, 2006
Production Date:	November 26, 2008
Construction Job-Years:	600
Annual O&M Jobs:	40
PPA/Tariff Date:	September 15, 2008
Tariff Rate:	27 euro cents per kWh
Tariff Period:	25 years
Tariff Information:	Real Decreto 661/2007

Participants

Developer:	ACS/Cobra Group
Owner(s) (%):	ACS/Cobra Group (75%), Solar Millennium Group (25%)
EPC Contractor(s):	UTE CT Andasol-1: Cobra (80%) and Sener (20%)
Operator(s):	Cobra O&M
Generation Offtaker(s):	Endesa

Plant Configuration

Solar Field

Solar-Field Aperture Area:	510,120 m²
# of SCAs:	624
# of Loops:	156
# SCAs per Loop:	4
SCA Length:	144 m
# Modules per SCA:	12
SCA Manufacturer (Model):	UTE CT Andasol-1 (SKAL-ET)
Mirror Manufacturer (Model):	Flabeg (RP3)

# of Heat Collector Elements (HCEs):	11,232 / 11,232
HCE Manufacturer:	Schott / Solel
HCE Length:	4 m / 4 m
Heat-Transfer Fluid Type:	Diphenyl/Biphenyl oxide
Solar-Field Inlet Temp.:	293°C
Solar-Field Outlet Temp.:	393°C

Power Block

Turbine Capacity (Net):	49.9 MW
Turbine Manufacturer:	Siemens (Germany)
Power Cycle:	Rankine cycle
Power-Cycle Pressure:	100 bars
Cooling Method:	Wet cooling
Cooling Method Description:	Cooling towers
Engine/Turbine Efficiency:	38.1% @ full load
Annual Solar-to-Electric Efficiency:	16%
Fossil Backup Type (%):	HTF heater (12%)

Thermal Storage

Storage Type:	2-tank indirect
Storage Capacity:	7.5 hours
Thermal Storage Description:	28,500 tons of molten salt, 60% sodium nitrate, 40% potassium nitrate. 1010 MWh. Tanks are 14 m high and 36 m in diameter

Planta Solar 10

The information provided on Planta Solar 10, a concentrating solar power (CSP) project, is organized by background, participants, and power plant configuration.

Solúcar Energía's Planta Solar 10 is the first solar central-receiver system producing grid-connected electricity under a purely commercial approach. PS10's technologies—including glass-metal heliostats, pressurized-water thermal storage system, and saturated-steam receiver and turbine—were previously tested and qualified at the Plataforma Solar de Almería facility. This testing helped to avoid technological uncertainties and allowed the project to focus on scaling up, integrating subsystems, demonstrating dispatchability, and reducing O&M costs. The plant's thermal storage system has a 50-minute capacity at 50% load to handle cloud transients. The tower was designed to reduce visual impact—its relatively narrow body includes a large open space to give a lightweight sense.

Status Date: April 21, 2009

Background

Lat/Long Location:	37°26'30.97"N, 6°14'59.98"W
Land Area:	55 hectares
Solar Resource:	2,012 kWh/m^2/yr
Electricity Generation:	23,400 MWh/yr (expected)
Contact(s):	Ana Cabañas, Abengoa Solar
Company Web:	www.abengoasolar.com
Break Ground:	2005
Production Date:	June 25, 2007
PPA/Tariff Date:	January 17, 2005
Tariff Rate:	27.1188 euro cents per kWh
Tariff Period:	25 years
Tariff Information:	Royal Decree 661/2007; Total Price = Pool + Tariff Rate
Project Type:	Commercial plant

Incentive 1:	5.0 million euros from European Commission under FP5
Incentive 2:	1.2 million euros from Andalusian Regional Government

Participants

Developer:	Abengoa Solar
Owner(s) (%):	Abengoa Solar
EPC Contractor(s):	Abener Energía
Operator(s):	Abengoa Solar
Generation Offtaker(s):	Endesa Distribución (FIT);
Electric market (pool)	

Project Overview	
Project Name:	Planta Solar 10 (PS10)
Country:	Spain
Location:	Sevilla, Sanlucar la Mayor
Owner(s):	Solucar Energia, S.A.; Ibabensa, CIEMAT, DLR, Fichtner
Technology:	Power tower
Turbine Capacity (Net):	11 MW
Status:	Operational
Start Year:	2007

Plant Configuration

Solar Field

Heliostat Solar-Field Aperture Area:	75,000 m^2
# of Heliostats:	624
Heliostat Aperture Area:	120 m^2
Heliostat Manufacturer (Model):	Abengoa (Solucar 120)
Heliostat Description:	Glass-metal
Tower Height:	115 m
Tower Configuration:	North-facing receiver
Receiver Manufacturer:	Technical-Tecnicas Reunidas
Receiver Type:	Cavity
Heat-Transfer Fluid Type:	Water
Receiver Outlet Temp.:	250°-300°C

Power Block

Turbine Capacity (Gross):	11.02 MW
Turbine Capacity (Net):	50 MW
Power Cycle:	Rankine cycle
Power-Cycle Pressure:	45 bars
Cooling Method:	Wet cooling
Cooling Method Description:	Refrigeration towers
Fossil Backup Type (%):	Natural gas (15%)

Thermal Storage

Storage Type:	Other
Storage Capacity:	1 hour

Kimberlina Solar Thermal Power Plant

The information provided on Kimberlina, a concentrating solar power (CSP) project, is organized by background, participants, and power plant configuration.

Kimberlina is the first Compact Linear Fresnel Reflector (CLFR) project in North America and is the first major solar thermal power plant to be built in California in nearly two decades. Located in Bakersfield, CA, Ausra began construction of the power plant in March 2008, with the plant entering operation in October 2008. Kimberlina will generate up to 5 megawatts of electricity at full output to help meet California's peak summer demand. Kimberlina's direct steam generation eliminates the need for heat-transfer fluids, such as synthetic oils, and uses common materials, including carbon steel and standard flat glass to allow for rapid scale-up.

Status Date: May 11, 2009

Background

Lat/Long Location:	35°34'0"N, 119°11'39.1"W
Land Area:	12 acres
Contact(s):	Bill Conton, Katherine Potter; Ausra
Key References:	New Release, Overview
Break Ground:	March, 2008
Start Production:	October, 2008
Project Type:	Demonstration
Incentives:	Federal investment tax credit, anticipated
Annual O&M Jobs:	7

Participants

Developer:	Ausra
Owner(s) (%):	Ausra (100%)
Operator(s):	Ausra
Generation Offtaker(s):	CA ISO

Plant Configuration

Solar Field

Solar-Field Aperture Area:	26,000 m^2
# of Lines:	3
Line Length:	385 m
Mirror Width in Line:	2 m
# of Mirrors across Line:	10
Collector Manufacturer (Model):	Ausra
Collector Description:	Compact Linear Fresnel
Mirror Manufacturer (Model):	Ausra
Drive Manufacturer(s):	Ausra
Receiver Manufacturer (Model):	Ausra
Receiver Type:	Non-evacuated
Receiver Length:	385 m
Heat-Transfer Fluid Type:	Water

Power Block

Turbine Capacity (Net):	5 MW
Power-Cycle Pressure:	40 bars

Thermal Storage

Project Overview	
Project Name:	Kimberlina Solar Thermal Power Plant (Kimberlina)
Country:	United States
Location:	Bakersfield, California
Owner(s):	Ausra
Technology:	Linear Fresnel reflector
Turbine Capacity (Net):	5 MW
Status:	Operational
Start Year:	2008

3.6 PLANTS UNDER CONSTRUCTION

Archimede

The information provided on Archimede, a concentrating solar power (CSP) project, is organized by background, participants, and power plant configuration.

Archimede is a parabolic trough plant being constructed in Sicily, Italy. The plant will produce steam (4.72-MW equivalent) to be sent to a combined-cycle steam turbine rated at 130 MW. A 2-tank direct system will provide 8 hours of thermal storage.

Status Date: April 10, 2009

Background

Lat/Long Location:	37°8'3.12"N, 15°13'0.15"E
Land Area:	8 hectares
Solar Resource (Source):	1,936 kWh/m^2/yr (ENEA/ENEL)
Contact(s):	Massimo Falchetta, ENEA
Break Ground:	July 21, 2008
Start Production:	May 30, 2010 (expected)
Annual Net Solar Electric Generation:	9,200 MWh/yr (expected/planned)

Participants

Developer:	ENEL
Owner(s) (%):	ENEL (100%)
Operator(s):	ENEL

Project Overview	
Project Name:	Archimede
Country:	Italy
Location:	Priolo Gargallo, Sicily
Owner(s):	ENEL
Technology:	Parabolic trough
Turbine Capacity (Gross):	4.72 MW
Status:	Under construction
Start Year:	2010

Plant Configuration

Solar Field

Solar-Field Aperture Area:	31,860 m^2
# of SCAs:	54
# of Loops:	9
# SCAs per Loop:	6
SCA Aperture Area:	590 m^2
SCA Length:	100 m
# of Modules per SCA:	8
SCA Manufacturer (Model):	COMES (ENEA)
Mirror Manufacturer:	Ronda Reflex
# of HCEs:	1,296
HCE Manufacturer:	Archimede Solar Energy
Heat-Transfer Fluid Type:	Molten salt (60% $NaNO_3$ + 40% KNO_3)
Solar-Field Inlet Temp.:	290°C
Solar-Field Outlet Temp.:	550°C
Temp. Difference:	260°C

Power Block

Turbine Capacity (Net):	4.72 MW equivalent
Turbine Manufacturer:	Tosi
Turbine Description:	The plant produces steam that is sent to the CC steam turbine, rated at 130 MW; the 4.72 MW datum is the calculated capacity added by the solar steam.
Power Cycle:	Rankine cycle
Power-Cycle Pressure:	93.83 bars
Cooling Type:	Wet cooling
Engine/Turbine Efficiency:	39.30% @ full load
Fossil Backup Type:	Natural gas
Annual Solar-to-Electric Efficiency:	15.60%

Thermal Storage

Thermal Storage Type:	2-tank direct
Storage Capacity:	8 hours
Thermal Storage Description:	Total of 1,580 tons of molten salt, 60% sodium nitrate, 40% potassium nitrate. Capacity 100 MWh (thermal). Tanks are 6.5 m high and 13.5 m in diameter

Ibersol Ciudad Real (Puertollano)

The information provided on Ibersol Cuidad Real (Puertollano), a concentrating solar power (CSP) project, is organized by background, participants, and power plant configuration.

Status Date:	April 16, 2009

Background

Lat/Long Location:	38°38'36.19"N, 3°58'29.6"W
Land Area:	150 hectares
Solar Resource:	2,061 kWh/m²/yr
Electricity Generation:	103,000 MWh/yr (expected)
Break Ground:	March, 2007
Production Date:	May, 2009 (estimated)
Cost:	200,000,000 euros
Construction Job-Years:	200 average; 650 peak
Annual O&M Jobs:	60
Tariff Period:	25 years
Tariff Information:	Market price with premium system

Participants

Developer:	IBERCAM (Iberdrola Renovables Castilla-La Mancha)
Owner(s) (%):	IBERCAM (90%), IDAE (10%)
Operator(s):	Iberdrola Renovables
Generation Offtaker(s):	Market

Project Overview	
Project Name:	Ibersol Ciudad Real (Puertollano)
Country:	Spain
Location:	Puertollano, Castilla-La Mancha
Owner(s):	IBERCAM, IDAE
Technology:	Parabolic trough
Turbine Capacity (Net):	50 MW
Status:	Under commissioning
Start Year:	2009

Plant Configuration

Solar Field

Solar-Field Aperture Area:	287,760 m²
# of SCAs:	352
# of Loops:	88
# SCAs per Loop:	4
# Modules per SCA:	12
SCA Manufacturer (Model):	Iderdrola Collector
Mirror Manufacturer (Model):	Flabeg, Rioglass
# of Heat Collector Elements (HCEs):	6,336 / 6,336
HCE Manufacturer:	Schott / Solel
HCE Length:	4 m / 4 m
Heat-Transfer Fluid Type:	Diphenyl/Diphenyl oxide
HTF Company:	Dow Chemical
Solar-Field Inlet Temp.:	304°C
Solar-Field Outlet Temp.:	391°C

Power Block

Turbine Capacity (Net):	50 MW
Turbine Manufacturer:	Siemens
Power Cycle:	Rankine cycle
Power-Cycle Pressure:	100 bars
Cooling Method:	Wet cooling
Engine/Turbine Efficiency:	38.9% @ full load
Fossil Backup Type:	HTF heater (gas-fired)

Thermal Storage

Gemasolar Thermosolar Plant

The information provided on Gemasolar Thermosolar Plant, a concentrating solar power (CSP) project, is organized by background, participants, and power plant configuration.

Status Date:	April 17, 2009

Background

Lat/Long Location:	37°33'40.95"N, 5°19'49.39"W
Land Area:	190 hectares
Solar Resource:	2,062 kWh/m²/yr
Electricity Generation:	100,000 MWh/yr (expected)
Contact(s):	Juan Ignacio Burgaleta, Sener
Break Ground:	February, 2009
Start Production:	December, 2010
Cost:	230,000,000 euros
Construction Job-Years:	800
Annual O&M Jobs:	45

Participants

Developer:	Torresol Energy
Owner(s) (%):	Sener (60%), Masdar (40%)
EPC Contractor(s):	UTE C.T. Solar Tres
Operator(s):	Gemasolar 2006, S.A.

Plant Configuration

Solar Field

Heliostat Solar-Field Aperture Area:	318,000 m²
# of Heliostats:	2650
Heliostat Aperture Area:	120 m²
Heliostat Manufacturer:	Sener
Heliostat Description:	Sheet-metal stamped facet
Heliostat Drive Manufacturer:	Sener
Tower Height:	150 m
Tower Manufacturer:	Sener
Heat-Transfer Fluid Type:	Molten salts (sodium and potassium nitrates)
Receiver Inlet Temp.:	290°C
Receiver Outlet Temp.:	565°C

Power Block

Turbine Capacity (Gross):	17 MW
Power Cycle:	Rankine cycle
Cooling Method:	Wet cooling
Fossil Backup Type:	Natural gas

Thermal Storage

Storage Type:	2-tank direct
Storage Capacity:	15 hours
Thermal Storage Description:	One cold-salt tank (290°C) from where salts are pumped to the tower receiver and heated up to 565°C, to be stored in one hot-salt tank (565°C)

Project Overview	
Project Name:	Gemasolar Thermo-solar Plant (Gemasolar)
Country:	Spain
Location:	Fuentes de Andalucia, Sevilla
Owner(s):	Sener, Masdar
Technology:	Central tower and molten-salt receiver
Turbine Capacity (Gross):	17 MW
Status:	Under construction
Start Year:	2010

3.7 PLANTS UNDER CONTRACT

Arcosol 50

The information provided on Arcosol 50, a concentrating solar power (CSP) project, is organized by background, participants, and power plant configuration.

Project Overview	
Project Name:	Arcosol 50 (Valle 1)
Country:	Spain
Location:	San José del Valle, Cádiz
Owner(s):	Torresol
Technology:	Parabolic trough
Turbine Capacity (Net):	49.9 MW
Status:	Under contract
Start Year:	

Status Date: April 20, 2009

Background

Lat/Long Location:	36°39’40”N, 5°50’0”W
Land Area:	230 hectares
Solar Resource:	2,097 kWh/m²/yr
Electricity Generation:	175,000 MWh/yr (expected)
Contact(s):	Juan Ignacio Burgaleta, Torresol
Break Ground:	May, 2009
Cost:	320,000,000 Euros
Construction Job-Years:	900
Annual O&M Jobs:	45

Participants

Developer:	Torresol
Owner(s) (%):	Torresol (100%)
EPC Contractor(s):	UTE Valle 1
Operator(s):	Torresol

Plant Configuration

Solar Field

Solar-Field Aperture Area:	510,120 m²
# of SCAs:	624
Heat-Transfer Fluid Type:	Diphenyl/Diphenyl oxide
Solar-Field Inlet Temp.:	293°C
Solar-Field Outlet Temp.:	393°C

Power Block

Turbine Capacity (Net):	49.9 MW
Power Cycle:	Rankine cycle
Power-Cycle Pressure:	100 bars
Cooling Method:	Wet cooling
Engine/Turbine Efficiency:	38.1% @ full load
Fossil Backup Type:	Natural gas

Thermal Storage

Storage Type:	2-tank indirect
Storage Capacity:	7.5 hours
Thermal Storage Description:	28,500 tons of molten salt, 60% sodium nitrate, 40% potassium nitrate

4 Task II: Solar Chemistry Research

Operating Agent:
Anton Meier, PSI, Switzerland

National Coordinators:

- Keith Lovegrove, ANU, Australia
- Gilles Flamant, CNRS-PROMES, France
- Karl-Heinz Funken, DLR, Germany
- Michael Epstein, WIS, Israel
- Alfonso Vidal, CIEMAT, Spain
- Anton Meier, PSI, Switzerland
- Alan Weimer, UC, USA

4.1 Nature of Work & Objectives

The primary objective of Task II – Solar Chemistry R&D – is to develop and optimize solar-driven thermochemical processes and to demonstrate their technical and economic feasibility at an industrial scale:

- *Production of energy carriers*: conversion of solar energy into chemical fuels that can be stored long-term and transported long-range. During this term, special focus is on solar thermal production of hydrogen and syngas.
- *Processing of chemical commodities*: use of solar energy for processing energy-intensive, high-temperature materials.
- *Detoxification and recycling of waste materials*: use of solar energy for detoxification and recycling of hazardous waste and of secondary raw materials.

Organization and Structure: The Task II Operating Agent, currently PSI, Switzerland, is responsible for organization, operation, and reporting. International solar chemical research, development and demonstration efforts are coordinated in cost, task and/or information-sharing activities by National Coordinators, making use of an efficient network, for the rapid exchange of technical and scientific information. The Task II Annual Meeting provides a forum for presenting and discussing major technological achievements.

The Task II Program of Work provides an up-to-date description of the national and international projects. When appropriate, Task II conducts a status review on novel technologies for assessing their technical and economical feasibility. Task II is continuously striving to stimulate public awareness of the potential contribution of solar chemistry to clean, sustainable energy services.

4.2 Status of Technology

This chapter provides a comprehensive overview of the many ways in which solar chemical technologies may be used for the delivery of clean, sustainable energy services. In 2008, special focus was on the solar thermal production of fuels (hydrogen and syngas) and chemicals for the power, transportation and chemical sectors of the world energy economy.

In 2008, solar chemistry research was presented at two major international conferences:

- *14th SolarPACES International Symposium*, Las Vegas, NV (USA), March 4-7, 2008: 20 papers were presented on the topic of solar fuels.
- *ASME Energy Sustainability Conference (ES2008), Jacksonville, August 10-14, 2008*: 11 papers were presented on solar chemistry and hydrogen production.

The most important achievements in 2008 are summarized with up-to-date information about project participation, objectives, status, and relevant publications.

4.2.1 SOLAR PRODUCTION OF ENERGY CARRIERS

SOLREF – Solar Steam Reforming of Methane Rich Gas for Synthesis Gas Production

Participants: DLR (D), APTL (GR), WIS (IL), ETH (CH), Johnson Matthey Fuel Cells Ltd. (UK), HyGear B.V. (NL), SHAP S.p.A. (I)

Contact: Christian Sattler, christian.sattler@dlr.de

Funding: EC funded project, cost shared: € 2,100,000

Duration: April 1, 2004 - March 31, 2009

Background: The work proposed in SOLREF is based on the activities performed in the previous SOLASYS project, in which the technical feasibility of solar steam reforming was proven. Based on the experience and know-how acquired in SOLASYS, SOLREF will take solar steam reforming a significant step closer to industrialization.

Purpose: The main purpose of this project is to develop and operate an innovative 400-kW$_{th}$ solar reformer for such applications as hydrogen production or electricity generation. The new solar reformer is more compact and cost-effective than the previous SOLASYS reformer.

Achievements in 2008: Due to a delay in the manufacturing/certification of the reformer, the project is being extended to March 2009. In Fall 2008, the 400-kW$_{th}$ solar reformer was assembled at DLR and shipped to WIS. Figure 4.1 shows the solar reactor before shipping. It has now been assembled on the solar tower of WIS. The test campaigns will start early 2009.

Figure 4.1. SOLREF reactor assembled at DLR Stuttgart and ready for shipping to WIS.

Models based on computer tomography (CT) were developed by ETH. A CT-based methodology was applied to determine the fluid transport properties for flow across porous media (Ref. [4.1]). The effective thermal conductivity of reticulate porous ceramics (RPCs) was determined based on the 3D digital representation of their pore geometry obtained by high-resolution multi-scale CT (Ref. [4.2]). X-ray micro-tomography with a digital resolution of 30 µm and synchrotron sub-micron tomography with a digital resolution of 350/700 nm was performed on catalyst-coated reticulate porous ceramics (Ref. [4.3]).

Better catalyst systems were developed by APTL in attempt to achieve cheaper catalysts than those selected for SOLREF.

Publications: [4.1]-[4.3]

SOLHYCARB – High Temperature Solar Chemical Reactor for Co-production of Hydrogen and Carbon Black from Natural Gas Cracking

Participants: CNRS-PROMES (F), ETH (CH), PSI (CH), WIS (IL), CERTH/CPERI (GR), DLR (D), TIMCAL (B), SOLUCAR R&D (E), CREED (F), N-GHY (F)

Contacts: Gilles Flamant, flamant@promes.cnrs.fr

Funding: EC funded project, cost shared: € 2,000,000

Duration: March 1, 2006 – February 28, 2010

Background: The SOLHYCARB project addresses the solar thermal decomposition of natural gas for the co-production of hydrogen and Carbon Black (CB) as a high-value nanomaterial. This process avoids CO_2 emissions and saves fossil fuels compared to conventional H_2 and CB production methods (natural gas steam reforming and incomplete hydrocarbon combustion, respectively).

Purpose: Research is aimed at designing, constructing, and testing innovative solar reactors at various scales (10 kW$_{th}$ and 50 kW$_{th}$) operating between 1400°C and 1800°C. The targeted results are: (1) CH_4 conversion over 80%; (2) off-gas H_2 yield over 75%; and (3) CB properties equivalent to industrial products. Research also focuses on solar reactor modeling, both separation of carbon nanoparticles from the gas-solid flow and hydrogen from the hydrogen-rich gas, characterization of CB, and the conceptual design of an up-scaled solar process.

Achievements in 2008: A multi-tubular solar reactor prototype (10 kW$_{th}$ scale) based on indirect heating was constructed and tested at CNRS-PROMES (Ref. [4.4]). The reactor features a cavity-type receiver (20 cm side) with a 9-cm-diameter aperture closed by a transparent quartz window which allows concentrated solar radiation to enter (Figure 4.2 and Figure 4.3). The reacting gas flows through four tubular reaction zones, each of which is made up of two concentric graphite tubes inserted vertically inside the cavity. A filtering system separates the CB particles at the reactor outlet. The off-gas composition is monitored online by specifically dedicated analyzers.

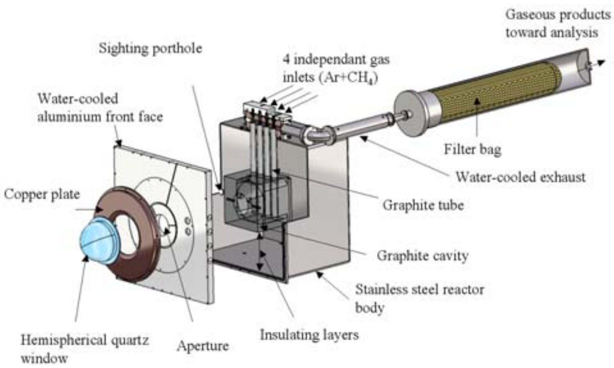

Figure 4.2. Diagram of the 10-kW solar reactor and filter developed at CNRS-PROMES.

The first test campaign was conducted at moderate temperatures (up to 1500°C). Gas composition at the reactor outlet, CH_4 conversion and H_2 yield, and the reactor thermal efficiencies were determined with respect to reaction temperature, residence time, gas flow rates, and feed gas composition. CH_4 conversion over 90% and H_2 yield of about 75% were measured (with 20% CH_4 in the feed gas and residence time of 18 ms),

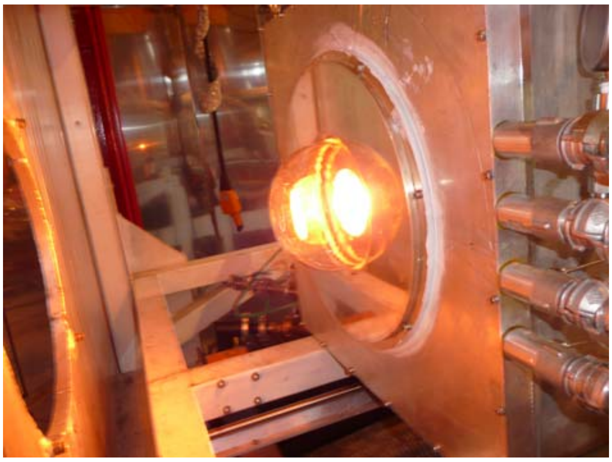

Figure 4.3. Close look at SOLHYCARB reactor aperture during cooling at CNRS-PROMES test rig.

but the CB contained polycyclic aromatic hydrocarbons (PAHs), and pyrocarbon was formed.

The second test campaign was performed at higher temperatures (1550-1800°C). Chemical conversion increased with temperature and gas residence time. Complete CH_4 conversion was achieved whatever the amount of CH_4 in the feed (up to 100%). H_2 yields were over 90%, and thermochemical efficiency was in the range 5-10%. Acetylene was the most important by-product with a mole fraction up to about 7%.

Thermal simulations for solar reactor modeling showed homogeneous temperature distribution inside the cavity receiver. The influence of the non-gray thermal radiation on the heating of Ar/CH_4 laminar flow was specifically investigated (Ref. [4.5]). The results showed that the temperature field is influenced markedly by radiation due to the participation of methane. Kinetic simulations were carried out with the Dsmoke calculation code using a detailed kinetic scheme for the wide range modeling of alkane transformation (Ref. [4.6]). Comparisons with experimental results between 1400°C and 1500°C showed good agreement for CH_4 conversion and off-gas composition.

Publications: [4.4]-[4.6]

SYNPET – Hydrogen Production by Steam-Gasification of Petcoke and Vacuum Residue

Participants: PDVSA (Venezuela), CIEMAT (E), ETH/PSI (CH)

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Funding: PDVSA-CIEMAT-ETH: $6,700,000

Duration: January 1, 2003 - June 30, 2009

Background: Hybrid solar/fossil endothermic processes make use of fossil fuels as the chemical source for H_2 production and of concentrated solar energy exclusively as the source of high-temperature process heat. PDVSA, CIEMAT and ETH have started a joint project to develop and test a 500 kW_{th} solar reactor for steam gasification. In Phase 1, after in-depth studies of the thermodynamic and kinetic behavior, a small 5-kW_{th} prototype was tested in the PSI Solar Furnace, Switzerland. The engineering design, experimentation, and modeling of the solar reactor were presented in [4.7]-[4.8], and literature cited therein. Phase 2 was devoted to the design, construction, modeling and optimization of a 500 kW_{th} reactor (Ref. [4.9]-[4.10]). Construction was managed by CIEMAT, and it will be operated on the SSPS tower at the Plataforma Solar de Almería in 2009.

Purpose: The project aims at experimental demonstration of the technology in a 500-kW_{th} solar reactor of heavy crude oil solid derivatives, such as petcoke.

Achievements in 2008: During 2008, the installation of the 500-kW_{th} Solar Gasification Plant on top of the SSPS/CRS tower at the Plataforma Solar de Almería was finalized. The receiver- reactor was placed at the 40 m platform of the SSPS tower. The pilot plant consists of the cavity reactor, upstream and downstream equipment, and measurement systems. A schematic layout of the plant is shown in Figure 4.4. The installation includes a multi-screw feeder and a mixing tank, as well as valves, flow meters and pumps. In the mixing tank, coke is mixed with water to form the slurry, which is conveyed to the entrance of the reactor by a pump. The coke reacts with steam at a temperature of 1100 -

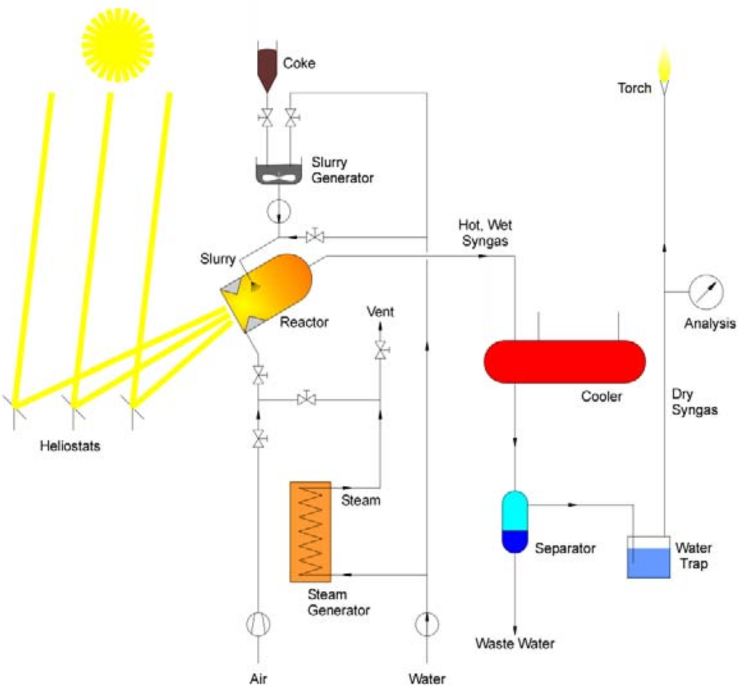


Figure 4.4. Schematic of the solar plant layout for the steam-gasification of petroleum coke at the Plataforma Solar de Almería.

1400°C to produce a raw fuel gas and un-gasified material. At the exit of the reactor, the product gas is simply cooled down by water in a standard TEMA-type BEU heat-exchanger to sufficiently reduce the temperature for accomplishing the requirements of the torch. For this plant, syngas production of around 100 to 180 kg/h has been estimated.

In 2009, it is planned to demonstrate the feasibility of solar gasification, determine critical process parameters, identify possible difficulties, and finally get a solid database for scale-up in Phase 3 of the project.

Publications: [4.7]-[4.10]

STCH – Solar-Powered Thermochemical Production of Hydrogen from Water

Participants: University of Nevada Las Vegas (UNLV), University of Colorado (UC), Sandia National Laboratories (SNL), National Renewable Energy Laboratory (NREL), Argonne National Laboratory (ANL), General Atomics (GA)

Contact: Alan W. Weimer, alan.weimer@colorado.edu

Funding: U.S. DOE funded project, cost shared: $13,005,000

Duration: June 25, 2003 - November 30, 2008, continuing

Background: Hundreds of thermochemical cycles to split water have been proposed. The feasibility of these processes can be assessed through thermodynamic analysis and experimentation. There is a need to evaluate these cycles in order to identify the most feasible and economical for further investigation. The most promising cycles should be demonstrated.

Purpose: Quantify cycle thermodynamics, reaction kinetics, reactant/product equilibrium quantities for each cycle step, and process economics for current thermochemical cycles. Ultimately, demonstrate integrated pilot plant designs, including on-sun testing for up to three competitive cycles.

Achievements in 2008: Five thermochemical cycles are currently under active study in the STCH. These include: (1) zinc oxide and cadmium oxide volatile metal oxide cycles, (2) sodium manganese and cobalt ferrite non-volatile metal oxide cycles, and (3) hybrid copper chloride cycle. In addition, a solid particle receiver is being constructed to interface to hybrid sulfur (HyS) and sulfur-iodine (SI) cycles.

Zinc Oxide – An experimental study of the thermal dissociation of ZnO particles (1st step) in an aerosol flow was completed (Ref. [4.11]). Experiments were performed at temperatures between 1600°C and 1750°C and residence times between 1.11 s and 1.78 s. The net conversions after recombination had a maximum value of 18%, with a mean value of 8%. Surface area of product particles, which ranged between 5 nm and 70 nm, were expected to increase the rate of the Zn hydrolysis step of the cycle.

The hydrolysis of zinc powder (2nd step) was studied in an aerosol to determine whether high conversions are feasible at short residence times and high dispersions (Ref. [4.12]). Zinc particles with an average size of 158 nm reacted with water vapor to form hydrogen and zinc oxide in an aerosol flow tube reactor at ambient pressure (82 kPa) between 380°C and 540°C and 3% water concentration. The highest conversion observed in the flow system was about 24% at 540°C and a gas residence time of ~0.6 s. Non-isothermal thermogravimetric analysis (TGA) indicated that complete conversion of Zn to ZnO could be achieved for longer residence times.

Significant progress has been made toward constructing and testing a new multi-tube reflective wall solar reactor (Figure 4.5). Validation and testing of the power and flux profile was done using the High Flux Solar Furnace (HFSF), capable of producing 2500 suns concentration, at the National Renewable Energy Laboratories (NREL). A new secondary concentrator has been constructed that produces up to 3000 suns. Both ray tracing and multi-physics models have been developed to simulate the performance of the HFSF test facility.

A three-dimensional computational fluid dynamics model of the multi-tube aerosol flow reactor is being developed using the finite-volume models in the commercial Fluent software. Simulations done for small reacting and non-reacting particles entrained in either a single inert gas or a mixture of gas species showed that the aerosol mixture in the flow tubes reached temperatures up to about 1377-1477°C.

Cadmium Oxide – A rotary kiln reactor was designed and constructed to improve the hydrolysis reaction of molten cadmium. Design modifications for a thermogravimetric analyzer (TGA) were completed to permit measurements of recombination rates during the dissociation of CdO; first measurements show a recombination of 30-40% for temperatures in the range 1000°C to 1475°C.

A window-closed reactor was designed for CdO dis-

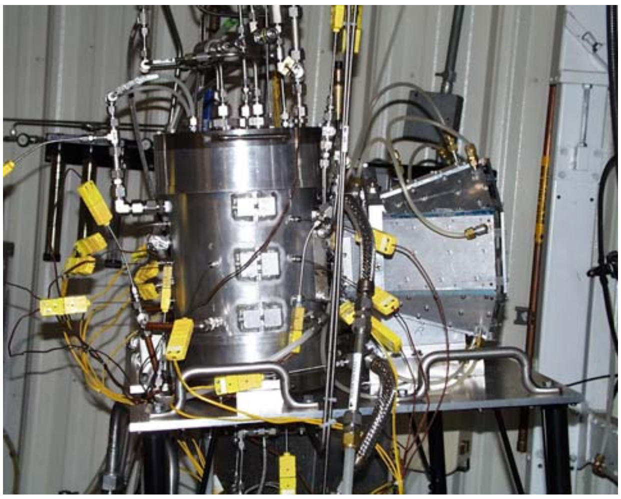


Figure 4.5. Multi-tube reactor installed and tested at NREL

sociation to prevent loss of Cd vapor. Modeling studies addressing the effect of negative pressure differential showed that the decomposition temperature could be reduced from 1500°C to 1255°C for operating pressures around 0.1 bar.

A CdO flow sheet for a 24-hr plant was developed. The thermal efficiency of the initial flow sheet was found to be 48.3% (LHV). Further optimization is expected to increase this predicted efficiency. A CdO central plant concept solar field has been developed to make use of a beam-down collector/concentrator to permit ground-level operation of all chemical processes.

Ferrites – Continuing ferrite feasibility work focuses on two areas: (1) evaluation of transport mechanisms and reaction rates for the water oxidation reaction and (2) fabrication of large-surface reactive structures (Ref. [4.13]). Performance of the ferrite cycles ultimately depends on improvements in the chemistry and on fabricating reactive structures that provide a good interface with concentrated solar energy and a large surface area for the reaction. Although the project had relied on Robocasting, a rapid prototyping technique for ceramics, to produce reactive structures, research has recently been employing other techniques to increase the reactive area of the materials beyond the capability of Robocasting and improve their manufacturability.

Construction of the CR5 reactor has been completed. The system is scheduled for first on-sun testing in Sandia's solar furnace facility. A recent image of the CR5 system is shown in Figure 4.6.

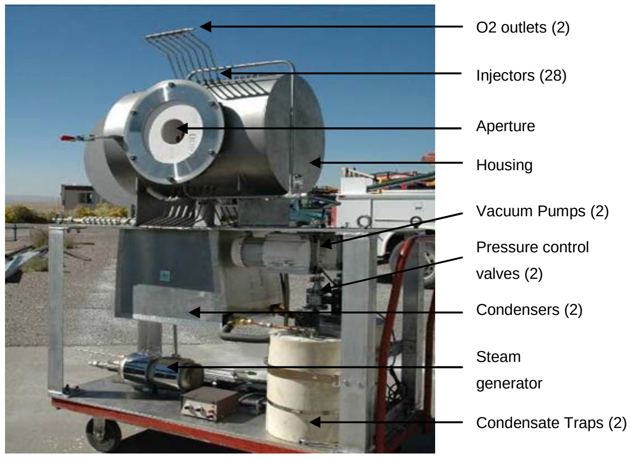


Figure 4.6. Recent image of the CR5 system.

Copper Chloride – The Cu-Cl cycle was selected as the most promising alternative thermochemical cycle under the Nuclear Hydrogen Initiative. The conceptual process design for the three-reaction Cu-Cl cycle was completed. It consists of four operating units: The electrolyzer, crystallizer, hydrolysis reactor, and oxychloride decomposition reactor. The current Aspen flow sheet is shown in Figure 4.7. So far, the nebulizer hydrolysis reactor has been designed, fabricated and successfully tested. The slurry $CuCl_2$ goes from the crystallizer to the hydrolysis reactor at 22 bar where it is sprayed into a superheated (400ºC) steam environment at 1 bar. The $CuCl_2$ forms a free jet. As the jet expands it sucks the superheated steam into the jet resulting in high mass and heat transfer between the $CuCl_2$ in the jet and the steam. The $CuCl_2$ is converted into Cu_2OCl_2 and HCl. The HCl and un-reacted steam leave the hydrolysis reactor to be cooled and are fed to the cathode of the electrolyzer, where hydrogen is produced.

Dry, free flowing solid Cu_2OCl_2 accumulates at the bottom of the hydrolysis reactor and is then transferred to the oxychloride decomposition reactor at 550°C where it decomposes into molten CuCl and oxygen. The heat is recovered from the molten CuCl in a direct heat exchanger where the CuCl is granulated while raising steam. The solidified CuCl then goes to the anode feed tank where it is dissolved in an HCl-$CuCl_2$ solution. At the anode of the electrolyzer, CuCl is oxidized to $CuCl_2$, which goes to the crystallizer.

A CuCl cycle plant producing 125 MT H_2/day requires 210 MW of thermal energy and 87.8 MW of electrical energy, resulting in an efficiency of about 40-42% (LHV). A preliminary H2A cost analysis has been completed.

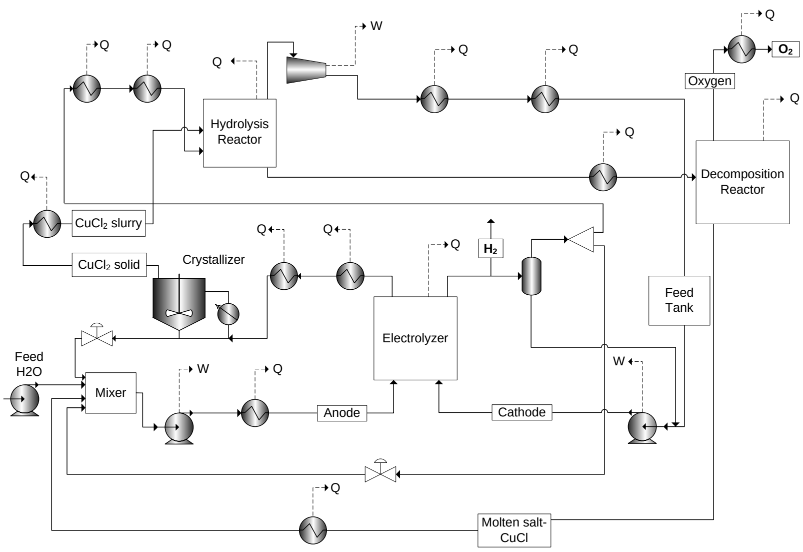
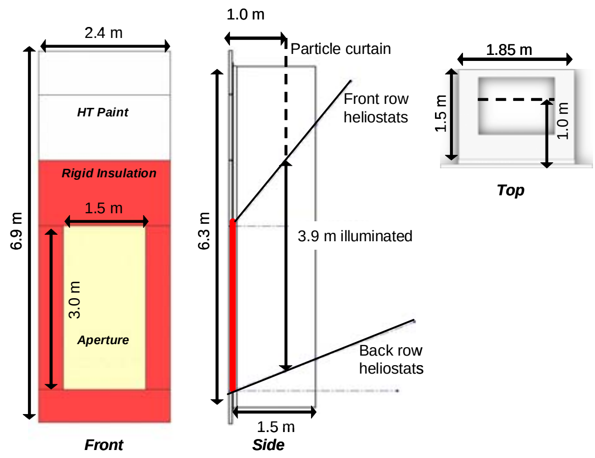


Figure 4.7. Aspen Plus™ flow sheet for the CuCl cycle.

Solid Particle Receiver – The solid particle receiver (SPR) is a direct absorption receiver, in which solar energy heats a curtain of falling ceramic particles to a temperature in excess of 1000ºC (Ref. [4.14]). On-sun testing of the 10 m tall receiver was conducted on top of a power tower at Sandia National Laboratories in early 2008. The test plan included three mass flow rates and three input power levels. During some tests winds exceeded 30 mph. A schematic drawing and photograph of the SPR are shown in Figure 4.8.

Particles entered through a hopper in the top of the receiver that provided sufficient storage for five-minute or more tests, depending on the flow rate. A distance of about 3.9 m was directly heated within the cavity. Receiver performance can be evaluated by considering the tem-



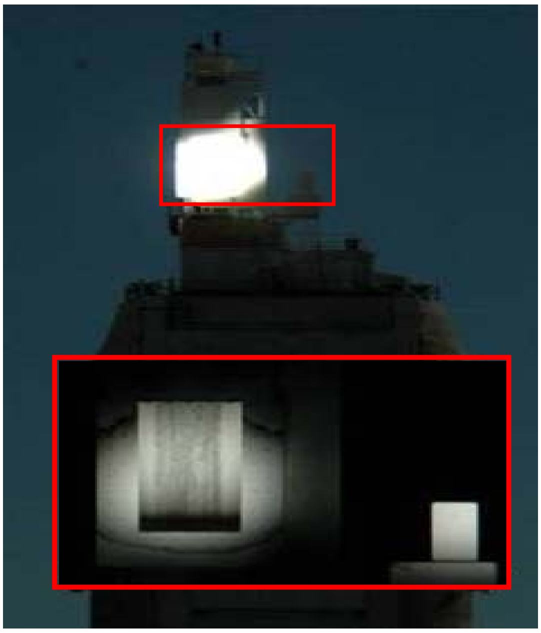


Figure 4.8. Top: Schematic drawing of the SPR. Bottom: The SPR during testing on top of Sandia's power tower. The inset region shows a detailed view of the particle curtain as it falls through the aperture.

perature change in the particles and the ratio of heat absorbed to heat incident on the aperture (receiver efficiency). A maximum particle temperature change of 247°C and maximum receiver efficiency of about 57% were measured.

Publications: [4.11]-[4.14]

Hydrogen Production from Solar Thermochemical Water-Splitting Cycles

Participants: CNRS-PROMES (F), CNRS-IEM (F)

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Funding: CNRS

Background: The production of hydrogen from solar-driven thermochemical cycles is under investigation. A preliminary screening identified the most promising metal-oxide redox cycles (Ref. [4.15]). Two and three-step cycles involving high-temperature solid-gas reactions are being considered. Innovative mixed-metal oxide systems are also being developed. Each cycle step requires thorough investigation of the chemical reaction systems and design and performance assessment of innovative solar reactor concepts.

Purpose: (1) Identify and investigate novel multi-step cycles for hydrogen production; (2) determine the characteristics of the solid-gas reactions involved in the cycles and propose kinetic rate laws; (3) design, manufacture, and operation of a solar reactor prototype for continuous-mode reduction reactions; (4) simulate reactor operation under steady-state and transient conditions; (5) evaluate the overall energy efficiencies of the solar chemical processes.

Achievements in 2008: Two-step cycles operating below 1700°C were investigated, and the innovative SnO_2/SnO system was proposed (Ref. [4.16]). Like ZnO/Zn, it is one of the volatile systems, because the solar thermal reduction step between 1500°C and 1700°C produces Zn or SnO vapor which later condense as nanoparticles. Dilution and quenching with a neutral gas favors the reaction yield. The reaction kinetics, found by TGA, increase when the temperature is raised or pressure is lowered.

A high temperature reactor prototype (cavity-type rotating receiver absorbing solar radiation) was designed, constructed, and operated. The solid reactant is continuously injected in a controlled atmosphere, and the particles produced are recovered in a filter downstream for hydrolysis. The solar reduction of ZnO was accomplished as a function of pressure and inert gas flow rate, and the Zn yield in the collected product was up to 90%.

The water-splitting step employs the reduced species that react efficiently with water to produce H_2 in the range 450-600°C. Experiments characterized the hydrolysis step in a fixed-bed reactor and determined the kinetic rate laws. The hydrolysis of Zn nanoparticles hardly yielded 60% H_2, whereas SnO hydrolysis was almost complete, but the reaction took longer (Figure 4.9 and Figure 4.10).

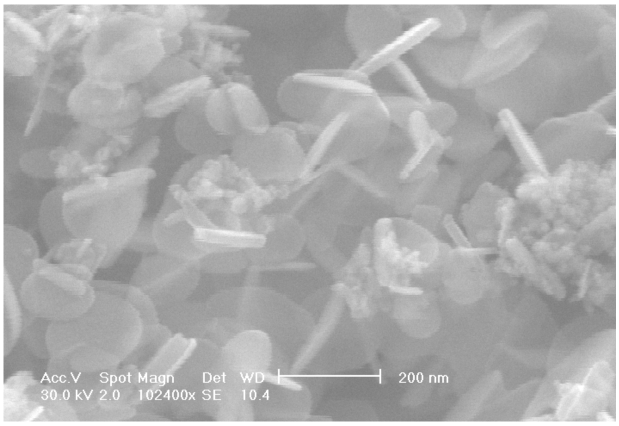

Figure 4.9. Solar-produced SnO nanoparticles.

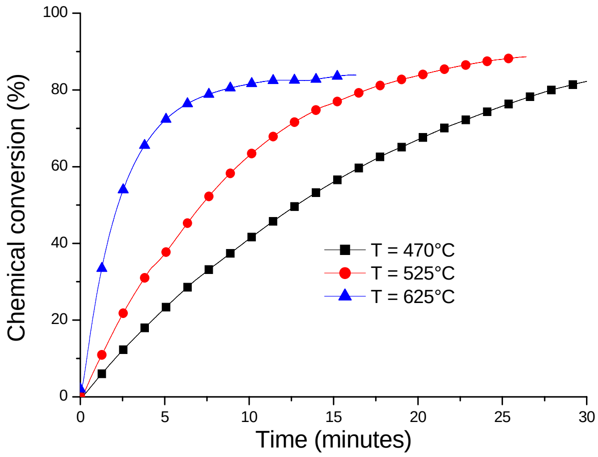

Figure 4.10. Chemical conversion of SnO hydrolysis at different temperatures.

Furthermore, three-step cycles involving mixed cerium oxides and alkali hydroxides were experimentally demonstrated. The high-temperature synthesis of reduced cerium-based mixed oxides ($Ce_2Ti_2O_7$, $Ce_2Si_2O_7$, $CeFeO_3$, $CeVO_4$, $CeNbO_4$) was performed in a lab-scale solar reactor at 1400-1500°C. The activation reaction with NaOH or KOH produced up to 1.94 mmol H_2 g^{-1} in the range 500-600°C.

A numerical unsteady-state model was developed to simulate the effect of transient conditions on solar reactor operation (Ref. [4.17]). On the basis of real solar irradiation data recorded at CNRS-PROMES (Odeillo, France), the daily and yearly Zn production was assessed for a 50-MW_{th} solar reactor, resulting in hydrogen production of about 1100 kg per day of operation.

Energy efficiency analyses of large-scale solar tower plants were performed. The global solar-to-hydrogen energy conversion efficiency for iron and zinc oxide cycles was estimated at about 20% with currently available data, by including the main losses occurring in the solar concentrating system, the solar receiver-reactor, and the chemical process itself.

Publications: [4.15]-[4.17]

Solar Hydrogen Production from a ZnO/Zn Thermochemical Cycle

Participants: PSI (CH), ETH (CH)

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Funding: BFE-Swiss Federal Office of Energy, PSI, ETH

Duration: January 1, 2003 - December, 2011

Background: Hydrogen production from water using solar energy in a two-step thermochemical cycle is being studied. The first, endothermic step is the thermal dissociation of ZnO(s) into Zn(g) and O_2 at temperatures above 2000 K using concentrated solar energy as the source of process heat. The second, non-solar, exothermic step is the hydrolysis of Zn at 700 K to form H_2 and ZnO(s); the latter separates naturally and is recycled to the first step.

Purpose: (1) Solar chemical reactor technology for the production of Zn by thermal dissociation of ZnO; (2) solar chemical reactor modeling using CFD and Monte Carlo ray-tracing simulations; (3) fundamental research on the reoxidation and quenching of Zn(g); (4) production of H_2 by hydrolysis of Zn.

Achievements in 2008: The proposed solar chemical reactor concept is based on a rotating cavity-receiver lined with ZnO particles that are held by centrifugal force and directly exposed to high-flux irradiation (Ref. [4.18]). A set of 15 experimental runs were performed with the 10 kW_{th} reactor prototype at PSI's High Flux Solar Simulator (HFSS). The number of feed cycles was varied between one and three. The maximum power input was set between 9.1 kW_{th} and 11.6 kW_{th} in order to obtain the desired cavity temperatures in the range 1757–2001 K. A typical experiment lasted from 50 to 90 min after heating up. The Ar flow rate was in the range of 7–28 l_N min^{-1} for purging the reactor window and aperture, and 30–90 l_N min^{-1} for quenching the product gases. The maximum Zn content of the quenched products was 44.9%, and the maximum Zn content of the filtered products was 51.1%, as determined by dissolution of the products in HCl with the measurement of evolved H_2.

Figure 4.11 shows the Zn yield $X_{Zn,QS}$ in the quenching section as a function of Zn partial pressure $P_{Zn,QS}$ for the 15 experimental runs (Ref. [4.19]). $X_{Zn,QS}$ is found to increase with decreasing $P_{Zn,QS}$. Two distinct regions of $X_{Zn,QS}$ are observed. Almost constant Zn yield $X_{Zn,QS}$ ~ 14% is found for $P_{Zn,QS}$ in the range 370–600 Pa. Hence, the quenching device is inefficient at these Zn partial pressures. For $P_{Zn,QS}$ < 370 Pa, $X_{Zn,QS}$ increases approximately linearly with decreasing $P_{Zn,QS}$. The maximum Zn yield of about 45% was measured at Zn partial pressure of 42 Pa. Zinc yield exceeding 90% was obtained

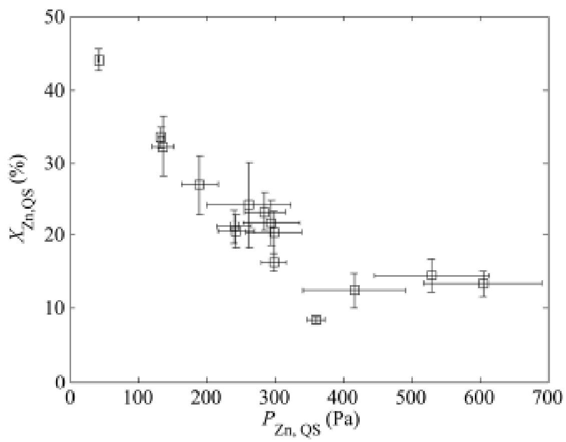

Figure 4.11. Zinc yield $X_{Zn,QS}$ of quenched products as a function of zinc partial pressure $P_{Zn,QS}$ in the quench section. Error bars account for the uncertainty of recovered and quenched particles. From [4.19].

with a sophisticated quenching device, which was tested in a solar thermogravimeter (TG) and previously described in [4.20].

The net Zn yield increased with decreasing Zn partial pressure in the quenching section, in agreement with a kinetic model for the separation of a mixture of Zn vapor and oxygen [4.21].

A transient heat transfer model was developed for analyzing the thermal performance of the solar reactor prototype for the solar-driven dissociation of ZnO in the 1600–2130-K range [4.22]. The model couples radiation, convection, and conduction heat transfer to the reaction kinetics for a shrinking domain and simulates a transient ablation regime with semi-batch feed cycles of ZnO particles. A set of four experimental runs with 3, 5, 7, and 9 consecutive feed cycles was used to validate the reactor model. Figure 4.12 shows the experimentally measured (solid curves) and numerically calculated (dashed curves) temperatures halfway along the reactor cavity at locations $T_{B,1}$, $T_{B,2}$, $T_{K,1}$, and $T_{K,2}$ for the run with 9 consecutive feed cycles. Also indicated are the measured power input P_{solar} and the calculated ZnO dissociation rate. The temperature agreement is reasonably good at all locations. As expected, temperatures dropped during ZnO feeding due to the interruption of P_{solar} and the addition of fresh ZnO particles. Discrepancies are attributed to slow and partial mixing of hot residual and cold fresh particles (not modeled).

Conduction losses in the water-cooled quenching unit and radiation losses in the annular outlet were identified as the main reasons for low efficiency of about 3%. Model calculations predict that the solar-to-chemical conversion efficiency of the prototype reactor can be increased up to 17% by downsizing the cavity outlet and by removing outlet water-cooling. Scaling up the reactor to 100 kW and 1000 kW nominal solar power input could potentially reaching maximum solar-to-chemical conversion efficiencies over 50%, mainly as a result of higher reaction rates at higher operating temperatures and lowered conduction losses through optimization of the geometry to minimize water-cooled components (Ref. [4.22]).

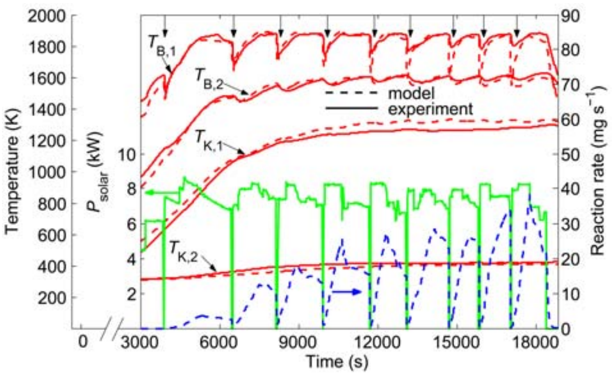

Figure 4.12. Experimentally measured (solid curves) and numerically calculated (dashed curves) temperatures, measured radiation power input, and numerically calculated ZnO dissociation rate as a function of time for the experimental run with 9 feed cycles. The top arrows point out to the times when the batch feeding of ZnO took place. From [4.19].

Hydrogen production by steam-hydrolysis of zinc as the second step of the two-step water-splitting thermochemical cycle based on ZnO/Zn redox reactions was investigated [4.23]. The hydrolysis reactor consists of a hot-wall tube containing a steam-quenched Zn(g) flow that co-produces H_2 and Zn/ZnO nanoparticles. The effects of the quenching gas flow rate and reactor wall temperature on the Zn-to-ZnO chemical conversion and particle yield were examined. Solid products were characterized by X-ray diffraction, N_2 adsorption, and SEM microscopy. Quench rates of 26×10^4 K/s yielded conversions of up to 95% at the expense of low particle yield due to significant wall deposition followed by hydrolysis. In contrast, operation at quench rates up to 10^6 K/s led to increased particle yield but lower conversion.

In another study, the hydrolysis rate of Zn particles by up to 50 mol% water vapor in Ar gas was measured by thermogravimetric analysis (TGA) at atmospheric pressure and 330–360°C and quantified by a core-shell model (Ref. [4.24]). A ready-to-use equation for the calculation of ZnO and H_2 formation during Zn hydrolysis was proposed and compared to literature data revealing enhanced hydrolysis rates for submicron Zn particles.

Publications: [4.18]-[4.24]

HYDROSOL-2 – Solar Hydrogen via Water Splitting in Advanced Monolithic Reactors for Future Solar Power Plants

Participants: CERTH/CPERI (GR), DLR (D), Stobbe Tech (DK), Johnson Matthey Fuel Cells Ltd. (UK), CIEMAT (E)

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Christian Sattler, christian.sattler@dlr.de

Funding: EC (FP6), DLR

Duration: November 1, 2005 - October 31, 2009

Background: A promising new method for solar-heated two-step water-splitting thermochemical processes operating at temperatures below 1500 K is being developed (Ref. [4.25]). It includes a support structure that can reach high temperatures when heated by concentrated solar radiation, combined with a redox system capable of water dissociation and suitable for high-temperature regeneration at the same time. The feasibility of this technology was previously demonstrated in the HYDROSOL project. A pilot-scale solar reactor was designed, built and operated in the DLR solar furnace facility in Cologne (Germany), and produced continuous “solar hydrogen”.

Purpose: (1) Develop an optimized pilot plant (100 kW_{th}) based on this innovative reactor concept and test it at the Plataforma Solar de Almería (PSA, Spain);

(2) further scale up this technology and demonstrate effective combination with solar concentrating systems; (3) provide stable metal oxide/ceramic support assemblies capable of performing at least 50 water-splitting cycles in a row; (4) decrease the temperature level of the regeneration step considerably below 1500 K; (5) optimize the efficiency of water-splitting and oxygen-releasing steps; (6) develop a solar field control strategy.

Achievements in 2008: The 100-kW_{th} pilot plant, including all peripheral systems like gas feeding, steam generator, mass flow controller, IR camera, flux measurement system, and analytics necessary for the two-step thermochemical water-splitting process, has been erected and installed on an experimental platform on the PSA SSPS tower. The plant was inaugurated at the end of March 2008. The following summer, its thermal behavior and characteristics were extensively tested (Figure 4.13). The effects of different operating parameters such as mass flow, gas preheating, and heliostat selection were investigated to define appropriate operating ranges and to find and demonstrate process control strategies. It was found that the process was controllable only by focusing and defocusing heliostats. The thermal tests made it possible to optimize and finally prove the process strategy and demonstrated the feasibility of the control concept implemented. It was shown that rapid changeover between the modules benefits process performance significantly.

Figure 4.13. 100 kW_{th} dual chamber pilot reactor during thermal testing at the SSPS tower at PSA.

In November 2008, the absorber was replaced and honeycombs coated with redox material based on ferrites were inserted. This allowed hydrogen production by water splitting to be tested for the first time. The tests were successful – some first cycles were run without problem. Significant amounts of hydrogen were produced with steam conversion of up to 30%.

Publications: [4.25]

HycycleS – Solar Production of Hydrogen by the Sulfur-Iodine and Westinghouse Thermochemical Cycles

Participants: DLR (D), CEA (F), University of Sheffield (UK), CERTH/CPERI (GR), JRC (NL), ENEA (I), ETH (CH), Empresarios Agrupados (E), BOOSTEC (F)

Contact: Martin Roeb, martin.roeb@dlr.de

Funding: EC (FP7), DLR

Duration: January 1, 2008 - December 31, 2010

Background: Solar energy is expected to play a major role in the production of future transportation fuels. In particular, solar thermochemical processes offer the potential of highly efficient mass hydrogen production at a competitive cost. Although most of these processes have been evaluated in theoretical studies, the technology is not yet ready for application. The highest worldwide priority is currently the sulfur-based cycles, i.e., the sulfur-iodine (SI) and hybrid sulfur (HyS) cycle, because they can be operated at temperatures at which it is possible to use concentrated solar radiation as the process heat source. However, high temperatures and corrosive environments in their key steps present major challenges. The severe operating conditions require advanced materials as well as special design and fabrication methods for key components common to both cycles, including oxygen separator, H_2SO_4 evaporator, and SO_3 decomposer. The latter has to withstand the highest temperature in the cycles, which is over 850°C and is one of the main foci of HycycleS.

Purpose: Development and improvement of materials and key components for H_2SO_4 decomposition by: (1) recommendations for suitable materials and catalyst/support systems needed for key components of sulfuric acid decomposition; (2) construction and test operation of a solar receiver-reactor for H_2SO_4 evaporation/decomposition ready for scale-up; (3) realization and verification of the feasibility of a compact SiC plate heat exchanger as an H_2SO_4 decomposer; (4) detailed understanding of transport properties and reaction performance of porous ceramic structures as reaction containment for the solar decomposition of H_2SO_4; (5) development of stable and reliable membranes for use in a separation step to significantly increase the conversion of SO_3 to SO_2.

Achievements in 2008: A major solar reactor concept was developed in the previous FP6-project HYTHEC. The porous absorber reactor was dedicated to the second step of the reaction, which is the reduction of sulfur trioxide, SO_3 (Ref. [4.26]). In HycycleS, this reactor concept is being further pursued and extended to the entire H_2SO_4 decomposition process including both the high temperature dissociation and the evaporation step.

A prototype receiver-reactor was designed and simulated and will subsequently be tested in the solar furnace to prove the feasibility of the concept, to investigate the process behavior, and to refine available experimental data for design studies and process simulation. The development of a multi-chamber reactor is of primary interest to examine the evaporation and SO_3 reduction processes separately. This allows optimization of both process steps to be highly independent.

The thermostructural integrity of the planned reactor was evaluated and predicted by FEM modeling for final design and proof of design.

As a core part of the receiver-reactor, absorber structure was analyzed in depth (Figure 4.14). Computer tomography in conjunction with numerical techniques was used to determine the morphological characteristics and the effective heat/mass transfer properties of the foam, such as extinction coefficient, scattering function, thermal conductivity, interfacial heat transfer coefficient, permeability, Dupuit-Forchheimer coefficient, tortuosity and residence time distributions, and dispersion tensor.

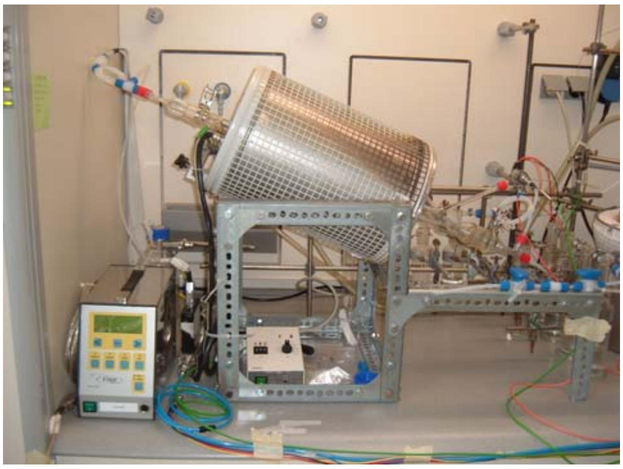

Figure 4.14. Lab rig for ageing tests: development of catalyst/substrate combinations for solar SO_3 reduction.

A pre-design of a compact heat exchanger as an SO_3 decomposer has been completed. Various mock-ups are being built to investigate other design challenges.

A review of high-temperature oxygen separation membrane materials, identified from previous work on fuel cells, has been undertaken. A pre-screening provided some candidate materials which are going to be tested in 2009.

Publication: [4.26]

SOLTERH – Solar Thermochemical Production of Hydrogen by Water-Splitting Processes

Participants: Solúcar Energía S.A. (E), Hynergreen Technologies S.A. (E), CIEMAT-PSA (E)

Contacts: Alfonso Vidal, alfonso.vidal@ciemat.es

Funding: Spanish Ministry of Science and Education (PROFIT): € 770,000

Duration: January 1, 2004 - December 31, 2008

Background: Thermochemical cycles are expected to be a cost and energy-efficient way to produce large amounts of hydrogen. Two-step water splitting processes based on ferrites are considered very attractive candidates since there is no phase transformation during the redox cycle. A study has been begun at the CIEMAT to identify critical factors for developing this technology [4.27]. For example, the choice of directly-irradiated volumetric receivers versus cavity receivers for solar driven catalytic reactions is still a key decision in technology development. This project seeks to solve the technical problems encountered in cavity receivers for driving solar heterogeneous reactions.

Purpose: Design, construction, and testing of innovative solar particle receiver-reactors at different scales (1 to 5 kW_{th}) at operating temperatures of about 800-1200ºC.

Figure 4.15. Photograph of the rotating cavity reactor at the PSA solar furnace.

Achievements in 2008: A considerable effort has been made throughout the year to demonstrate an advanced rotary kiln for gasification applications based on industrial experience.

The solar rotary kiln is shown in Figure 4.15. It features a refractory-lined steel cavity about 470-mm long with a 370-mm internal diameter, inclined about 2 degrees to the horizontal and rotating at about 10-50 rpm. Granular material is fed into the reactor and is moved during operation by the combined effects of rotation and gravity.

In parallel, the activity of five commercially available ferrites with different compositions was evaluated in the lab. In these tests, the potential cyclability of $NiFe_2O_4$ was confirmed, making it possible to employ this material for several hydrogen production cycles. In view of this, it was selected as the first candidate for solar experiments.

Publication: [4.27]

PHYSICO2 – Clean Hydrogen Production by Carbon Dioxide Free Alternatives

Participants: University Rey Juan Carlos I Madrid (E), ICP-CSIC (E), CIEMAT (E), REPSOL-YPF (E), Hynergreen Technologies S.A. (E)

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Funding: The Community of Madrid: € 2,017,000

Duration: January 1, 2006 - December 31, 2009

Background: The PHISICO2 project (Clean production of hydrogen: CO_2 emission-free alternatives) progresses in solving current technological and economic limitations by exploring different processes for clean hydrogen production, essential to future transition towards a hydrogen economy. The alternatives in this project feature prevention of CO_2 as a hydrogen by-product by using renewable energy sources to power its generation. The research in this project considers hydrogen production (1) from decomposition of natural gas assisted by heterogeneous catalysts; (2) by water photo-dissociation; (3) from water through solar-thermal processes based on thermochemical cycles.

Purpose: Evaluation and optimization of three different processes for clean, carbon dioxide-free emission hydrogen production.

Achievements in 2008: In previous work, the ferrites under consideration were usually synthesized in the laboratory by various preparation methods and assayed for the thermochemical cycles under different reaction conditions. Some examples of materials which have been studied by the CIEMAT are metal-doped ferrites with the chemical formula $M_{0.25}Mn_{0.75}Fe_2O_4$ (M: Mn, Co, Ni, Cu) [4.28]. However, since the figures of merit have not yet been established for this process, it is difficult to compare their activity with reports in the literature.

Therefore, commercially available ferrites such as nickel, zinc, copper, nickel-zinc, and copper-zinc ferrites were used as the reference standard for evaluating their feasibility for solar hydrogen production [4.29]. In addition to basic chemical and structural characterization, a study on hydrogen production and potential cyclability is currently underway.

Among the samples studied, $NiFe_2O_4$ appears to be the most active material both for net hydrogen production and cyclability. The results of four cycles with the $NiFe_2O_4$ ferrite are summarized in Table 4.1. The oxygen release decreases from the first cycle to the second one and so on. This may be due to the fact that, in the first three cycles, part of the activated ferrite was not re-oxidized during the water-splitting steps; however, the fully oxidized state is completely recovered in the fourth hydrolysis cycle. Indeed, the average molar ratio of H_2/O_2 produced throughout the four cycles is essentially stoichiometric. This nickel ferrite is proposed as possible reference material. Regarding the rest of the tested ferrites, NiZn shows the highest hydrogen production in the first cycle.

Table 4.1. Water dissociation results for four cycles with the Ni-ferrite

Cycle no.	O_2 (mmol/g ferrite)	H_2 (mmol/g ferrite)	H_2 / O_2 molar ratio
1	0.55	0.63	1.15
2	0.35	0.54	1.54
3	0.29	0.57	1.97
4	0.34	1.48	4.35
Total	1.53	3.22	2.10
Average	0.38	0.81	2.10

Publications: [4.28]-[4.29]

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5 Task III: Solar Technology and Advanced Applications

Operating Agent: Peter Heller, DLR

National Representatives:

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- Rolf Oström, European Union
- Alain Ferrière, France
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- Carlos Ramos, Mexico
- Diego Martinez, Spain
- Louis van Herden, South Africa
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5.1 Nature of Work & Objectives

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

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

5.2 Task III Objectives for 2011

In the context of growing commercial CSP project activities, further development and improvement of all CSP plant components is an obvious Task III challenge. The findings of studies like ECOSTAR on the impact of technology R&D on final CSP plant cost reduction should be borne in mind and refined to efficiently allocate R&D funds to the most promising topics.

As our industrial partners competitively pursue project development and R&D on component development, the following activities appear to be appropriate for supportive collaboration, moving the technology forward:

- **Guidelines for component performance measurement**, which can help component suppliers and plant operators qualify and validate their specifications.
- **Prioritization of R&D activities with high impact on cost reduction.** The findings of studies like Ecostar on the impact of technology R&D on reduction in the final cost of CSP plants will be further refined. In addition, SolarPACES Task III will work as a catalyst in setting up international R&D projects by leveraging funds to follow the roadmap laid out.
- **Reliability Evaluation of solar components and systems**. SolarPACES Task III will develop methods and procedures for predicting the life-time performance of solar plant components and systems. This also includes the development of methods for long-term stability testing (e.g., accelerated aging procedures).
- **Concentrator system quality assurance tools and methods**, to assure the optical quality of concentrators during installation and operation, including fast measuring systems for internationally standardized concentrator quality control and component performance characterization, including harmonization of simulation tools to offer investors reliable product and performance data.
- **Comparison and evaluation of storage concepts** Define a methodology for comparing and assessing

storage concepts and collecting design and operation data from systems under testing in different locations

- **Power plant optimization for arid regions.** SolarPACES TaskIII will analyze options to operate solar thermal power plants efficiently at sites with low water availability. This analysis will be based on experience in conventional power plant operation under dry cooling conditions.

Reported Task III Activities in 2008 are summarized in Table 1. The different ways of cost- and/or task sharing are marked in the last column:

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

5.3 Summary of Achievements in 2008

5.3.1 Components and subsystems

5.3.1.1 STORAGE

ITES – Storage System for Direct Steam Generation

Contact: Doerte Laing,
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Participants: German Aerospace Center (DLR), Ed. Züblin AG, Siemens Energy Sector;

Funding: Partly by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU)

Cost effective storage systems demand the adaptation of the storage technology to the heat source and the consumer. For direct steam generation, there is a significant advantage when storage modules specially adapted for preheating, evaporation and superheating are applied.

In the ITES project, a complete storage system for

Table 5.1. Summarized Task VI reported activities organized by Sector

	Concentrating Solar Technology and Applications	***Contact***	***Sharing***			
	Components and Subsystems		**I**	**M**	**T**	**C**
Storage	ITES – Storage System for Direct Steam Generation	Doerte Laing	x			
Trough	Reflector Optical Properties Measurement	Eckhard Luepfert	x			
	Reflector Shape Analysis	Eckhard Luepfert/Steffen Ulmer				
Tower	Solar hybrid power and cogeneration plants (SOLHYCO)	Peter Heller	x			
	A 200 kWe Solar Thermal Power Tower Development	Yong-Heack Kang/ Moon-Hee Park	x			
	Korea-China Co-Project 1- MWe Solar Power Tower Plant	Yong-Heack Kang/ Moon-Hee Park	x			
	A Novel Pressurized Air Receiver for Concentrated Solar Power via Combined Cycles	Aldo Steinfeld	x			
Fresnel	Fresnel process heat collector for industrial applications and solar cooling	Christian Zahler	x			
	Fresquali-Qualification for Linear Fresnel Collector Technology- Development and Modification of Optical and Thermal Measurement Systems	Anna Heimsath	x			
	Supporting Tools and Test Facilities					
	National Laboratory of Solar Concentration Technology and Solar Chemistry	Claudio Estrada	x			
	HFSF-High Flux Solar Furnace for Production of Solar Fuel	Yong-Heack Kang/ Jin -Soo Kim	x			
	Advanced Technologies and Applications					

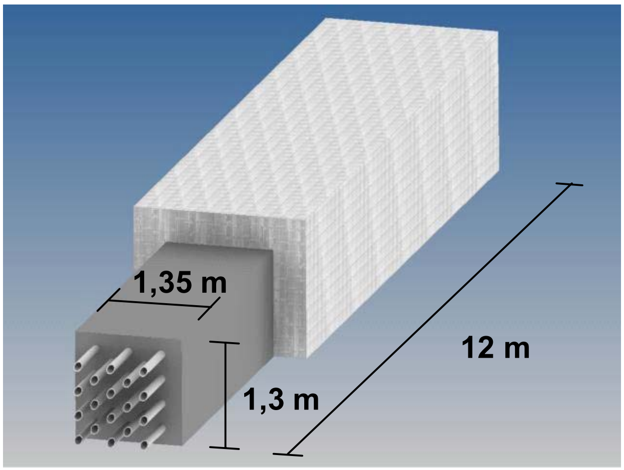

Figure 5.1 Drawing of concrete superheater demo-module

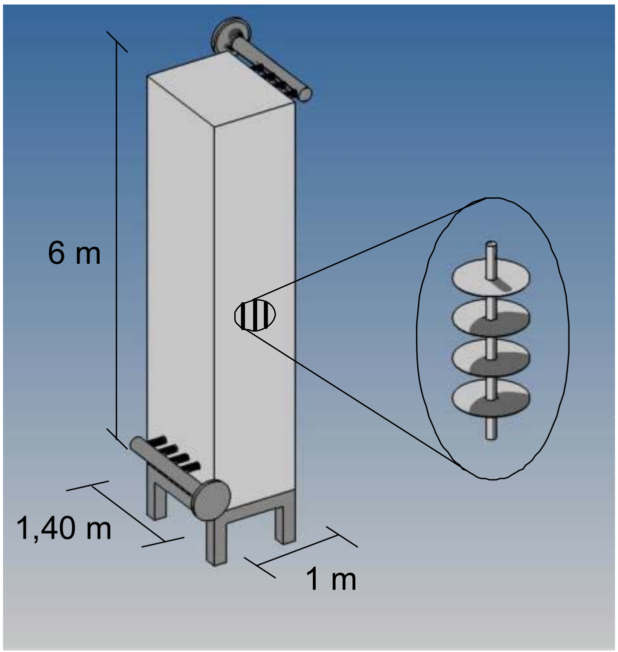

Figure 5.2 Drawing of PCM-storage demo-module

direct steam generation with specially adapted storage modules is developed. The concrete storage technology developed by Ed. Züblin AG and DLR is applied for preheating and superheating, while PCM storage was developed by DLR for the evaporation section. Adaptation of the process control system to the specific requirements of solar thermal power plants was developed by DLR and Siemens Energy Sector.

The concrete storage technology developed for trough power plants with thermal oil as the heat transfer fluid was successfully demonstrated in 2008 in a 100 kW test loop in Stuttgart, Germany. At the same time, the technology was adapted to the requirements of the water/steam heat transfer fluid and to a 500ºC storage temperature. A 300 kWh superheating storage module designed for demonstration in Spain is currently under construction (see Figure 5.1).

For condensation and evaporation of the heat transfer carrier, a PCM-storage unit with sodium nitrate as the phase-change material was developed. The PCM storage module uses a specially developed sandwich design to reach the high heat transfer rates required. The PCM has a melting temperature of 306°C, which leads to a steam pressure of 112 bars during charging and 78 bars during discharging. A first 4-kW test module with approx. 140 kg of salt was successfully tested in the DLR laboratory in 2008. The design was scaled up to about 14 tons of salt with a latent heat capacity of approx. 700 kWh (see Figure 5.2), and is currently under construction.

The 1-MW demonstration storage system, made up of the PCM storage module and the concrete superheater module will be tested in 2009 in a DSG test facility specially erected at a conventional ENDESA power plant in Carboneras (Spain). Commissioning is scheduled for May 2009. Facility operation and thus investigation of the storage system will start in June 2009.

Publications: [5.1], [5.2], [5.3]

5.3.1.2 PARABOLIC TROUGH

Reflector Optical Properties Measurement

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DLR

Participants: DLR

Funding: German Federal Ministry for the Environment (BMU) and DLR

The optical performance of reflective materials for application in concentrating solar collectors was characterized using their spectral hemispherical reflectance ρ_{hem} and direct reflectance ρ_{direct}. The hemispherical reflectance spectra of different samples were weighted with the direct solar spectrum according to ASTM G173 (respectively ISO 9050) to get the solar weighted hemispherical reflectance ρ_{SWH}. ρ_{direct} was measured at 660 nm and allocated with the hemispherical measurements to get the solar weighted direct reflectance ρ_{SWD}. This is the relevant parameter for solar applications because it describes the fraction of the solar energy that can be concentrated onto the absorber by the mirrors.

Table 5.2. Solar-weighted hemispherical reflectance ρ_{hem} and direct reflectance ρ_{direct} .of different reflector materials

	Glass	Polymer	Alu1	Alu2
ρ_{SWH} ASTM G173	0.939	0.922	0.903	0.868
ρ_{SWH} ISO 9050	0.937	0.913	0.901	0.866
$\rho_{SWD,25}$ ASTM G173	0.939	0.874	0.830	0.837
$\rho_{SWD,25}$ ISO 9050	0.937	0.866	0.827	0.833
$\rho_{direct,r}$ after 100 cycles	0.995	0.320	0.920	0.66

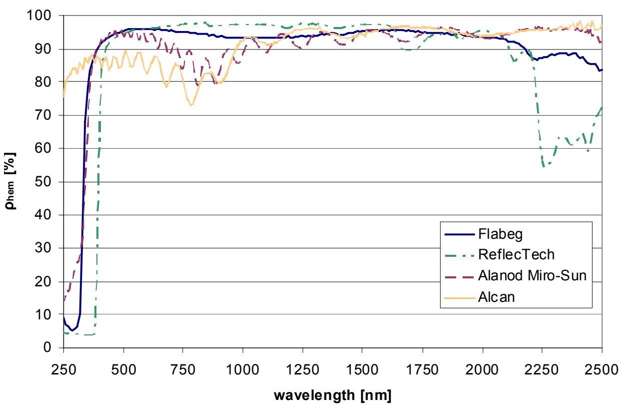

Figure 5.3 Hemispherical spectra of reflector materials

A mechanical durability test, making use of the linear movement of abrading rubber on the optical surface, was defined. Based on DIN ISO 9211-4, the parameters of the test have been systematically optimized to be able to resolve differences between mirror materials.

All measurement-techniques were used in combination as a tool for comparative evaluation of different reflective materials. The results demonstrate the optical advantage of silver reflector layers and also the excellent durability of glass as front reflector material compared to coated aluminum and polymer films. The tests described are proposed as standardized procedures for component testing for concentrating solar collectors.

Reflector Shape Analysis

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Participants: DLR, CIEMAT, industry

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

The performance of concentrating solar collectors depends to a significant extent on accurate shape of the mirrors reflecting the sunlight onto the absorber. On the basis of previous work on shape measurement and ray-tracing, a quality parameter has been defined for parabolic trough mirrors, which quantifies the average deviation of the reflected beam from the design focal line. It was demonstrated that the standard distribution (Gaussian distribution) is sufficiently related to derive the relevant performance intercept factor from it.

Based on measurement results and ray-tracing analyses it is proposed to specify mirror shape quality with the transversal standard focus deviation parameter FDx in horizontally and FDy vertically. This specification can replace previously used standard slope deviations and definitions related to laser-beam intercept factors on the receiver size without changing measurement procedures, but much more significantly, as a quality parameter for this key element of CSP technology.

As objective for the glass reflector for high performance trough collectors a typical value for the standard focus deviation in transversal direction is about 15% of the absorber diameter.

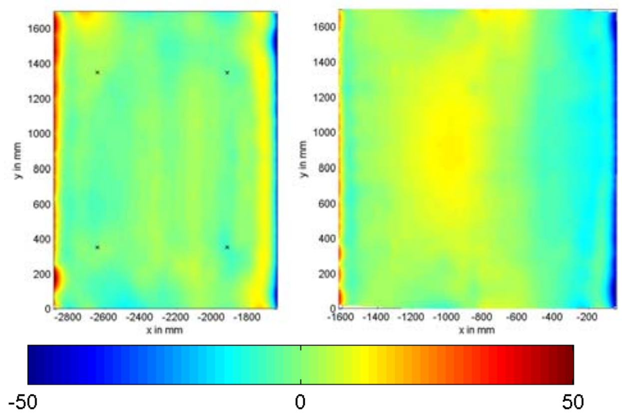

Figure 5.4 Example of a measurement result of the spatial distribution of the transversal focal deviation for the surface analysis of a pair of mirrors, scale in mm Tower

5.3.1.3 TOWER

Solar hybrid power and cogeneration plants (SOLHYCO)

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Participants: DLR (D), Turbec (Sw), CEA (F), CIEMAT (E), Solucar (E), Ormat (I), GEA (Pol), NEAL (Alg), FUSP (Bra), Vitalux (Bra), IIE (Mex)

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

Duration: 42 months

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

- Development of a solar-hybrid microturbine prototype unit based on a commercial microturbine
- Development of a new receiver based on a new high- performance tube technology
- Development of biofuel combustion system

During the third year of the project, development of the multilayer tube manufacturing technology was delayed due to insolvency of one of the partners FTF (SME). A new manufacturer started producing the first samples of an inconel-copper-inconel tube. These have already been thermally tested in the CEA test furnace and showed promising results. The layers seemed to withstand the thermal stress without delamination. Extensive lab tests up to 850°C are planned, first with the tube samples and later on with complete tubes.

Meanwhile, manufacturing of the prototype 100-kW cogeneration system receiver has begun. The tubes are made of monolayer Inconel, but may be replaced by multilayer tubes. The turbine package is finished and is

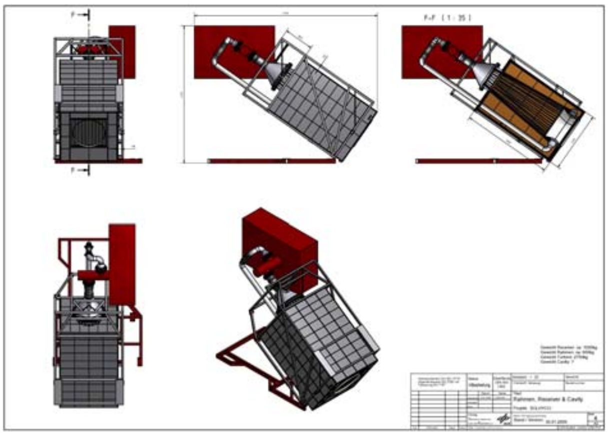

Figure 5.5 Solar receiver (cavity not shown) design for TURBEC microturbine (100 kW$_e$) for cogen applications

now ready to be shipped to the test site in Almeria, Spain, for testing in a 6-month solar-hybrid operation. Tests are scheduled to start in June 2009.

Figure 5.5 shows details of the turbine and receiver package design.

Apart from 100-kW cogen system development, a new, modified biofuel combustion system was put into operation in the former SOLGATE test bed using the OST3 turbine (250 kWe) system with the 3 solar receivers. In the first tests, the modified system was run without problem. The test setup was then modified to integrate two different additional mass-flow measurement systems, a rotameter and a system based on the tracer gas method, allowing the pitot tube used throughout the former turbine tests to be compared to these alternative methods. The rotameter could only be used for lower turbine power levels due to its upper range limit. Tests with the turbine and solar components were done at lower powers, for which the tracer gas method showed good precision. Full load tests are planned as the next step. Therefore the rotameter were dismantled and a second test phase started. Results are expected by March 2009.

Website: www.solhyco.com

Publication: [5.4]

A 200-kW$_e$ Solar Thermal Power Tower Development

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Participants: Daegu City Gas, DIC, CMSTech, Max Tech, KIER; IHU, SNUT, CNU.

Funding: Approx. $9,600,000 from Korea MKE funded project, cost shared with Participants

The 200 kW$_e$ solar thermal power tower plant project started at the end of 2008. The final goal of the project is to develop a cost-effective small-scale (200 kW$_e$) solar power system which adapts high-temperature volumetric air receiver, thermal storage and steam generator to operate a steam turbine for electricity production.

Four industrial, one research (KIER) and three university partners are collaborating for this project and the Daegu City Gas Co. Ltd. is leading this project. This three year project will hopefully deliver the first power tower system in Korea in 2011. It will be utilized as a mid-scale test bed for concentrated solar technologies after termination of the project.

Korea-China Co-Project for 1-MW Solar Thermal Power Tower Plant

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Participants: KIER, Halla Energy & Environment, Shinyang Energy, Kopacets, SNUT, IHU

Funding: Approx. $2,500,000 from Korea MKE funded project, cost shared with Participants

This project is an international Korean and Chinese collaboration project for development and operation of a 1-MW power plant in China. For this project, the Korean and Chinese governments are contributing major research funding and some academic and industrial partners are collaborating. The project was started in Korea at the end 2005, and in China in the middle of 2006, respectively. KIER and IEE (Institute of Electrical Engineering) CAS (Chinese Academy of Science) are leading both sides of the project. The Korean role is to develop a solar receiver and a thermal storage/transportation system. After some years of fundamental research, designing, and component development research in China, actual building of the solar field

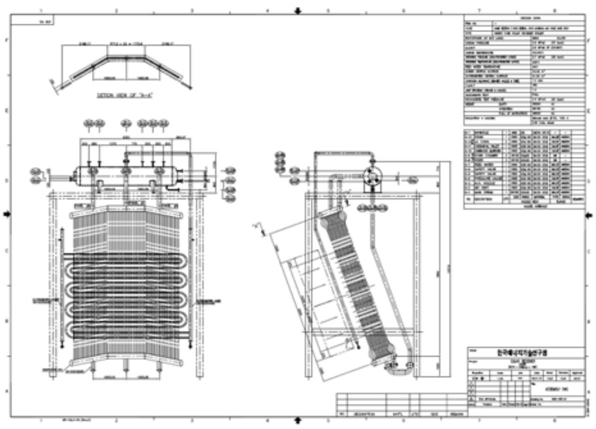

Figure 5.6 Assembly drawing of receiver for production of superheated steam of 2.8 MPa and 400 °C.

and tower will take place during 2009. A water/steam receiver will be adapted for the power tower system and a designed receiver (Figure 1) is ready for manufacturing by KIER. Major thermal energy storage is now under detailed design by KIER as well. The power tower system is expected to start operation and produce electricity in 2010.

A Novel Pressurized Air Receiver for Concentrating solar power via Combined Cycles

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Participants: ALSTOM, ETH Zurich/PSI

Central receiver systems using solar tower technology can achieve solar concentration ratios exceeding 2000 suns, and therefore, supply solar process heat at above 1000°C. Significant improvement in terms of solar-to-electricity efficiency can be achieved by supplying high-temperature thermal energy directly to the topping Brayton cycle in combined cycle power generation. The key component of such a solar-driven combined cycle (SCC) is the solar receiver, where concentrated solar thermal energy is absorbed and transferred to pressurized air (or any other working fluid expanded in the gas turbine). The receiver requirements for an SCC are defined by the gas turbine inlet conditions, i.e., temperatures in the range 1000–1400°C and pressures in the range 8–30 bars.

Previous designs of solar receivers for SCC were based on windowed concepts which use directly-irradiated volumetric absorbers made of ceramic fins or foams. The direct irradiation was proven to provide an efficient means of heat transfer. Nevertheless, windows are critical and troublesome components. Alternative designs use opaque heat exchangers. The indirectly-irradiated concepts eliminate the need of a window at the expense of having less efficient heat transfer by conduction through the absorber walls. Thus, the disadvantages, such as the maximum operating temperature, thermal conductivity, resistance to thermal shocks, and inertness to oxidation by air, are linked to limitations imposed by the metal/ceramic absorber construction materials.

A novel design of an indirectly-irradiated solar receiver is shown schematically in Figure 5.7. It consists of an annular reticulate porous ceramic foam (RPC) bounded by two concentric cylinders. The inner cylinder has a small aperture to let in concentrated solar energy. Because of its cavity-type configuration, it can efficiently capture incoming radiation that undergoes multiple internal reflections. A 3D compound parabolic concentrator (CPC) is incorporated at the aperture to boost the solar concentration ratio and reduce the aperture size and re-radiation losses. Absorbed radiant heat is transferred by conduction, radiation, and convection to the pressurized air flowing across the RPC. The outer cylinder is made of non-porous insulating material and is surrounded by a metal shell to maintain the 10 bar internal pressure.

This solar receiver design offers several intriguing advantages: 1) high apparent absorptivity due to cavity-type geometry; 2) high convective heat transfer from the RPC to air; 3) homogeneous and monotonously increasing temperature profile; 4) uniform compressive load on the cavity; 5) reduced re-radiation losses at the cavity inlet due to entering cold air; and 6) scalability as a single or multi-receiver array. The disadvantages are those common to indirectly-irradiated receiver concepts, i.e., the limitation associated with the thermal transport properties of the construction materials. Candidate materials for the cylindrical cavity and RPC are ceramics (SiC, Al_2O_3) and high-temperature metal alloys.

A 2D steady-state energy conservation equation coupling the three heat transfer modes has been formulated and solved by the finite volume technique and by applying the Rosseland diffusion, P_1, and Monte Carlo radiation methods. The model allows identification of critical material properties and optimization of geometrical dimensions as a function of desired air outlet temperature and mass flow rate. For a solar concentration ratio of 3000 suns, the outlet air temperature reaches 1000°C at 10 bar, yielding a 77% thermal efficiency. In general, the dominating loss mechanism is re-radiation through the cavity's aperture, which can be reduced to some extent by incorporating a CPC. Increasing air mass flow rates across the RPC lead to a beneficial cooling effect at the cavity entrance, further minimizing re-radiation losses. For solar concentration ratios above 3500 suns, conduction through the cavity becomes the limiting heat transfer mode. The cavity wall thickness will have to be minimized in accordance with its mechanical and thermal stability to withstand the operating pressures and temperatures.

Publication: [5.5]

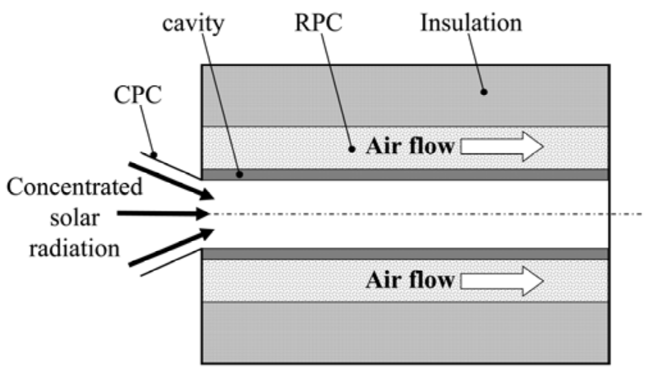

Figure 5.7 Solar receiver concept featuring an annular reticulate porous ceramic foam (RPC) bounded by two concentric cylinders. Concentrated solar radiation absorbed by the inner cylindrical cavity is transferred by conduction, radiation, and convection to the pressurized air flowing across the RPC.

5.3.1.4 FRESNEL

Fresnel process heat collector for industrial applications and solar cooling

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Participants: PSE AG (D), Gas Natural (E), ESI (E);

Funding: Deutsche Bundesstiftung Umwelt DBU

Industrial process heat in the temperature range of up to 250°C is a huge but almost untouched field for solar thermal technologies. State-of-the-art non-tracking collectors are limited to a maximum operating temperature of 150°C. Higher temperatures can be reached with concentrating collectors with operating temperatures above 300°C and a field size of at least several MW_p., mostly developed for solar thermal power generation. Only a handful of companies and institutes target the enormous potential for solar industrial process heat, which can be defined by an operating temperature range of 100°C to 250°C and a power range from around 50 kW_{th} to a few MW_{th} (peak capacity). Plenty of applications for this power and temperature range can be found, e.g., in the food and textile industries, but presently, the most attractive option is solar thermal air conditioning.

PSE AG developed a linear concentrating Fresnel collector, which uses individually tracked reflector rows to concentrate direct solar radiation to a stationary linear receiver. The Fresnel approach offers a relatively simple and low cost construction with low wind loads and high ground coverage, which makes this technology well suited to installation on flat roofs.

In December 2005, a first prototype of the PSE linear Fresnel process heat collector was installed in Freiburg, Germany. The collector was operated and evaluated in cooperation with the Fraunhofer Institute for Solar Energy Systems.

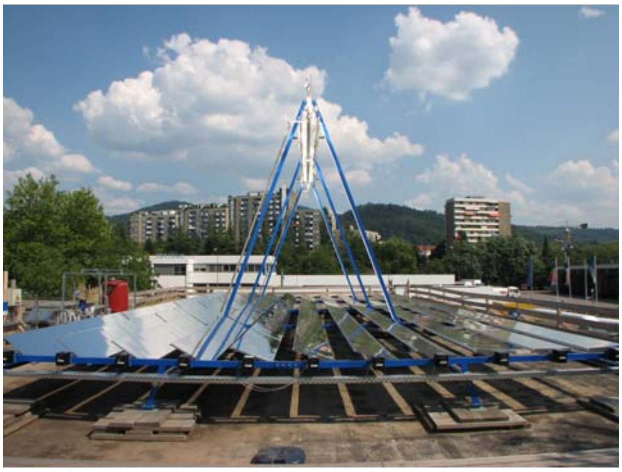

Figure 5.8 First prototype of PSE Fresnel process heat collector (2005, Freiburg, Germany)

Figure 5.9 PSE Fresnel process heat collector powering two NH_3/H_2O absorption chillers (2006, Bergamo, Italy)

Figure 5.10 PSE Fresnel process heat collector powering a NH_3/H_2O absorption chillers (2008, Grombalia, Tunisia)

A second prototype with an aperture area of 132-m^2 (66 $kW_{p,th}$) was installed in Bergamo, Italy to power an ammonia-water absorption chiller. The complete solar cooling system has been operated and monitored since August 2006 to evaluate system performance as well as the performance of the individual components.

The third installation, with 352 m² (176 $kW_{p,th}$) was installed in late 2007 to power a double effect H_2O/LiBr chiller at the University of Seville, Spain. The latest installation is a solar cooling system with a NH_3/H_2O chiller at a winery in Tunisia.

A water circuit pressurized at 16 bar is a cost-effective and efficient way to transfer process heat with temperatures up to 200°C. For temperatures above 250°C, a thermal oil circuit is the appropriate technology. The maximum output temperature of the Fresnel collector is only limited by the vacuum absorber tube, a PTR 70 receiver manufactured by Schott Solar GmbH, which is approved for 400°C and 40 bar pressure.

With the Mirroxx GmbH spin-off in December 2008, the structure for industrial series production and strategic marketing of the Fresnel collector technology has been formed. The target group consists of industries in sunny countries which require process heat at temperatures up to 400°C, an enormous market which will be tapped by sales cooperation in the targeted countries and through installation of pilot plants.

In late 2007, a Fresnel process heat collector with a 352-m^2 aperture area (176 $kW_{p,th}$) was installed on the roof of the Escuela Técnica Superior de Ingenieros (ESI), a School of Engineering building in Seville, Spain. The collector has a total length of 64 m (16 4-m-long modules) and otherwise similar in design to the ones in Freiburg and Bergamo. The collector powers a double effect H_2O/LiBr absorption chiller (Broad), with a maximum cooling capacity of 174 kW_{th} for air-conditioning the building. At this site the wet-cooling tower for heat rejection, which is usually necessary for H_2O/LiBr absorption chillers, was substituted by a water heat exchanger fed by water from the nearby Guadalquivir River. The double effect absorption chiller offers a high COP of up to 1.3, which makes this system an even more attractive application of solar process heat for solar thermal cooling. First system operation experience is positive and measurement results are expected soon.

Figure 5.11 Fresnel process heat collector on the roof of Escuela Técnica Superior de Ingenieros, Sevilla

It is possible to provide industrial process heat at 200°C with roof-mounted linear Fresnel collectors, which makes them well suited to power efficient absorption chillers.

Two prototypes and two commercial PSE/Mirroxx linear Fresnel process-heat collector units have been installed so far. Pilot solar-cooling system testing and measurement in Bergamo show reliable automatic operation and typical efficiency of the PSE/Mirroxx Fresnel collector of approx. 40% with respect to DNI at 180°C.

Table 5.3. Technical data of PSE / Mirroxx Fresnel process heat collector

Length	Modular in steps of 4 m
Width of the mirror field	7.5 m
Aperture width	5.5 m
Total height	4,5 m
Number of mirrors	11
Width of mirrors	0.5 m
Optical efficiency	0,62
Thermal loss coefficient	4.3 10^{-4} W/(m^2K^2)
Peak capacity	500 W/m²

The system has been in continuous operation since late summer 2006.

In late 2007 and early 2008 the first commercial systems were commissioned in Spain and Tunisia. Both are being evaluated by the customers in the frame of research/demonstration projects.

In spring 2009 a demonstration system for direct production of saturated steam in a linear Fresnel collector with a 132-m^2 aperture area will be installed in Freiburg. Operating pressures will be adjustable in the range of 2 to 16 bars.

Figure 5.12 Fresnel process heat collector in operation

We are gradually upgrading our production facilities in Freiburg, Germany and expect more projects for solar cooling and industrial process heat generation in the near future.

5.3.2 Supporting Tools and Test Facilities

National Laboratory of Solar Concentration Technology and Solar Chemistry

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Participants: CIE-UNAM, UNISON, INAOE, UAM, IIE

Funding: CONACYT, UNAM, and UNISON. 40 Million Mexican Pesos.

Duration: 36 months, starting July 2007.

Background: Mexico is ideal for implementing solar technologies due to its favorable geographic location in the Sunbelt. In particular, in the northwest states, insolation has a very important beam solar radiation component. This high quality solar resource makes that area ideal for the implementation of concentrating solar technologies (CST). With the aim of supporting the development of concentrating solar technologies in Mexico, a grant was awarded the CIE-UNAM by the Consejo Nacional de Ciencia y Tecnología (CONACYT), for the creation of three research facilities: a high radiative flux solar furnace (HRFSF), a solar photocatalytic water treatment plant (SPWTP), and a heliostat test field (HTF). The first two will be located at CIE-UNAM, in Temixco, Morelos, and the latter at UNISON, in Hermosillo, Sonora. These facilities are grouped as a National Laboratory of Solar Concentrating Systems and Solar Chemistry, and their development is also partially funded by two of the participant institutions (CIE-UNAM and UNISON).

Purpose: Design and construction of a high radiative flux solar furnace, a solar photocatalytic water treatment plant, and a heliostat testing field.

Achievements in 2008:

High radiative flux solar furnace. The architectural design of the building was finished, and the construction began at the end of 2008. The optical design of the furnace has been completed as well as the mechanical design of the support frame for the concentrator. The concentrator will be made up of 409 hexagonal-shaped spherical mirrors, each with a 40-cm diameter. These mirrors will have 6 different focal distances depending on their position on the frame, which will be spherical. The mirrors are being made at INAOE. The mechanical design of the heliostat is in progress.

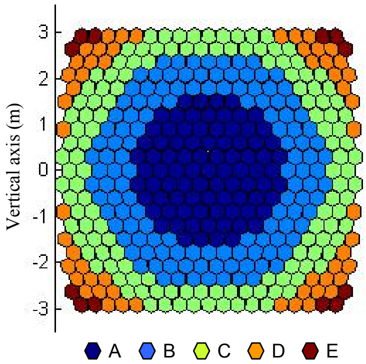

Figure 5.13 Architectonic concept of the high radiative flux solar furnace, and distribution of focal distances of the concentrator mirrors.

Solar photocatalytic water treatment plant. The general plant and associated laboratories have been designed. Construction of two laboratories, a chemical analysis laboratory, adjacent to the plant, and a laboratory for the development and characterization of catalysts and photocatalytic processes began in 2008. The plant solar photoreactors, designed as CPC collectors with 2-sun concentration ratio and fixed catalysts, are under construction.

Heliostat test field. The University of Sonora (UNISON) has assigned a plot of land outside the city of Hermosillo for the deployment of the HTS. The layouts for this plant and for other future installations have already been designed. A 6-m^2 heliostat prototype has been designed, built and tested. Based on this experience, a 36-m^2 prototype is being designed.

HFSF-High Flux Solar Furnace for Production of Solar Fuel

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Participants: KIER, KAU (KOR)

Funding: Approx. $810,000 from KIER

This three- year project started in 2007 based on the solar concentration system and technologies from our previous solar reforming research with some modifications for this solar furnace.

Figure 5.14 High Flux Solar Furnace in KIER

As the first step for solar fuel research, a 40-kW$_{th}$ on-axis solar furnace system was fully built in KIER in 2008. It consists of a 120-m^2 heliostat, a 52.7-m^2 dish concentrator, a secondary concentrator for higher concentration ratio. It also includes a number of control, measuring, and mapping devices for an easy, rapid experiment when required. The highest solar concentration ratio is estimated to be over 10,000 suns. At the moment thermal performance of the furnace is under the test.

5.4 Meetings, Reports, Publications

5.4.1 Meetings

Task meetings were held at the 14th SolarPaces Symposium in Las Vegas, USA on March 8, 2008. These were organized in conjunction with Task I in order to review current tools for assessing component and system performance and identifying the requirements for measurement standards. It was decided to form a joint Task I/III work group to create a roadmap for "Testing guidelines and standards". Twelve participants offered to participate in the group. Afterwards, the roadmap was implemented and existing standards and measurement parameter definitions were identified. These should be used as a basis for discussion in a follow-up standardization workshop to be held at the 15th SolarPaces Workshop in September 2009.

5.4.2 Publications:

[5.1] Steinmann, Wolf-Dieter; Laing, Doerte; Tamme, Rainer (2008): Latent Heat Storage Systems for Solarthermal Power Plants and Process Heat Applications. In: *Proceedings 14th Biennial Solar Paces Symposium*, 14th Solar Paces Symposium, Las Vegas (USA), 2008-03-03 - 2008-03-07

[5.2] Birnbaum, Jürgen; Eck, Markus; Fichtner, Markus; Hirsch, Tobias; Lehmann, Dorothea; Zimmermann, Gerhard (2008): A Direct Steam Generation Solar Power Plant with Integrated Thermal Storage. In: *Proceedings, 14th SolarPACES Symposium*, Las Vegas (USA), 2008-03-03 - 2008-03-07

[5.3] Laing, Doerte; Lehmann, Dorothea; Bahl, Carsten (2008): Concrete Storage for Solar Thermal Power Plants and Industrial Process Heat. In: *EUROSOLAR [Hrsg.]: Conference Proceedings, Third International Renewable Energy Storage Conference* (IRES 2008), Berlin, 2008-11-24 - 2008-11-25

[5.4] Ulmer S., Heinz B., Pottler K., Lüpfert E.: Slope Error Measurements of Parabolic Troughs Using the Reflected Image of the Absorber Tube. *J. Sol. En. Eng*. Vol. 131, 2009, p 011014

[5.5] Hischier I., Hess D., Lipinski W., Modest M., Steinfeld A., "A heat transfer analysis of a novel pressurized AIR receiver for concentrating solar power via combined cycles". *Proc. 2009 ASME Summer Heat Transfer Conference*, San Francisco, July 19-23, 2009.

[5.6] A. Häberle, C. Zahler, F. Luginsland, M. Berger: Practical Experience with a Linear Concentrating Fresnel Collector for Process Heat Applications, *14th International SolarPACES Symposium on Solar Thermal Concentrating Technologies*, Las Vegas, 2008

[5.7] A. Häberle, C. Zahler, F. Luginsland, M. Berger: A Linear Concentrating Fresnel Collector for Process Heat Applications, *EUROSUN 2008: 1st International Conference on Solar Heating, Cooling and Buildings*, Lisbon, 2008

[5.8] C. Estrada, D. Riveros-Rosas, J. Herrera-Vázquez, S. Vázquez-Montiel, C. A. Arancibia-Bulnes, C. Pérez-Rábago, F. Granados-Agustín. Optical design of a high radiative flux solar furnace for Mexico, *Proceedings of the EUROSUN 2008 Conference,* October 7th-10th, Lisbon, Portugal, paper 515.

6 Task IV
Solar Heat for Industrial Applications

Werner Weiss, Klaus Hennecke, (C. Richter)

Task IV ended in 2007, but final reports and deliverables were published in 2008. This overview of accomplishments and deliverables is therefore included in the 2008 report.

Solar Heat for Industrial Applications was a collaborative project of the IEA's Solar Heating and Cooling and SolarPACES Programs in which 16 institutes and 11 companies in 8 countries participated. The purpose of the project was to provide the knowledge and technology necessary to foster installation of solar thermal plants for industrial process heat.

To do this, studies on the technology's potential were conducted in the participating countries, medium-temperature collectors were developed for the production of process heat up to temperature levels of 250°C, and solutions to the problems involved in integrating solar heat into industrial processes were sought. In addition, demonstration projects were carried out in cooperation with the solar industry.

Participants carried out research and development in the framework of the following four Subtasks:

Subtask A: Solar Process Heat Survey and Dissemination of Task Results
Subtask Leader: Riccardo Battisti (I)

Subtask B: Investigation of Industrial Processes
Subtask Leader: Hans Schnitzer (A)

Subtask C: Collectors and Components
Subtask Leader: Matthias Rommel (D)

Subtask D: System Integration and Demonstration
Subtask Leader: Klaus Hennecke (D)

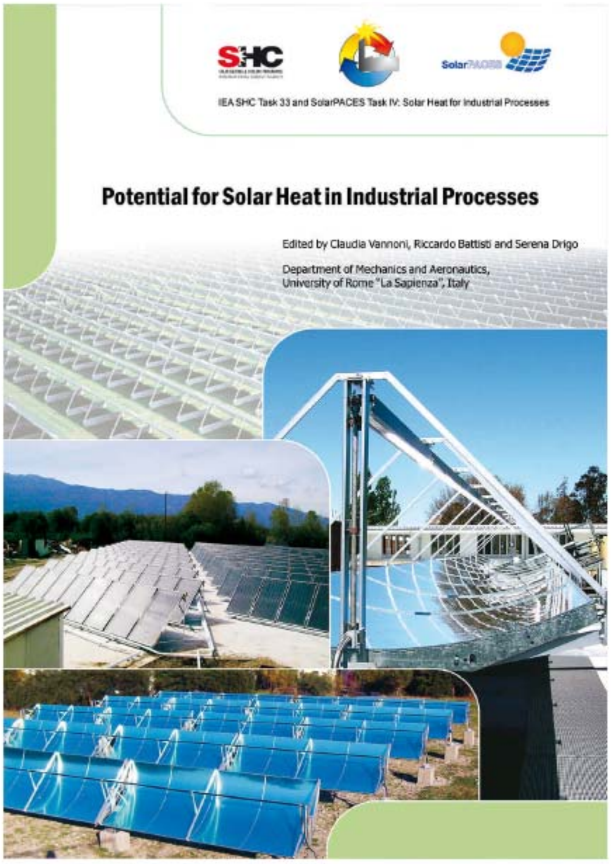
The project definition phase was organized by Werner Weiss (AEE INTEC), who also served as the Task Operating Agent. Task 33 was a four-year project that ended in October 2007.

Commencement date: November 1, 2003
Completion date: October 31, 2007

The main Task findings are published in four booklets, summarized briefly below:

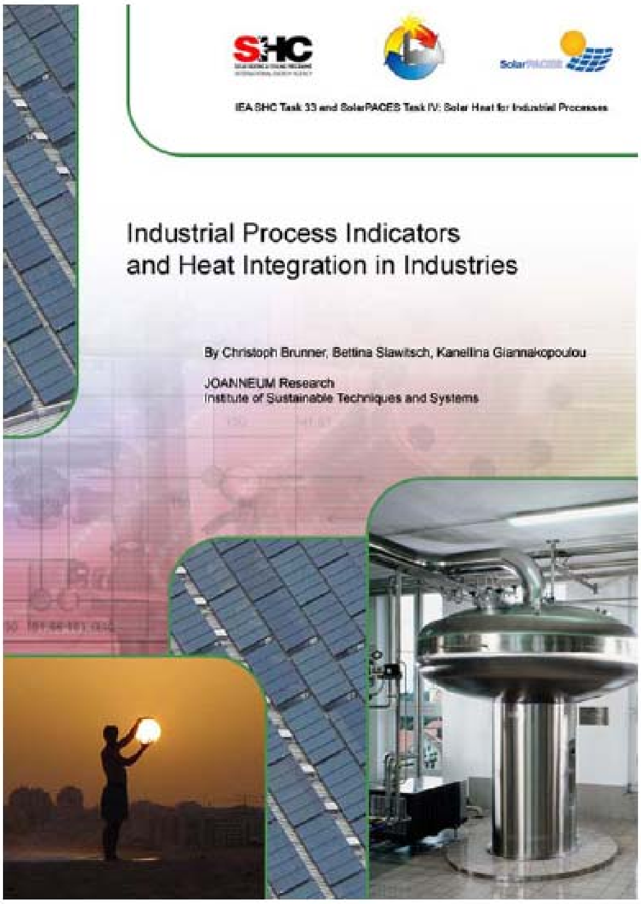
6.1 Potential for Solar Heat in Industrial Processes:

The purpose of this report, developed in the framework of IEA Solar Heating and Cooling Program Task33 and IEA SolarPACES Program Task IV, Solar Heat for Industrial Processes (SHIP), is to show the potential of solar thermal (ST) plants for industrial heat applications. To do this, several local potential studies in different countries were surveyed and compared with a focus on the key results and the methodologies applied. The primary targets of this report are ***the solar industry and policymakers***, who can learn about the relevant and so far unexploited market sector in industrial applications. Moreover, policymakers will realize that solar thermal energy should not only be promoted for the more "traditional" residential applications, but also for such innovative applications as solar process heat. ***This report is designed as a reference for developing national and local campaigns and policies on solar thermal energy for industrial use***. It reports on the main outcomes of the potential studies performed in different countries all over the world and extrapolates these results to a figure indicative of the European potential. The country studies carried out in Austria, the Iberian Peninsula (Spain and Portugal), Italy and the Netherlands are included in this report as well as two regional studies (Wallonia for Belgium and Victoria for Australia) and two specific industrial sectors studies from Greece and Germany.

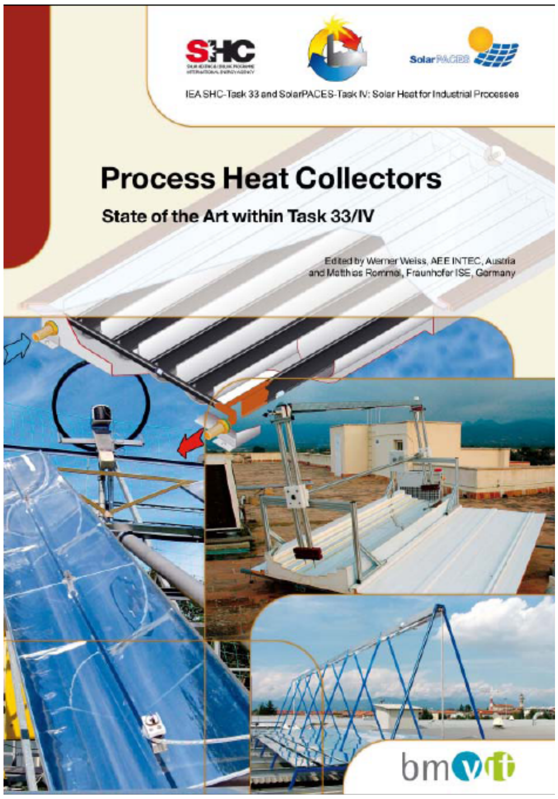


6.2 *Industrial Process Indicators and Heat Integration in Industry*

This report, developed in the framework of International Energy Agency Task 33/IV Solar Heat for Industrial Processes (SHIP), provides an overview of the tools developed under IEA Task 33/IV. The first tool is the "Matrix of Industrial process indicators – MATRIX", which is a comprehensive database developed in Subtask B as a decision support tool for solar experts. MATRIX facilitates work with industry and identification of suitable solar applications. The solar process heat production installation can be studied and calculated without detailed knowledge of the relevant unit operation and production processes. Some industries such as food, chemistry, plastics, textile and surface treatment have been identified as very promising sectors for solar thermal applications. For these industries, detailed information like general benchmark data, process temperatures, production line flow sheets and generic hydraulic schemes for solar integration can be found in the specific Sub-MATRICES. Economic feasibility studies of these industries must focus on an integrated analysis of cooling and heating demands which takes into account competitive solar thermal energy technologies. Among the competing technologies are heat integration, cogeneration and heat pumps, which are also described in MATRIX in the relevant parts. In addition to technology optimization, energy consumption also has to be reduced by system optimization. Most industries have a production heat demand and at the same time a lot of waste heat which can be used, with the advantage of being simultaneous with the heat demand of other processes. Waste heat has to be reused at the highest possible temperature. The most promising methodology for identifying the maximum heat recovery in a predefined system (industrial process) is to design a heat exchanger network using Pinch Analysis, which can indicate how to optimize the system and minimize external heating and cooling demand. The Pinch Energy Efficiency (PE^2) computer program, which calculates the heat recovery potential and designs a technically and economically feasible heat exchanger network for a given process, was developed under IEA Task 33/IV. PE^2 meets the requirements of heat integration calculation in suitable industries. One of the main advantages of the program is automatic calculation of an ideal heat exchanger network (based on mathematical criteria and aiming at maximum energy savings in kWh per year). Furthermore, heat exchanger surfaces can be calculated and a dynamic cost function gives the payback period for a given heat exchanger network based on user defined economic data, as well as the visualization of energy savings with a Sankey Editor, provide fast energy optimization and documentation of the entire process. PE^2 analysis shows the energy demand remaining at the corresponding temperature after the process has been optimized by heat recovery, and gives the temperature at which external heat/cold is necessary, which is important to know for implementing solar energy for heating.

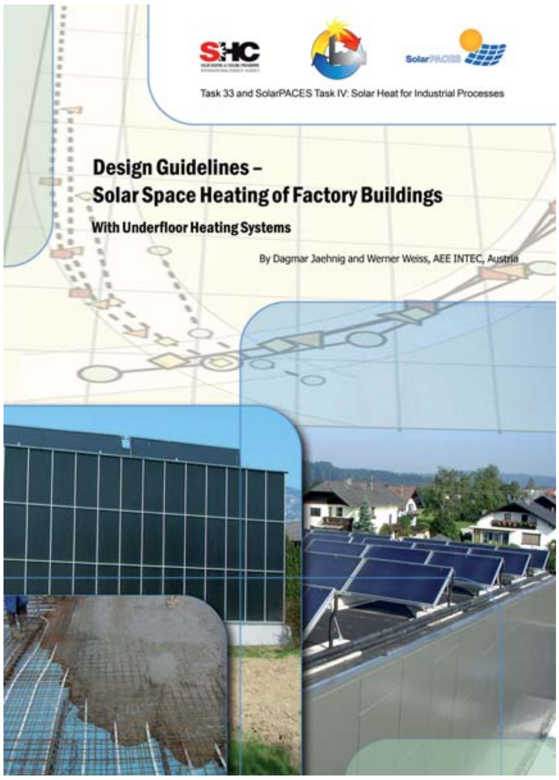


6.3 Process Heat Collectors



By 2006, approximately 128 GW_{th}, the equivalent of 183 million m^2 of solar thermal collectors, had been installed worldwide (Weiss et al., 2008). To date, the widespread use of solar thermal applications has focused almost exclusively on swimming pools and domestic hot water and residential space heating. The use of solar energy in commerce and industry is currently insignificant compared to those mentioned above. Solar industrial process applications have only been on a relatively small scale and mostly experimental. However, a comparison of energy consumption in industry, transportation, household and service sectors shows that industry consumes approximately 30%, the most in OECD countries. Only one third of this energy demand is related to electricity, while two thirds are related to heat. The majority of this heat is for commercial and industrial production, processes and factory space heating, all at below 250°C and this low temperature (< 80°C) is consistent with the temperature that can easily be reached with solar thermal collectors already on the market.

6.4 Design Guidelines – Solar Space Heating of Factory Buildings



This booklet presents a solar thermal heating system design method for underfloor space heating in factories. The method uses nomograms that were expanded upon using simulations of typical system configurations. There are nomograms for two different system configurations that can be used to determine reasonable values for the collector and storage tank size for a factory building with a known heat demand. Nomograms are useful because they help to decide whether it is necessary to use a water filled storage tank or if it makes sense to use the thermal mass of the concrete floor slab as heat storage, with the consequent advantageous saving of the cost of a (often large) storage tank.

The booklet further covers the need for an insulating layer underneath the floor slab, reasonable orientation of the collectors and specific collector yields that can be achieved with the different system configurations.

7 Task V: Solar Resource Knowledge Management

Task Representative:
Dr. Richard Meyer, EPURON GmbH

Task Participants:

- Austria: BlueSkyWetteranalysen, ASIC
- Canada: Environment Canada, CANMET
- European Union / Italy: Joint Research Center (JRC)
- France: EdM/Armines, ENTPE
- Germany: DLR, Hochschule Magdeburg (H2M), Univ. of Oldenburg (EHF), EPURON
- Slovakia: GeoModel s.r.o.
- Spain: CIEMAT, CENER, Univ. of Navarro, Univ. of Jaén
- Switzerland: UNIGE, Meteotest
- USA: NREL (Operating Agent), NASA, SUNY

7.1 Nature of Work and Objectives

"Solar Resource Knowledge Management" is an IEA Task under the Solar Heating and Cooling (SHC) Programme Implementing Agreement. It is also guided by the IEA SolarPACES ExCo, where it is Task V. It further maintains low-level collaboration with the IEA PVPS (Photovoltaic Power Systems) Implementing Agreement.

In July 2005, it became an official IEA Task with a five-year duration. The scope of work addresses all solar resource issues. It covers satellite-derived solar resource products, ground-based solar measurements (mainly for validation purposes) as well as solar forecasting and data dissemination methodologies.

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

- Standardization and benchmarking of solar resource data sets to ensure worldwide inter-comparability and acceptance of data products, e.g. for financing,
- Improved data availability and accessibility in formats that address user needs,
- Development of methods that improve the quality and the spatio-temporal coverage of solar resource products, including reliable solar radiation forecasts which form the basis for definition of three subtasks.

7.2 Scope of the Task

Subtask A: Standard Qualification for Solar Resource Products (Led by Prof. Hans-Georg Beyer, Hochschule Magdeburg-Stendal (H2 Magdeburg), Germany)

Subtask B: Common Structure for Archiving and Accessing Data Products (Led by Prof. Lucien Wald, EdM/Armines, France)

Subtask C: Improved Techniques for Solar Resource Characterization and Forecasting (Led by Dr. Detlev Heinemann, Oldenburg University, Germany)

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

7.3 *Activities During 2008*

Progress continues to be made on all aspects of Task V, although in some areas progress has been slowed due primarily to funding issues or conflicts of time by researchers. A Task Experts Meeting was held on June 9-10, 2008, in Austria to discuss results achieved and coordinate next steps.

7.3.1 Benchmarking and Standardization

Subtask A defines procedures for benchmarking and applies them to the available solar resource datasets. A key activity in benchmark exercises is setting up qualified reference datasets, which are based on high-quality ground-based radiation measurements. Benchmarking is an essential prerequisite for standardizing solar resource products and their further application.

Identification of high-quality ground-based measurements is the first step in the benchmarking process. To be usable as reference data, the quality of these time-series must be clearly much higher than the satellite-derived time-series, which are to be benchmarked.

Selection and quality control of measurement time-series in the Task is mainly done by NASA/LaRC (Langley Research Center) in the course of their project "Solar Radiation Budget" (SRB) and by DLR in the EU-project "Management and Exploitation of Solar Resource Knowledge" (MESoR). Established measurement archives like those of the WRDC (World Radiation Data Center) and the GEBA (Global Energy Balance Archive) offer a multitude of measurement sites all over the Earth. The WRDC keeps around 1600 and the GEBA subset has almost 1300 stations. However from the analysis of GEBA and WRDC datasets it is recognized that only very few sites provide Direct Normal Irradiance (DNI) and data often show gaps or quality is insufficient. The WRDC currently ends in 1992 and GEBA in 2003. This is far from present, which makes it difficult to compare with satellite data which is usually more recent. The daily or monthly time resolution provided does not qualify for benchmarking the satellite derived time-series. Satellite time-series resolution delivered today is usually hourly, but could now be enhanced towards 15 min with

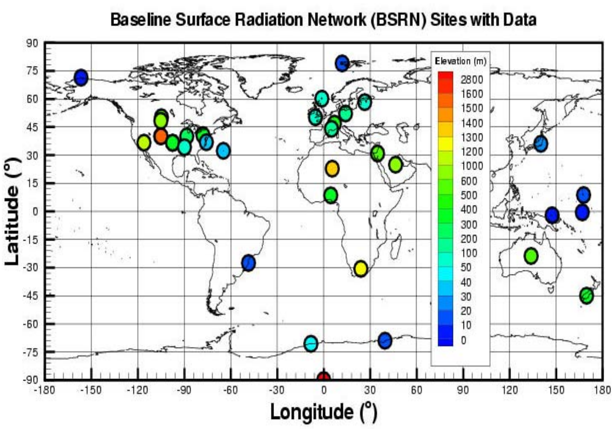


Figure 7.1. BSRN sites available for use in the Task´s benchmarking studies (from Stackhouse & Zhang, NASA/LaRC).

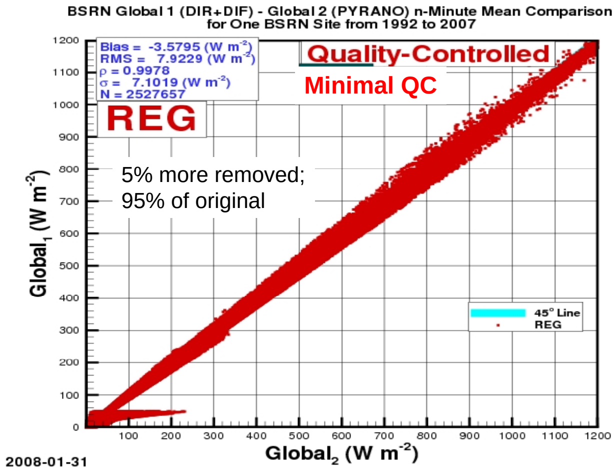


Figure 7.2. Result of applying the minimum BSRN standard of QC control eliminating data that fails the BSRN test.

the latest satellite technology. High-quality datasets from up to 35 Baseline Surface Radiation Network stations are valid for benchmarking (BSRN, see Figure 7.1) and some from the Global Atmosphere Watch (GAW) – two climatology networks coordinated by the World Meteorological Organization (WMO) which measure in up to 1-min time resolution with well-maintained instruments. Up to 18 high-quality stations are operated in the course of the DOE's Atmospheric Radiation Mission (ARM). Furthermore, the International Daylight Monitoring Program (IDMP) also provides a few good stations.

All good measurement time-series are cataloged, converted into a common format, and pass intensive quality control (QC). It has been found that QC flags are useful, but insufficient to determine data quality, particularly at low sun conditions (i.e., large solar zenith angles) in the hours after sunrise and before sunset. At those times direct/diffuse flux tests are inconclusive. If those measurements are screened, then biased daily averages result. The result of the assessment is that QC tests for low solar angle conditions are required. The study also evaluated the sensitivity of using various assumptions regarding data gaps during the course of determining the hourly average. NASA/LaRC found that applying additional QC testing beyond the BSRN QC flags are required.

Figure 7.2 through Figure 7.4 display the progressive levels of quality control applied to 1-min averages for BSRN total (i.e., direct + diffuse) and unshaded pyranometer measurements for the Regina, Canada site. Figure 2 shows comparisons without applying any QC and Figure 3 shows results of removing those points that failed BSRN QC quality flags. The procedures of Long and Shi (2008) were applied to total measurements of 50 W/m² or higher. Those under 50 W/m² were then removed (Figure 4). At this site, applying the BSRN QC plus the Long and Shi procedures removed about 15% of

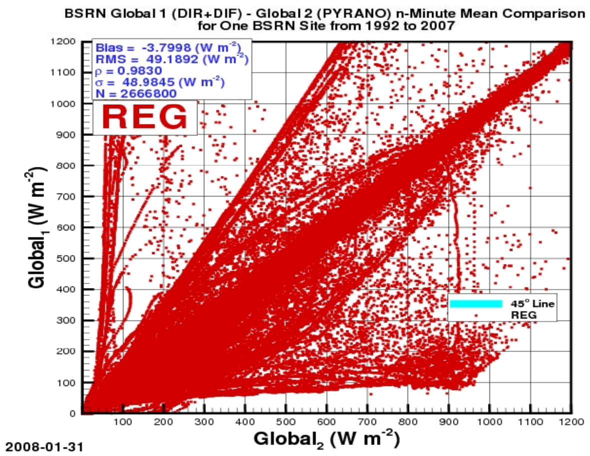


Figure 7.3. *Example of the comparisons of 1-minute averaged BSRN total (direct plus diffuse, or global 1) versus unshaded pyranometer measurements (global 2) for the BSRN site of Regina, Canada.*

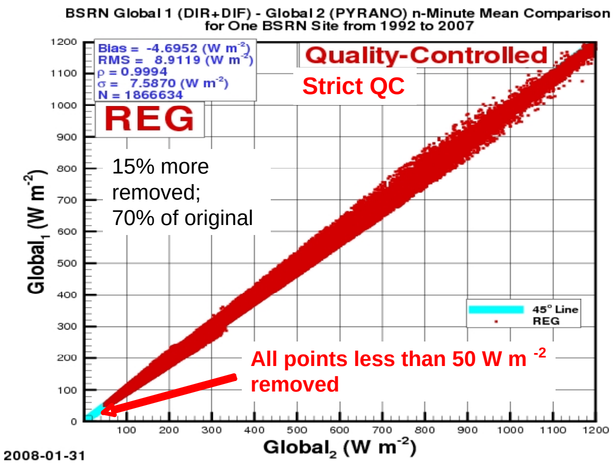


Figure 7.4. *Results of eliminating all data points < 50 W/m² showing reduction in hourly measurements resulting from the various applications of the QC criteria.*

the data, but removing values under 50 W/m² removes an additional 15% of the data.

Due to the large number of points removed for low sun elevation measurements, NASA continues to evaluate methods providing some QC for low irradiance values, including extending the Long and Shi procedures to zero. Upon completion of this study, a report of the findings will be submitted to the IEA for evaluation and assessment of other high-quality measurements. The result of these updated recommended procedures will be a survey of known QC procedures and the processing of all BSRN and similar high quality data sets with similar assumptions for the production of reliable surface validation dataset.

New measures for intercomparison of solar irradiance data are also developed in Subtask A. The reason is that established measures like the Mean Bias (MB) or the Root Mean Square Deviation (RMSD) or the Standard Deviation (SD) of two time-series do not indicate how well the frequency distribution coincides. However, for realistic simulation of expected yields from solar systems, the match of the frequency distribution can be much more important than a low bias or low deviations from hour to hour. For the purpose of a good yield prognosis, a good match of actual values is of less importance than a good match of the distribution functions. Based on earlier work by Kolmogorov and Smirnov, new measures like the KSE or RIO parameter are being introduced by members of the Task and meanwhile have been published by Espinar et al. (2008).

A comprehensive report on benchmarking solar radiation products has been prepared in the MESoR project as Deliverable D1.1.1 "Handbook on Benchmarking." It describes benchmarking rules for time series products (1st and 2nd order), angular distributions, maps, and solar forecasts. This report will form the basis for an extended IEA Task document.

The benchmarking rules set up in this Task have also been applied to several solar resource products, which provide global horizontal irradiance (GHI), see, e.g., by Šúri et al. (2008). Detailed intercomparison of beam radiation (Direct Normal Irradiance = DNI) is still missing.

In 2008, intense benchmarking exercises were executed for various methods that convert GHI into DNI. Ineichen (2008) intercompares three established methods. A new project coordinated by Lourdes Ramírez with participants from the Spanish institutions CENER, CIEMAT, UPNA, AICIA-GTER develops several new methods for converting GHI to DNI especially adapting it to Spain. Figure 7.5 shows the results for the Reindl model and a similar model derived from measured data in one of the Spanish locations.

7.3.2 Archiving and Accessing

Much progress has been made towards unified access to solar resource data in the course of the EU project

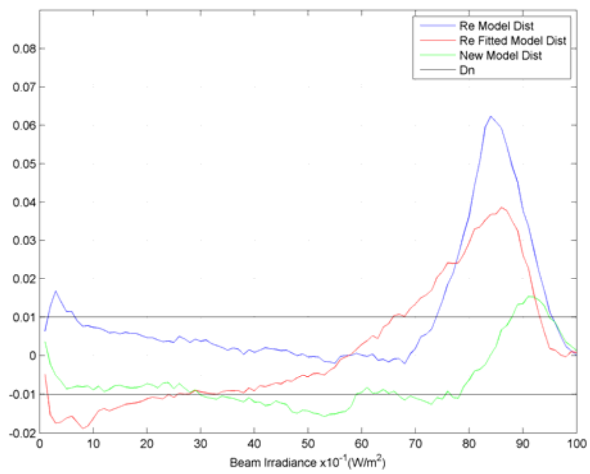


Figure 7.5. *Kolmogorov-Smirnov test for Reindl and a similar model fitted to Spanish conditions.*

“Management and Exploitation of Solar Resource Knowledge” (MESoR, Hoyer-Klick et al., 2008). The goal of **Subtask B** is to set up a user-oriented data portal for accessing solar resource data. A prototype has been set up, and can be accessed at http://project.mesor.net. An example of the Web interface for accessing solar resource data for a location in Europe is shown in Figure 7.6. Using a Google Earth interface, users can click on a specific location of interest and a file containing the various sources of data available for that location will appear.

As more providers make data available to the portal, more data sources become available. Users will then have a larger source to select from. The site will link the user directly to the source provider’s website (e.g., Cebecauer and Šúri, 2008). Not all of the features are installed in the current prototype, as it focuses on demonstrating access to different solar radiation databases, and shows that it is possible to provide the service in this standardized environment. It is intended to become fully compliant with the GEOSS (Global Earth Observation System of Systems) portals. The developers of these portals and other tools are constantly consulted.

The new Release 6.0 Surface Meteorology and Solar Energy (SSE) dataset contains numerous upgrades increasing data accessibility for uses including output of global/regional datasets, daily averaged time series, and global/regional plots, in addition to the ASCII table output for specific locations. It has also provided solar irradiance datasets from near-real time products. Release 6.0 now has over 73,000 individual registered users from 160 countries. As of October 1, 2008, there have been 9.5 million hits and 1.75 million data file downloads since the Website came on-line in 1997. The NASA SSE support group continues to collaborate with new users in the renewable, and now the power industry, providing solar and meteorological parameters.

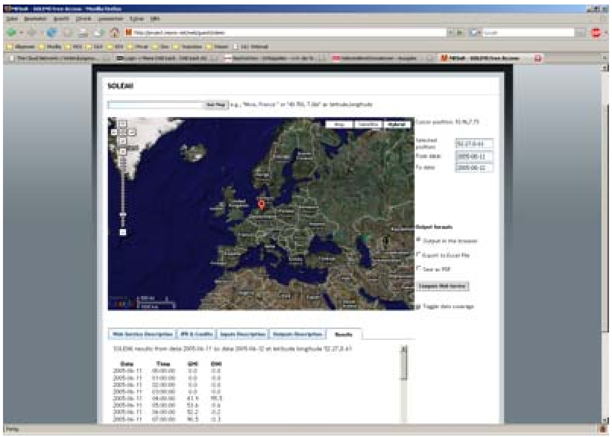


Figure 7.6. Example of Web interface for the data portal being established under the EU’s MESoR project (image provided by Lucien Wald).

DLR has been assisted by the Ecole des Mines (EdM) in setting up a Web service for its SOLEMI solar resource database. A “how-to” manual was released in July 2008 to guide potential providers in developing Web services that could be connected and accessed via the portal. At the time of writing, 3 Web services are available at Armines, one from DLR, one from Meteotest, and one from Meteocontrol, demonstrating that the service is possible. The effort made to comply with GEOSS portals and tools ensures that the Web services developed for the IEA Task can be reused and exploited in other cases by other portals as the provider wishes. Services from NREL, CanMet (Meteorology Canada), and the Australian Bureau of Meteorology will be sought in addition to NASA.

Data exchange protocols and standards for metadata are also set in Subtask B. This activity includes close monitoring of standardization procedures, investigation of available tools, their limits and advantages, and participation in international working groups, such as the European INSPIRE project or GEOSS. A thesaurus has been adopted. A revised implementation is now available on the website at www.soda-is.com.

7.3.3 Improved Techniques for Solar Resource Characterization and Forecasting

The purpose of **Subtask C** is to R&D to improve existing products and generate new ones. Spatial and temporal coverage of current satellite-based solar resource products are improved leading to higher absolute and relative accuracy. Long-term variability of solar resources in connection to climate change are monitored and assessed. Techniques for forecasting solar radiation are a new key activity of this Subtask.

To prepare improvement of satellite models, several task participants analyzed the uncertainties in solar radiative transfer models (Oumbe, et al., 2008). Aerosol data are mainly found to be inadequately characterized in current satellite procedures. This strongly influences the quality of DNI and is currently subject to improvement.

An additional topic requiring R&D is the development of methods for deriving typical meteorological datasets, which are best suited for yield simulation at a specific site. The first step is to solve is the question of how the long-term average may best be derived from a multi-annual dataset of typically varying quality. For this purpose Meyer et al. (2008) developed a method, which can take into account various satellite-derived DNI products to derive a long-term best estimate. To provide even more reliability site-specific measurements with good quality may be added.

The next processing step is then to generate a full year of data in high time resolution, e.g. 60 min or even 15 min. Such a reference year also ideally well incorporates the corresponding auxiliary meteorological parameters like wind, temperature and humidity, which are essential for proper simulation of solar thermal power plants. Existing methods like the TMY methodology by

Hall et al. (1978) require more than 10 years of site measurements, which is not practical for project development. Work towards this is under way at DLR and CENER.

Ongoing climatological analysis of solar resources by NASA/LaRC includes several studies assessing the long-term variability of GHI, e.g., the recently-released 23-year GEWEX SRB dataset (also used for the SSE Release 6.0). Natural long-term fluctuations associated within the ocean-atmosphere system, such as the Southern Oscillation/El Niño also lead to oscillation in solar radiation, not just in South America and Southeast Asia, but in many other regions worldwide.

The SRB dataset is in general agreement with the time series of an ensemble of surface measurements from the Global Energy Balance Archive (GEBA), and shows a drop in solar irradiance over a large number of sites until about 1992, after which fluxes increase at many sites, in what is called the “global dimming and brightening” phenomenon. Linear changes in globally averaged solar irradiance over the entire 22-year period (1983 - 2004) showed a long-term positive change, but the confidence interval was shown to include 0. However, a piecewise analysis showed much stronger significant short-term changes (Figure 7.7, from Chandler, et al., 2008). This analysis showed that from 2000 – 2004 there was actually a decrease in solar irradiance on the Earth’s surface. The alternating upward and downward trends are more indicative of an overall atmospheric oscillation. To further investigate the phenomenon, NASA/LaRC has studied an ensemble of long-term surface sites, such as those from GEBA, selected on the basis of long-term continuity. The ensemble mean of these sites corresponds well with the variability in SRB for those grid boxes containing those sites, even given linear trends within the confidence interval. However, there was much less correlation with the global mean in all SRB grid boxes. It was found that data gaps had significant effects on trend calculation. The BSRN network, which has fewer sites than GEBA, provides better representation of the global mean by containing sites in diverse locations. Using the current 35-site configuration and using SRB to

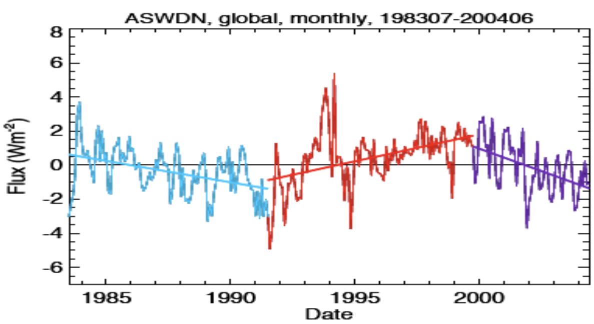


Figure 7.7. A piecewise analysis of the monthly globally averaged solar irradiance with seasonal variations removed, showing an oscillation between dimming, brightening, and dimming again (From Stackhouse and Zhang, NASA/LaRC).

represent fluxes at the BSRN locations (necessary because only 8 of the BSRN sites date back as far as 1992), shows that the variability corresponds well with the actual global average.

DNI tends to show much more pronounced variability than GHI. Unfortunately, since the findings of Lohmann et al. (2007) and the DLR/ISIS dataset, no special studies on DNI variability have been undertaken.

Much emphasis is now laid on development of procedures for forecasting of solar radiation. SUNY/Albany (Perez et al., 2009) analyzed forecasts derived from the NASA Goddard Space Flight Institute Global Modeling and Assimilation Office (GMAO). The model is tested using hourly forecasts of up to 60 hours for August and September 2007 for three BSRN/SURFRAD solar measurement sites in the United States: 1) Goodwin Creek, Mississippi, 2) Boulder, Colorado, and 3) Desert Rock, Nevada. All forecast models are shown to handle clear sky conditions quite adequately, but the performance of solar forecast models is highly dependent on their ability to predict cloud cover conditions accurately, as might be expected. Other models being tested include two versions of post-processing applied to ECMWF (European Center for Mid Range Weather Forecasting) global model irradiance forecasts by Oldenburg University, a version of the Weather Research and Forecasting (WRF) model being implemented by Meteotest, and the U.S. National Digital Forecast Database (NDFD). Performance of these models varied from site to site.

Similar studies done for the Iberian Peninsula (Martin et al, 2008) also show that nesting the WRF regional model in the ECMWF global forecasts shows good forecasting results. Martin et al. also developed studies showing the use of artificial neural networks to provide cloud cover forecasts.

ECMWF forecasts are also being used by task participants to test the ability to forecast the output of ensembles of spatially diverse PV systems in Germany (Lorenz et al., 2008). Several approaches for deriving hourly forecasts from the three hourly ECMWF forecasts were tested. The results show that regional irradiance forecast quality can be considerably improved by correcting systematic deviations in the original forecasts. A representative system model is proposed as a first approach for predicting the PV output of a large ensemble of systems.

Meteotest (Switzerland) has also been examining operation forecasting of PV power production in Europe as part of its Task 36 work. At PVSEC, a study (Remund et al., 2008) downscaling Global Forecast System results to a regional area using the WRF model were also reported. This study is being done in parallel with the SUNY/Albany United States study mentioned above.

DLR developed its AFSOL method (Wittmann et al., 2008), which mainly aims for direct irradiance forecasting. It combines satellite-based nowcasting, ECMWF deterministic and ensemble models and aerosol forecasting. It is especially designed for solar thermal power plant operation.

7.3.4 Conclusion and next steps

In June 2010, the first 5 years of the Task will be completed with several reports documenting the results of individual activities in the subtask. A Manual on Solar Resources will then document best practices in benchmarking, data dissemination, satellite algorithms, and resource forecast validations. Furthermore, follow-on activities continuing the Task beyond 2010 are under discussion.

The new SESK project intends to push standardization of yield assessments for solar thermal power plants. This project, funded by the German Ministry of Environment (BMU), goes beyond solar resources. Issues like simulation of parabolic-trough plants benefit from other SolarPACES standardization topics like those for components, and will be coordinated with SolarPACES Tasks I and III.

Task participants continue to hold periodic task experts meetings through the completion of the Task. The next meeting is scheduled in conjunction with the SolarPACES Symposium in Berlin, Germany in September 2009.

IEA Task SHC 36 / SolarPACES Task V also continues to maintain liaison with the Global Earth Observation System of Systems (GEOSS) program and strong ties with other international activities such as WMO Global Energy and Water Experiment (GEWEX), the EU/ESA Project GAS (GMES Atmospheric Service), and Solar and Wind Energy Resource Assessment (SWERA), a Program of the United Nations Environment Programme's (UNEP).

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8 Task VI: Solar Energy and Water Processes and Applications

Operating Agent:

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Plataforma Solar de Almería. CIEMAT

Contributions:

- Christian Sattler (DLR, Germany)
- Claudio Estrada (CIE-UNAM, Mexico)

8.1 Nature of Work & Objectives

With the existing energy crisis, water problems are expected to substantially worsen. Conversely, due to the close relationship between water and energy issues, water problems are expected to also contribute to increasing energy problems and aggravate their consequences. In addition to all this, environmental considerations such as global warming, are adding significant pressure resulting in additional large amounts of water needed in the near future. Not only will this water be unavailable from existing renewable resources, the energy to produce it will not be readily available either.

These were some of the arguments for the creation in 2007 of Task VI, which formally started its activities on January 1, 2008 to encourage the development of solar technologies simultaneously addressing energy and water issues. In this sense, the Scope of Work covers any solar radiation technology supplying either thermal or photon primary energy for water treatment, which includes:

- Brackish and seawater desalination: Any technical procedure or methodology for removing or reducing the salt content from water.
- CSP+D: solar power and water cogeneration plants
- Water detoxification: Removal of organic compounds, heavy metals and/or hazardous substances in general from water.
    - Water disinfection: Control and/or elimination of pathogenic populations from water for human or animal consumption or irrigation.

The purpose of the Task is to improve the conditions for solar water treatment market introduction and solve water problems, while contributing to reduced fossil-fuel consumption. The main specific focus of the activities and initiatives addressed is to demonstrate the potential of solar energy for such water applications.

8.2 Task VI Organization and Structure

Task VI is organized into the following three domains or subtasks:

- Subtask VI.1. CONCENTRATING SOLAR POWER AND DESALINATION PLANTS.
  The goals of this Subtask are to:
  - i) Collect existing knowledge and experience on hybrid power and desalination plants for application to MW-size plants;
  - ii) Analyze and determine the main technological characteristics of hybrid solar power and desalination plants;
  - iii) Promote cooperative initiatives in assessment of the specific technical and economic feasibility of hybrid solar power and desalination plants, and also identify potential follow-up demonstration case studies.

- Subtask VI.2. INDEPENDENT SOLAR THERMAL DESALINATION SYSTEMS (kW-SIZE).
  The goals of this Subtask are to:
  - i) Provide a comprehensive description of the state-of-the-art and potential applications of solar thermal desalination systems. This includes evaluating completed research programs and projects and ongoing developments in this field, as well as their economics;
  - ii) Publicize the knowledge among main stakeholders: solar manufacturers, process engineers, related associated industry, installers and potential customers and users;
  - iii) Promote collaborative initiatives for assessment of the specific technical and economic feasibility of the most appropriate and promising technologies

Table 8.1 Summarized Task VI reported activities organized by Sector

Sectors and Activities	Contact	Sharing			
		I	M	T	C
Sector 1. Concentrating solar power & Desalination Plants					
CONSOLI+DA	J. Blanco	x			
CSPD-COMISJO	M. Schmitz		x		
Sector 2. Solar Thermal Desalination Systems					
MEDESOL	J. Blanco		x		
POWERSOL	J. Blanco		x		
PRODES	M. Papapetrou		x		
MEDIODIA	J. Blanco	x			
Sector 3. Solar water detoxification and disinfection					
SOWARLA	C. Jung	x			
INNOWATECH	A. López		x		
TRAGUA	B. Sánchez	x			
SODISWATER	P. Fernández		x		
DETOX-H2S	B. Sánchez	x			
Decolorization of dye polluted water	A. Jiménez	x			

- Subtask VI.3. SOLAR WATER DETOXIFICATION AND DISINFECTION SYSTEMS. The goals of this Subtask are to:
  - i) Provide a comprehensive description of the state-of-the-art and potential applications of solar water detoxification and disinfection systems. This includes evaluating completed research programs and projects and ongoing developments in this field, as well as their economics;
  - ii) To publicize the knowledge among main stakeholders: solar manufacturers, process engineers, related associated industry, installers and potential customers and users;
  - iii) To promote collaborative initiatives for assessment of technical and economic feasibility of specific water detoxification and disinfection problems, also identifying potential follow-up demonstration case studies.

8.3 Participation and National Contributions in 2008

Task VI is open to all IEA/SolarPACES members, who wish to actively participate in any activity described within the scope of the Task. Current Task VI participants are Germany, Mexico and Spain.

Ongoing Task VI activities are presented in Table 8.1, following the previous structure. In the sharing column, "I" refers to information sharing; "M" to task sharing by member countries, "T" to task sharing trough SolarPACES; and "C" to cost sharing. Main SolarPACES contact person is indicated.

The most important achievements in 2008 with up-to-date information about project participation, objectives, status, and relevant publications, are summarized below.

8.4 Summary of achievements

8.4.1 Concentrating solar power and Desalination Plants

CSPD-COMISJO – Concentrating Solar Power and Desalination for Communities in Israel and Jordan

Participants: Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR) (D),
Ben Gurion Univ. of the Negev (BGU) (IL),
National Energy Research Center (NERC) (JOR),
Univ. Bremen (UB) (D)

Contact: Ralf Olwig, DLR, ralf.olwig@dlr.de

Funding: German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety: 429k€

Duration: May 1, 2007 - April 31, 2010

Background: The CSPD-COMISJO project studies the main solar desalination systems combining concentrating solar power, thermal desalination and reverse osmosis desalination technologies. Reverse osmosis/thermal desalination systems driven by concentrating solar power are compared to PV-powered reverse osmosis systems and thermal desalination systems driven by non-concentrating solar collectors. In addition to the technology analysis, three possible sites for future pilot plants in Israel and Jordan are being evaluated for weather, irradiation and water conditions using precise ground measurements and long-term satellite data.

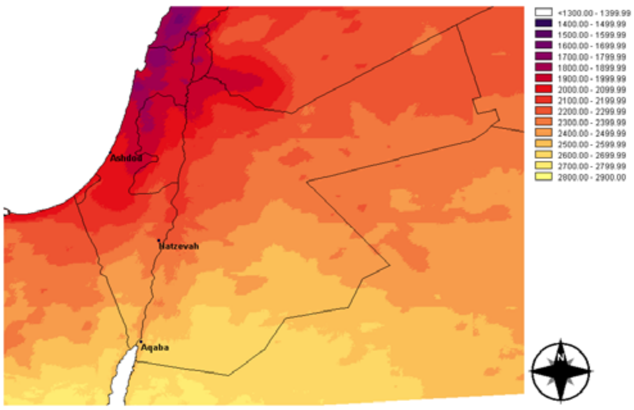

Figure 8.1 Average annual direct normal irradiance from the year 2001 to 2005 in kWh/m²/a.

Purpose: (i) Evaluation of different solar technologies for small-to-midsized desalination plants (< 50 000 m³/d) for sustainable fresh water production. (ii) Comparison of the technology and economics of three different types of solar desalination systems under site-specific conditions in Israel and Jordan. (iii) Screening potential combinations of solar energy conversion technologies. (iv) Exploratory study of a feasible, durable, cost-effective and sustainable solar-driven desalination technology. (v) Pre-study for a future demonstration plant.

Achievements in 2008: Installation of meteorological stations and ground measurements, satellite irradiation data study, collection of site-specific input data for system modeling and feedwater analysis.

Publications: [8.2], [8.3], [8.4]

CONSOLI+DA – Consortium of Solar Research and Development

Participants: 20 Spanish Companies and 18 subcontracted Spanish Research Institutions.

Contact: Julián Blanco, PSA-CIEMAT, julian.blanco@psa.es

Funding: Spanish Ministry of Industry, Commerce and Tourism (INGENIO program CENIT project): 24 M€.

Duration: January 1, 2008 – December 31, 2010

Background: Despite the importance of R&D in reducing the cost of solar thermal technologies, the number of scientists and engineers involved in their technical development is still relatively small. The International Energy Agency recommends multidisciplinary R&D teams, encompassing optics, materials science, heat transfer, instrumentation and measuring techniques, energy engineering, and thermal storage.

Purpose: The general project goal is to lay an R&D infrastructure that consolidates the leading role of Spain in concentrating solar power technologies. The specific objective of PSA-CIEMAT participation concerns desalination, i.e., the integration of multi-effect distillation (MED) plants in solar power cycles.

Achievements in 2008: The main PSA-CIEMAT accomplishment has been comprehensive state-of-the-art reports on combined solar thermal and (i) reverse osmosis; (ii) multi-effect distillation; and (iii) membrane distillation desalination systems.

Publications: No publications are yet available.

8.4.2 Solar Thermal Desalination Systems

MEDESOL – Seawater Desalination by Innovative Solar-Powered Membrane-Distillation System

Participants: CIEMAT-PSA (E); Univ. La Laguna (E); Acciona Infraestructuras (E); ACUAMED (E); AO SOL (P); Univ. Stuttgart (DE); Tinep (MEX); National Autonomous Univ. Mexico (MEX); Royal Institute of Technology (S); Scarab AB (S); Iberinsa (E).

Contact: Julián Blanco, PSA-CIEMAT, julian.blanco@psa.es

Funding: EC-funded project, cost-shared: 1,385 k€

Duration: October 1, 2006 - September 30, 2009

Background: There is a consistent lack of effective, robust small-to-medium-scale desalination processes. Such technologies are needed mostly in remote areas, typically located in arid or semi-arid zones, and therefore,

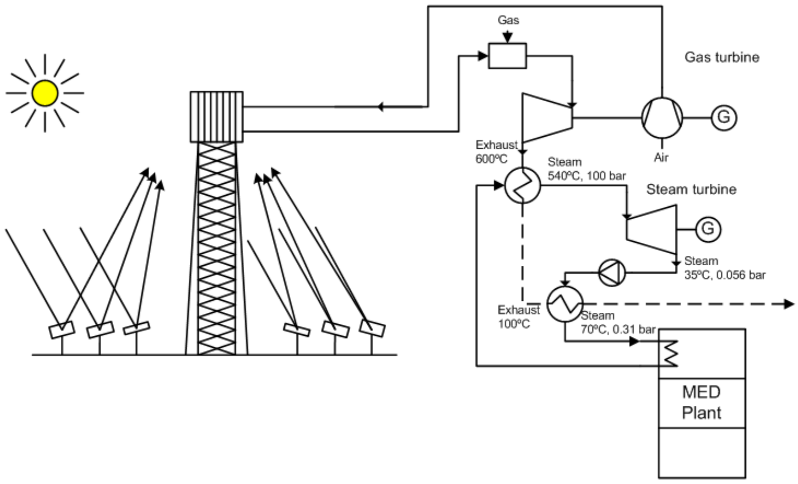

Figure 8.3 Scheme of a possible combined solar power cycle and MED desalination plant

development of renewable energy desalination processes must be considered highly desirable. Solar thermal membrane distillation seems to be a promising option for filling this gap.

Purpose: (i) Study membrane distillation to improve its efficiency, (ii) develop effective heat recovery concepts; (iii) develop system components, e.g., a solar collector optimized for the target working temperatures (80-100ºC) and non-fouling coating for heat transfer surface, (iv) develop complete medium (a few m^3/day) and small-capacity systems (several hundred L/day).

Achievements in 2008: (i) the newly developed advanced anti-fouling, anti-scaling heat exchanger surfaces have been tested; (ii) a modified compound parabolic concentrator design for temperatures around 80-110ºC has been tested; (iii) a multi-stage membrane distillation concept for a 0.5 m^3/d to 50 m^3/d production capacity range has been developed that consumes less energy than current systems.

Figure 8.2 Scarab distillation membranes in the experimental facility built at the PSA-CIEMAT (Almería, Spain).

Publications: [8.5], [8.6], [8.7], [8.8]

POWERSOL – Mechanical Power Generation Based on Solar Thermodynamic Engines

Participants: CIEMAT-PSA (E); Univ. La Laguna (E); Instituto de Engenharia Mecanica (P); Ao Sol (P); ETH (CH); Ecosystem Environmental Services (E); INETI (P); École Nationale d'Ingénieurs de Tunis (TUN); Ain Shams University (EGY); LOTUS Solar Technologies (EGY); Alternative Energy Systems (TUN); Suez Canal Univ. (EGY); Univ. Ouargla (ALG); Univ. Seville (E).

Contact: Julián Blanco, PSA-CIEMAT, julian.blanco@psa.es; Lourdes García, Univ. of Seville, lourdesg@esi.us.es

Funding: EC funded project, cost shared (FP6): 1,050 k€

Duration: January 1, 2007 - December 31, 2009

Background: The project focuses on the development of solar thermal generation of mechanical power based on a solar-heated thermodynamic cycle (Figure 8.4). Mechanical energy could be used either for direct electricity generation (with a generator) or for brackish or seawater desalination by hooking it up to a high-pressure pump and a conventional reverse osmosis system.

Purpose: The main purpose of the project is to develop an environmentally-friendly improved-cost solar-thermal shaft power generation technology optimized for supplying basic needs to rural or small communities.

Achievements in 2008: The main PSA-CIEMAT achievement was the definition, construction and commissioning by Eneftech Innovation SA of a 5-kW Organic Rankine Cycle (ORC) pilot plant for solar applications,

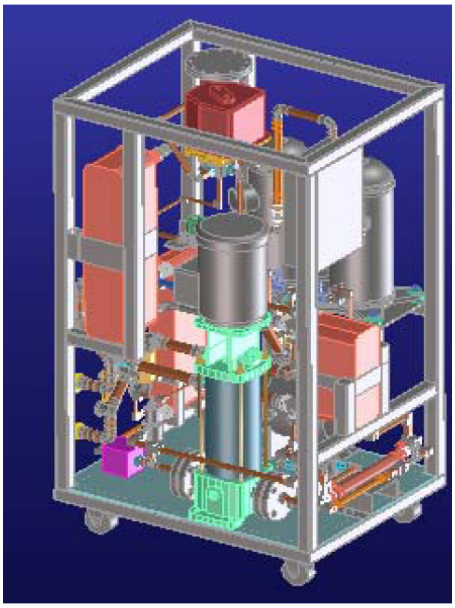

Figure 8.4 Design of the 5kW ORC pilot plant for solar application.

with net electrical efficiency 12-15% (See Figure 8.4).

Publications: [8.9], [8.10], [8.11]

PRODES – Promotion of Renewable Energy for Water Production through Desalination

Participants: WIP (D); Centre for Renewable Energy Sources (CRES) (GR); Univ. Palermo (I); INETI (P); Ao Sol (P); Fraunhofer Gesellschaft ISE (D); Befesa (E); AquaMarine Power (UK); Hellas Energy (GR); European Desalination Society (EDS) (I); CIEMAT-PSA (E); Tinox (D); Instituto Tecnológico de Canarias (ITC) (E); Capital Connect (GR).

Contact: Michael Papapetrou, WIP, michael@papape.com

Funding: EC-funded project, cost-shared (IEE): 1,023 k€

Duration: October 1, 2008 – September 30, 2010

Background: In Southern Europe, desalination is an increasingly important energy demand factor. Using renewable energy to power desalination, either in stand-alone or grid connected systems, will provide better load control and consequently wider use of renewable energies in this region. The project will support the use of renewable energy in remote areas where the grid cannot accommodate high penetration of intermittent sources.

Purpose: (i) Bring together the actors and coordinate their activities; (ii) Lay the foundation for training specialists; (iii) Help the technology providers to reach their niche markets; (iv) Facilitate the flow of capital for product and project development; (v) Improve regulatory framework conditions; (vi) raise awareness of the technology.

Achievements in 2008: A research actor database has been prepared, as well as an SME and sector professional database; educational material has been collected and organized, and the main contents of a higher education course have been outlined.

Publications: No publications are yet available.

MEDIODIA – Multiplication of Efforts for the Development, Innovation, Optimization and Design of Advanced Greenhouses

Participants: Repsol YPF (E); Acciona Solar (E) (CIEMAT-PSA as subcontracted); Ulma Agrícola (E); Ulma Packaging (E); Acciona Agua (E); Ulma Handling Systems (E); Fundación Cajamar (E); Agrobio (E); Biomiva (E); Grupo AN (E); Ingeteam (E).

Contact: Julián Blanco, PSA-CIEMAT, julian.blanco@psa.es

Funding: Spanish Ministry of Industry, Commerce and Tourism (INGENIO Programme CENIT Project); 25 M€.

Duration: January 1, 2007 – December 31, 2010

Background: Intensive agriculture is one of the most significant agricultural sectors in Spain. Advanced R&D is required to push Spain to the front line in agri-food technology. Results in this field will go beyond boosting other industrial and service activities.

Purpose: The main goal is to develop a new concept for an advanced, highly automated greenhouse, with efficient water and energy consumption, which allows diversified, profitable growing under all climate conditions in Spain

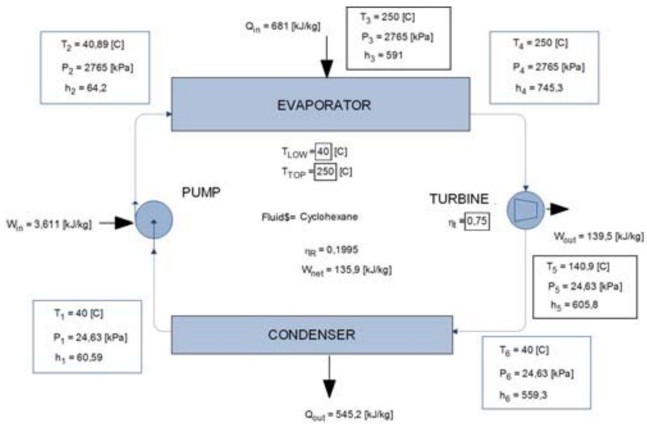

Figure 8.5 Diagram of the Engineering Equation Solver (EES) program for the Organic Rankine Cycle (ORC) of cyclohexane.

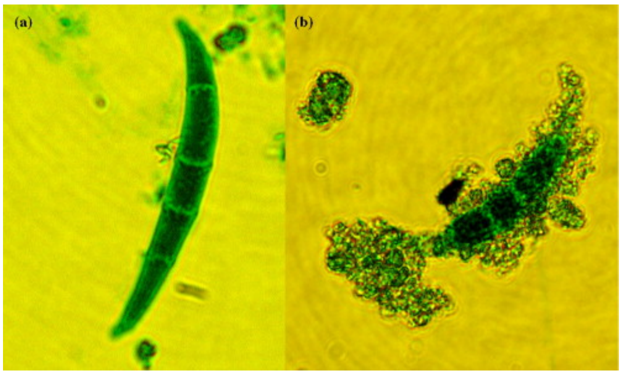

Figure 8.6 *1000× image of the macroconidia of Fusarium equiseti (dyed with green malaquite) before (a); and after a 5 h solar photocatalysis treatment (b).*

year round. The contribution of PSA-CIEMAT is the use of solar energy for both cogeneration and water disinfection.

Achievements in 2008: The main accomplishment of PSA-CIEMAT was beginning the design of: (i) water disinfection treatments that can be applied to closed-water cycle irrigation in greenhouses (see Figure 8.6); (ii) specific solar co-generation cycles.

Publications: [8.12], [8.13]

8.4.3 Solar water detoxification and disinfection systems

SOWARLA - Solar Water Treatment for the DLR Lampoldshausen Site

Participants: Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR),
Hirschmann Laborgeräte GmbH,
KACO Gerätetechnik GmbH (D)

Contact: Christian Jung, DLR, christian.jung@dlr.de

Funding: Deutsche Bundesstiftung Umwelt (DBU): 779 k€

Duration: April 1, 2005 – January 31, 2010

Background: The DLR's rocket engine test facilities at Lampoldshausen produce waste water contaminated mainly by hydrazine. At present this waste water is treated very ineffectively. A solar water treatment plant will be installed to enhance the current treatment capacities in Lampoldshausen and to demonstrate solar photocatalytic waste water treatment technology. The DLR and two German companies, Kaco Gerätetechnik GmbH and Hirschmann Laborgeräte GmbH have formed a consortium to develop a new market-ready solar reactor, called the Non-Concentrating Tubular Reactor (NCTR). The potential of the new reactor design was demonstrated in comparative tests using state-of-the-art solar receivers. Small-scale (1 m²) and pilot-plant reactor (7 m² and 32 m²) designs were tested in the first two phases of the project.

In the third phase of the SOWARLA project, started in late 2008, a demonstration plant will be built at the DLR Lampoldshausen site. 250 m² of NCTR receiver area will be installed to treat the local waste water. Startup of demonstration plant operation is scheduled for summer 2009.

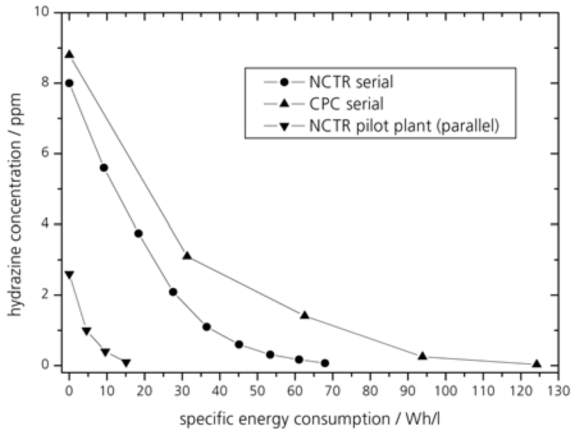

Figure 8.7 *Comparison of hydrazine degradation tests in the NCTR prototypes and pilot-plant applying light-enhanced Fenton treatment*

Purpose: (i) Installation of a demonstration plant with 250 m² receiver area at DLR site Lampoldshausen. (ii) Automation of the plant. (iii) Commissioning of the demonstration plant.

Achievements in 2008: Evaluation of the experimental results achieved in 2007. Improvement of the NCTR design. Engineering of the demonstration plant to be built in 2009. The SOWARLA project was awarded with the Energy Globe Award 2008 (national winner in Germany).

Publications: [8.14]

Figure 8.8 *Energy Globe Awards Ceremony*

INNOWATECH – Innovative and Integrated Technologies for the Treatment of Industrial Wastewater

Participants: CNR - Istituto di Ricerca Sulle Acque (I), Aachen Univ. Technol. (D), Tech. Univ. Delft (NL), Swedish Env. Res. Inst. Ltd (S), Cranfield Univ. (UK), Swiss Fed. Inst. Tech. (CH), CIEMAT-PSA (E), Norw. Inst. Wat. Res. (N), SolSep BV (NL), Bayer MaterialScience AG (D), ITT Wedeco (D), Austep S.r.l. (It), Albaida S.A. (ES), Anox-Kaldnes (S), Water Innovate Ltd (UK), DHV (NL), Adv. Wastewater Manag. Centre (AUS).

Contact: Antonio López, CNR-IRSA antonio.lopez@ba.irsa.cnr.it; Sixto Malato, CIEMAT-PSA sixto.malato@psa.es

Funding: EC funded project, cost-shared (FP6, sub-priority 6.6.3 Global Change & Ecosystems): 2,750 k€

Duration: November 1, 2006 – October 31, 2009

Background: New concepts and processes in industrial wastewater treatment with great potential benefits for the stable quality of effluents, for saving energy and operating costs and for environmental protection, which is the goal of the EU Environmental Technologies Action Plan.

Purpose: Development of aerobic granulation bioreactors, coupling of Advanced Biotreatment and Advanced Oxidation Processes, new membrane processes, Life Cycle Assessments and Life Cycle Costs. CIEMAT focuses on further development of solar photo-Fenton treatment for coupling with aerobic biological treatment.

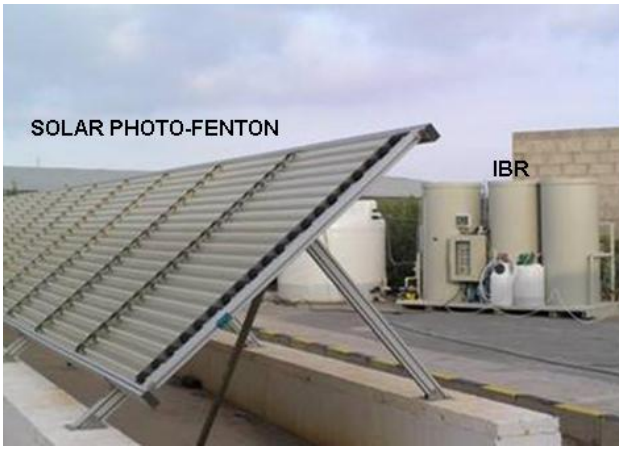

Figure 8.9 General view of the IBR plant installed at Albaida (Almeria, Spain).

Achievements in 2008: In 2008, CIEMAT-PSA treated pesticide wastewater by solar photo-Fenton technology combined with biotreatment (immobilized biomass, IBR) to find the best point to connect the two processes. These experiments were done for design of a real plant to be installed at the Albaida facilities in Almeria. This installation was completed at end of 2008. At the Albaida facilities, water used for washing pesticide containers is currently treated only by photo-Fenton, and further biological treatment seems to be necessary for complete degradation of the effluent at a low operating cost. Installation of the IBR is expected to shorten the treatment time by a factor of three.

Publications: [8.15] - [8.22]

TRAGUA– Treatment and Reuse of Waste Water for Sustainable Management

Participants: Up to 24 Spanish Public Institutions and Companies

Contact: Benigno Sánchez, CIEMAT-PSA, benigno.sanchez@ciemat.es; Sixto Malato Rodríguez, CIEMAT-PSA, sixto.malato@psa.es

Funding: Spanish Ministry of Education and Science (National R&D Programme): 4,900 k€.

Duration: January 1, 2006 – December 31, 2011

Background: Spain has the highest water deficit of any European country and only 5% of waste water is reused. There are many reasons why there is so little reuse of water, the most important among them being the lack of treatment protocols for water treated by Municipal Wastewater Treatment Plants (MWTP) and a lack of clear criteria for choosing technologies. In this regard, any treatment should include elimination of pathogenic microorganisms like bacteria and viruses, as well as the removal of heavy metal and micropollutants (pharmaceuticals, toiletries additives, etc.).

Purpose: This project focuses on increasing reuse of wastewater in Spain. Its main goals are an inventory of MWTP to determine the volume available for potential reuse, and recommend treatment protocols according to their specific characteristics, taking the efficiency and cost of detoxification into consideration. Furthermore, standard methods of chemical, microbiological and toxicological analysis will be developed, and the environmental and socioeconomic impacts of water reuse will be assessed. More specifically, the group of CIEMAT-PSA is in charge of evaluating the feasibility of using both homogeneous (Photo-Fenton) and heterogeneous (TiO_2) solar photocatalysis technologies for the elimination of nonbiodegradable micropollutants usually found in the wastewater.

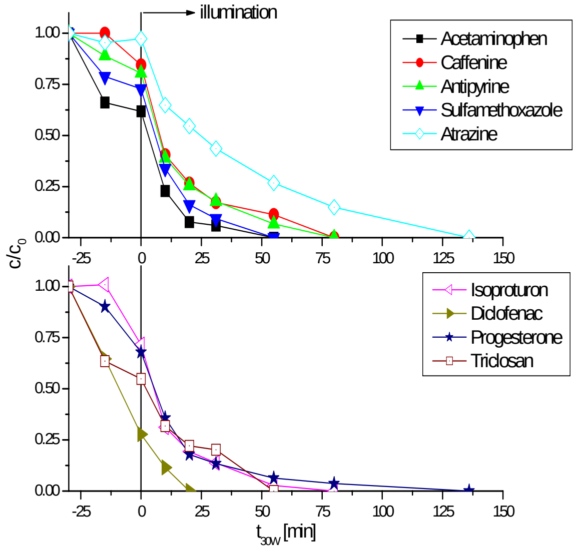

Figure 8.10 Degradation of the 9 emerging pollutants ($0.1\ mg\ L^{-1}$ each) by photo-Fenton with $5\ mg\ L^{-1}$ Fe with no pH adjustment in simulated fresh water

Achievements in 2008: The following emerging pollutants detected in trace amounts in municipal wastewater were selected for this study: acetaminophen, antipyrine, atrazine, caffeine, diclofenac, isoproturon, progesterone, sulfamethoxazole, and triclosan. Photodegradation experiments were performed in a pilot compound parabolic collector (CPC) solar plant at the Plataforma Solar de Almería using a concentration of $100\ \mu g\ L^{-1}$ for each pollutant. Mineralization was monitored by measuring the dissolved organic carbon (DOC), and the concentration profile of each compound during degradation was determined by HPLC-UV. Two different approaches, photo-Fenton (pH = 2.8) and TiO_2 were tested at low iron and TiO_2 concentrations. Photo-Fenton was by far more effective than TiO_2 for degrading these pollutants using pure water solutions, and was therefore selected for further study. However, when the assays were performed with simulated freshwater containing them, the degradation rate was significantly reduced. It was demonstrated that low efficiency in some cases is mainly due to bicarbonates, and it is therefore proposed that the process could be improved, either by increasing the iron concentration, or eliminating bicarbonates. This will be the subject of future research.

Publications: [8.23] - [8.26]

SODISWATER - Solar Disinfection of Drinking Water for Use in Developing Countries or in Emergency Situations

Participants: Royal College of Surgeons in Ireland, coordinator, (IR); University of Ulster (UK); Council for Scientific and Industrial Research, (South Africa); Swiss Federal Institute of Aquatic Science and Technology (CH); The Institute of Water and Sanitation Development (ZWE); CIEMAT-PSA (Spain); University of Leicester (UK); The International Commission for the Relief of Suffering & Starvation (KEN); University of Santiago de Compostela, (E).

Contact: K.G. McGuigan,RCSI, kmcguigan@rcsi.ie
Pilar Fernández Ibáñez, CIEMAT-PSA, pilar.fernandez@psa.es

Funding: EC funded project, cost-shared (FP6, Specific measures in support of international co-operation 'INCO'): 1,900 k€

Duration: September 1, 2006 – August 30, 2009.

Background: Drinking water disinfection using *E. coli* as a water-quality indicator.

Purpose: The main purpose of the project is to develop an implementation strategy for the adoption of solar disinfection of drinking water as an appropriate, effective and acceptable intervention against waterborne disease for vulnerable communities in developing countries without reliable access to safe water, or in the immediate aftermath of natural or manmade disasters. It will also develop appropriate SODIS technology enhancement innovations that can be matched to varying socioeconomic conditions. Such technological innovations would include dosimetric

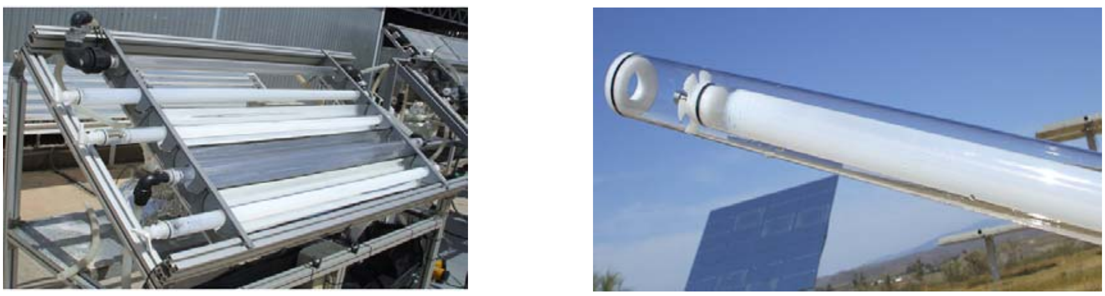

Figure 8.11 CPC SODIS reactor containing different immobilised catalyst configurations (left). Picture of "Uncoated external, TiO_2 coated internal" configuration before installing (right).

indicators of UV disinfection, photocatalytic inactivation and continuous water flow in solar collector arrays for small community distribution systems.

Achievements in 2008: In 2008, CIEMAT completed several different tasks with the Univ. Ulster (testing of batch and continuous flow photocatalytic reactors using *E. coli* as a model, including a complete study using CPC mirrors to enhance the SODIS process with *E. coli* and *C. parvum*), the Univ. Santiago de Compostela and Univ. Leicester we have validated the capability of SODIS to inactivate untested pathogens under real sunlight conditions. CIEMAT have also constructed a 25l SODIS batch photoreactor for testing under real conditions (natural well water, real soil for turbidity samples, and real sunlight).

Publications: [8.27], [8.28]

DETOX-H2S - Development of a new system for the elimination of airborne toxic and corrosive compounds generated in sewage treatment plants

Participants: CIEMAT-PSA (ES), UNED (ES), ICP-CSIC (ES), ICV-CSIC (ES), USACH (Chile), University of Wisconsin (USA).

Contact: Benigno Sánchez, CIEMAT-PSA, benigno.sanchez@ciemat.es

Funding: Madrid Region Autonomous Government (CAM): 700 k€

Duration: January 1, 2006 – December 31, 2009

Background: Unpleasant odors released from sewage plants hinder the social acceptance of wastewater treatment facilities. Among other fetid chemicals, these emissions contain, H_2S, mercaptans and amines. However, the possible nuisance to the population is not the only problem associated with air pollutants in these plants. At the concentrations usually found in treatment stations, these substances are toxic for workers and corrode equipment and building materials. Commercial treatments for the removal of these pollutants available are either inefficient or expensive.

Purpose: In order to avoid these limitations, this project proposes the following objectives: (i) Development of a photocatalytic reactor activated by sunlight and UVA lamps capable of continuous operation under real process conditions; (ii) Development of an adsorption treatment system that retains the pollutants present in the gas streams under normal process conditions; (iii) Based on the results of both systems, design and assemble a new combined photocatalysis-adsorption device to exploit the synergy of both treatments. Achievement of these goals should lead to a drastic reduction in the volume of chemicals currently used to control these emissions, creating a safer environment for plant workers and the vicinity.

Achievements in 2008: Last year, the main task undertaken was the manufacture of a hybrid photoreactor designed to operate in single-pass mode on a 24-hour basis. In order to achieve this goal, the system is provided with both a non-concentrating compound parabolic collector (CPC) and a UVA–lamp. A photoelectric sensor switches on the artificial illumination when the solar irradiance is too weak to activate the reaction. Durability was the main criterion for the selection of the anodized aluminum used in the collector, while a low-iron high transparency borosilicate glass was used for manufacturing the reactor tube. In the preliminary assays, performed with real solar irradiation, the H_2S present in the air stream was efficiently degraded using the photocatalyst previously developed in this project. Polymeric monoliths of PET coated with TiO_2 by means of a sol-gel technique were among the most effective photocatalysts used for the degradation of H_2S.

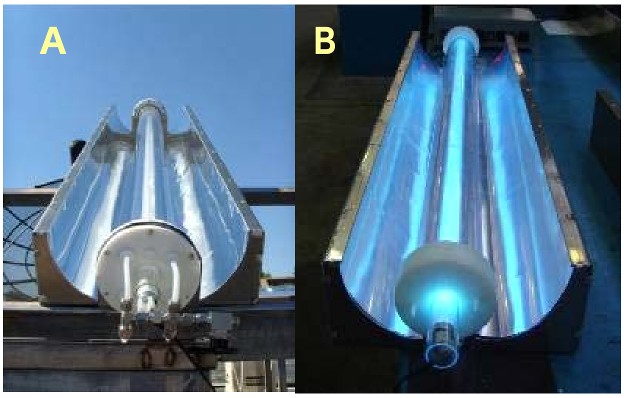

Figure 8.12 Picture of the prototype hybrid photoreactor for continuous operation, A) under sunlight and B) artificial illumination. Madrid, Spain.

Publications: [8.29], [8.30]

Decolorization of dye polluted water by photochemical processes

Participants: Centro de Investigación en Energía de la Univ. Nacional de México (CIE-UNAM) (MEX)

Contact: Antonio E. Jiménez González (ajg@cie.unam.mx)
Camilo A. Arancibia-Bulnes (caab@cie.unam.mx)

Funding: CONACYT, PAPIIT-UNAM

Duration: ongoing

Background: For more than a decade, researchers at CIE-UNAM have been studying the degradation of water pollutants by solar-assisted heterogeneous photocatalysis and photo-Fenton processes. These activities continued in 2008 with funding from several grants. Particular emphasis has been given recently to the development of methods for the degradation of water polluted with dyes from the textile industry.

Purpose: Development of solar heterogeneous photocatalysis and photo-Fenton water purification technologies.

Achievements in 2008: Several photoreactors based on linear CPC geometry have been constructed and tested with solar concentration ratios of 1 to 2. TiO_2 catalyst is fixed on several glass tubes inserted in the cylindrical reactor. The reactors have been used to degrade the pesticide Carbaryl, and their energy efficiency and cost compared.

Figure 8.13 Comparison of CPC solar photoreactors with fixed catalyst, with 2 (right) and 1 (left) suns concentration ratio, CIE-UNAM

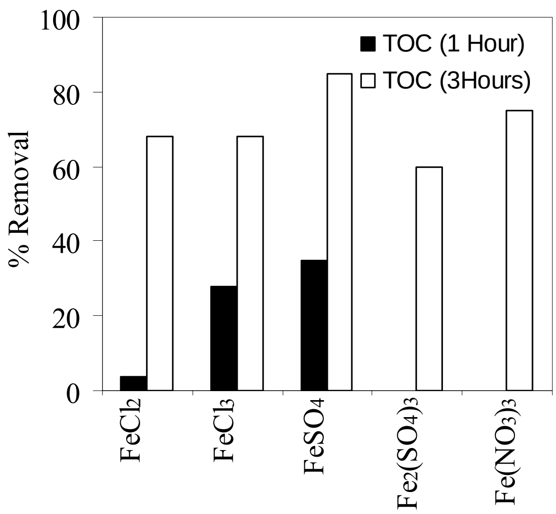

Figure 8.14 Influence of different iron salts in the removal of the Reactive Blue 69 dye by the photo-Fenton process.

A 100-L capacity hybrid photoreactor which uses radiation from the sun as the energy source, and residential lamps for backup, was developed and tested. Textile dyes were degraded in this system by both heterogeneous photocatalysis with a suspended catalyst and photo-Fenton. Black or white light lamps may be used in the reactor depending on whether UV (photocatalysis) or visible radiation (photo-Fenton) is needed in the process. In addition to synthetic dye solutions, real wastewater samples from a local textile industry have been treated in the system. The influence of different iron salts for the degradation of a textile dye by the photo-Fenton process has been investigated.

Publications: [8.31]

8.5 Outlook

During the year reported there was significant growth in the awareness and interest of Spanish regulatory authorities in studying the possible implementation of funding mechanisms for promoting CSP+D demonstration projects in the context of the Renewal Energy Plan (2005-2010), which ends in 2010. The next one, covering 2010 to 2020 is now under discussion and development.

8.6 Meetings, Reports, Literature

8.6.1 Meetings:

A Task Meeting was held in Las Vegas, on March 8, 2008, just after the 14th International SolarPACES Symposium on the same location.

8.6.2 Publications:

[8.1] J. Blanco, S. Malato, P. Fernández, D. Alarcón, W. Gernjak, M.I. Maldonado. Review of Solar Energy applications to Water Processes. Renew Sustain Energy Rev (2008), doi: 10.1016/j.rser.2008.08.016.

[8.2] Haitham Adas, Firas Alawneh, Sakher Batayneh, Norbert Geuder, Andrea Ghermandi, Heike Glade, Klaus Hennecke, Tobias Hirsch, Malek Kabariti, Carsten Hoyer-Klick, Avraham Kudish, Rami Messalem, Ralf Olwig, Klaus Pottler, Christian Sattler, Christoph Schillings, Mark Schmitz, "Concentrating solar power driven desalination for communities in Israel and Jordan (CSPD-COMISJO)", Proceedings of the EU-ROMED 2008 Conference, Desalination for Clean Water and Energy, Cooperation among Mediterranean Countries of Europe and the

MENA region. November 9 – 13 2008, Dead Sea, Jordan.

[8.3] Andrea Ghermandi, Rami Messalem, "Solar-driven desalination with reverse osmosis: the state of the art", Proceedings of the EUROMED 2008 Conference, Desalination for Clean Water and Energy, Cooperation among Mediterranean Countries of Europe and the MENA region. November 9 – 13 2008, Dead Sea, Jordan.

[8.4] Andrea Ghermandi, Rami Messalem, "Design considerations and feasibility of solar desalination for agricultural application in the Arava Valley, Israel", Proceedings of the EUROMED 2008 Conference, Desalination for Clean Water and Energy, Cooperation among Mediterranean Countries of Europe and the MENA region. November 9 – 13 2008, Dead Sea, Jordan.

[8.5] A. Herz, M.R. Malayeri, and H. Müller-Steinhagen, Fouling of roughened stainless steel surfaces during convective heat transfer to aqueous solutions, Energy Conversion and Management, Vol. 49, pp. 3381-3386, (2008).

[8.6] A. Al-Janabi, M.R. Malayeri, and H. Müller-Steinhagen, Experimental investigation of crystallization fouling on grooved stainless steel surfaces during convective heat transfer, Vol. 30. No. 10-11, pp. Accepted for pub. in Heat Transfer Eng. (2008).

[8.7] Julián Blanco-Gálvez, Lourdes García-Rodríguez and Isabel Martín-Mateos. Seawater Desalination by Innovative Solar-Powered Membrane Distillation System: MEDESOL project, accepted for publication in Desalination (2008).

[8.8] Lourdes García-Rodríguez, Isabel Martín-Mateos & Juan Carlos Vega-Beltrán, Design recommendations of a membrane distillation unit for solar desalination, submitted to Journal Membrane Science (2008).

[8.9] J.C. Bruno, et al. Modelling and optimisation of solar organic rankine cycle engines for reverse osmosis desalination. Applied Thermal Engineering 28 (2008) 2212-2226.

[8.10] Julián Blanco-Gálvez, Lourdes García-Rodríguez, Agustín Delgado-Torres, Diego C. Alarcón-Padilla and Martín Vincent. Organic Rankine cycle driven by parabolic trough solar collectors: pilot test facility at the Plataforma Solar de Almería. Las Vegas, SOLARPACES 2008.

[8.11] P. Horta, J. Farinha Mendes, A.M. Delgado-Torres. Preliminary assessment of a small scale shaft power generation system based on a solar thermal driven Organic Rankine Cycle. Proc. EUROSUN 2008. 1st International Congress on Heating, Cooling and Buildings. Lisbon-Portugal, 7-10 October, 2008.

[8.12] Ubomba-Jaswa et.al. Solar disinfection of drinking water (SODIS): An investigation of the effect of UVA dose on inactivation efficiency. Photochem. Photobiol. Science, in press, 2008.

[8.13] Cosima Sichel. Solar Photocatalytic Disinfection of Plant Pathogen Fusarium Species. PhD Thesis. Almería, 2008.

[8.14] Christian Sattler, Hans-Jürgen Bigus, Volker Dietrich, Daniela Graf, Richard Huth, Christian Jung, Alexander Müller, Timo Olbrich, Lamark de Oliveira, Ralf Olwig, Jan-Peter Säck, "Solar Photocatalytic Detoxification of Rocket Test Facility Waste Water with a Non Concentrating Tubular Receiver (NCTR) Pilot Plant", 14th Biannual SolarPACES Symposium March 4 – 7 2008, Las Vegas, USA.

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