SolarPACES

Concentrating Solar Power in 2001

An IEA/SolarPACES Summary of Present Status and Future Prospects

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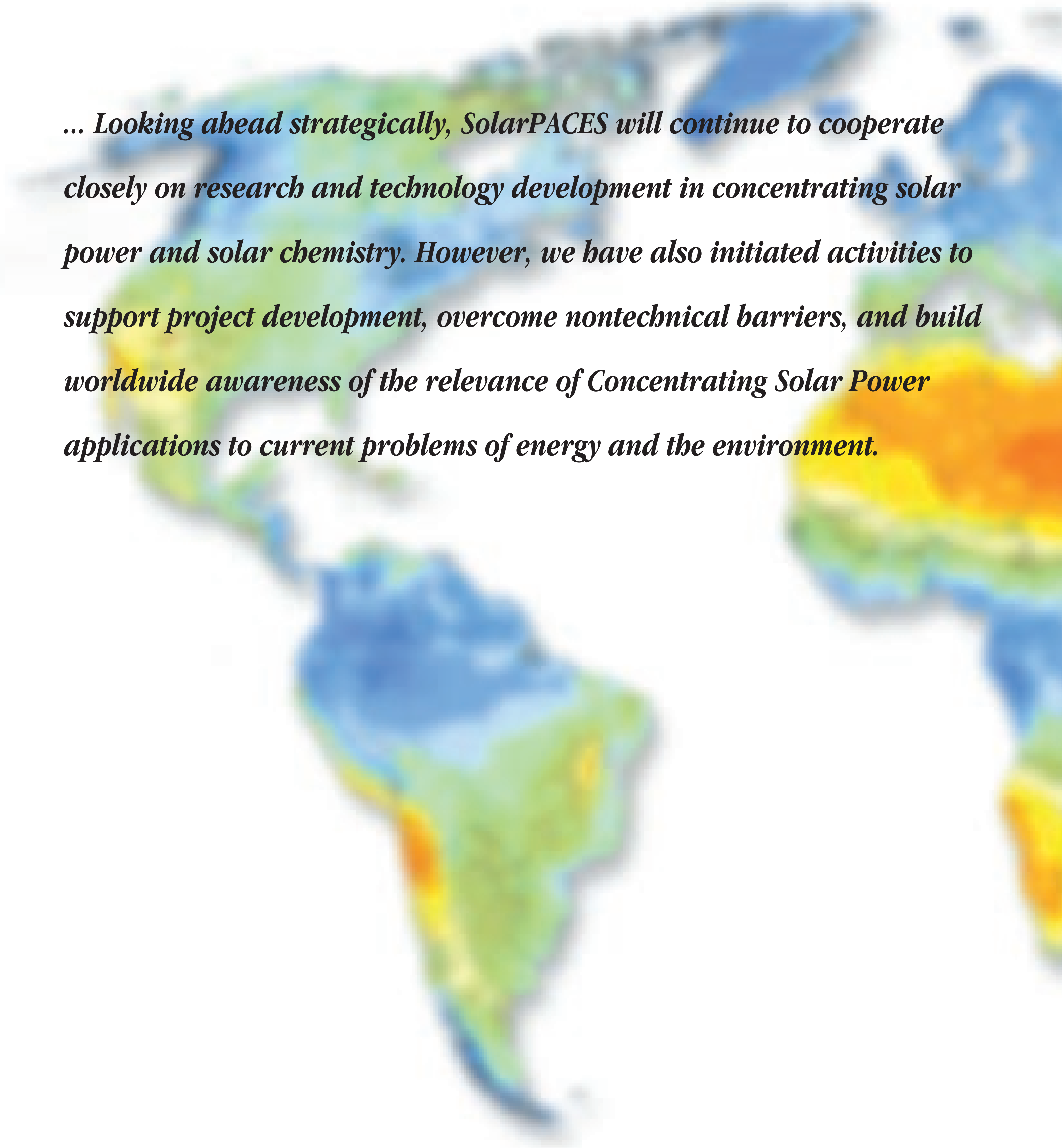
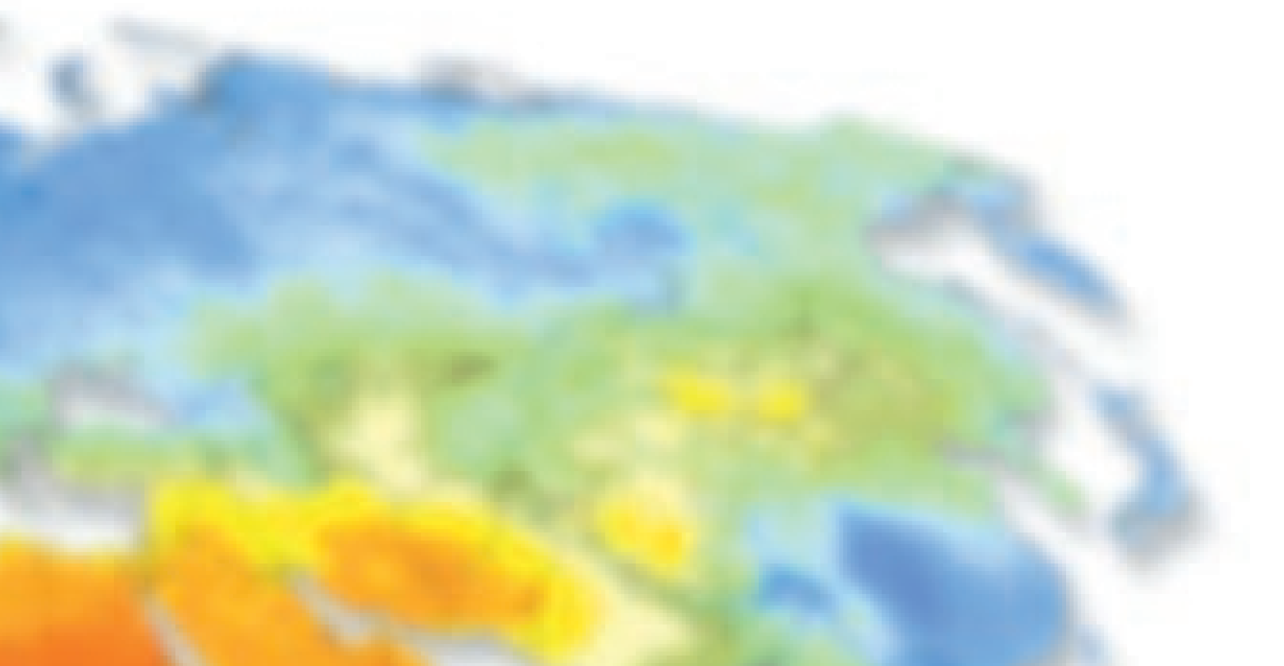
… Looking ahead strategically, SolarPACES will continue to cooperate closely on research and technology development in concentrating solar power and solar chemistry. However, we have also initiated activities to support project development, overcome nontechnical barriers, and build worldwide awareness of the relevance of Concentrating Solar Power applications to current problems of energy and the environment.





Concentrating Solar Power —

The Lowest Cost Solar Energy in the World

Research and development activities sponsored by countries within the International Energy Agency's (IEA's) concentrating solar technologies working group, SolarPACES (Solar Power and Chemical Energy Systems), have, during the past two decades, helped to dramatically reduce the cost and improve the performance of concentrating solar power (CSP, also often called solar thermal power) plants. Significant technological improvements have recently been demonstrated in next-generation pilot plants and other large-scale testing. These advances, along with cost reductions made possible by scale-up to larger mass-production rates and construction of a succession of power plants, have made CSP systems the lowest-cost solar energy in the world and promise cost competitiveness with fossil-fuel plants in the future. Concentrating solar technologies are appropriate for a wide range of applications, including dispatchable central-station power plants where they can meet peak-load to near-base-load needs of a utility, and distributed, modular power plants for both grid-connected and remote/off-grid applications.

In this paper, we present the collective position of the SolarPACES community on CSP-generating technology. We discuss the current status of the technology and likely near-term improvements, the needs of target markets, and important technical and financial issues that must be resolved for successful penetration of near-term global markets.

Introduction

Since 1977, IEA/SolarPACES has pursued a focused program of research and development in the field of concentrating solar power and chemical energy systems. Systematic development of three CSP technologies—troughs, towers, and dishes—has led to the ever-increasing ability of these technologies to concentrate and harness solar energy for electricity production and other uses with efficiency, reliability, and cost effectiveness. Our vision within the IEA/SolarPACES community is that by 2010, CSP technologies will be making a significant contribution to the delivery of clean, sustainable energy services in the world's sunbelt [1,2].

Commercial applications from a few kilowatts (kW) to hundreds of megawatts (MW) are now feasible, and plants totaling 354 MW have been in operation in California since the 1980s. Plants can function in dispatchable, grid-connected markets or in distributed, stand-alone applications. They are suitable for fossil-hybrid operation or can include cost-effective storage to meet dispatchability requirements. They can operate worldwide in regions having high direct-normal insolation, including large areas of Africa, Australia, China, India, the Mediterranean region, the Middle East, the southwestern United States, and Central and South America. Commercial solar plants in California with 80 MW capacity have achieved costs of about 12¢ per kilowatt hour (kWh) with a 75% annual solar share and 2700 kWh/m^{2}yr of annual direct solar radiation (the lowest cost of any solar technology), and the potential for cost reduction will ultimately lead to costs below 6¢/kWh for large plants in high insolation regions [3]. (All costs discussed in this paper are in U.S. dollars ($) or cents (¢).)

Recognizing both the environmental and climatic hazards to be faced in the coming decades and the continued depletion of the world's most valuable fossil energy resources, CSP can provide critical solutions to global energy problems within a relatively short time frame and is capable of contributing substantially to carbon dioxide reduction efforts. Of all the renewable technologies available for large-scale power production today and for the next few decades, CSP is one of a few with the potential to make major contributions of clean energy because of its relatively conventional technology and ease of scale-up [4]. Nonetheless, the present-day potential of CSP generation is not broadly known, even within communities concerned with renewable energy use. In this paper, we summarize the issues involved in making large-scale CSP a reality.

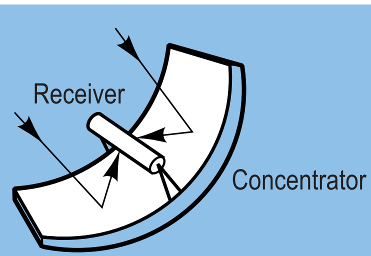
It is clear that CSP technologies are now nearing readiness for full-scale market introduction, and SolarPACES is poised to play a key role in this new phase. To facilitate their entry into the international energy market, SolarPACES has broadened its focus. Looking ahead strategically, we will continue to cooperate closely on research and technology development in CSP and solar chemistry. However, we have also initiated activities to support project development, overcome nontechnical barriers, and build worldwide awareness of the relevance of CSP applications to current problems of energy and the environment [2,5].

Status of the Technologies

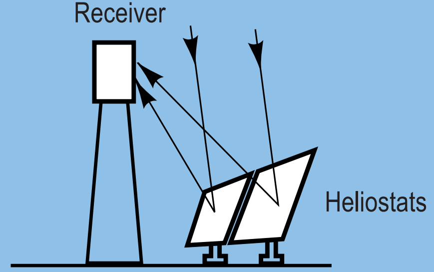
The architectures of the three main types of CSP systems are shown at right. **Trough systems** use linear parabolic concentrators to focus sunlight to a receiver running along the focal line of the collector. The solar energy is absorbed in a working fluid (typically a heat-transfer oil, or in advanced systems, steam), which is then piped to a central location to power a conventional steam turbine. In a **power tower system,** a field of large two-axis tracking mirrors reflects the solar energy onto a receiver that is mounted on top of a centrally located tower. The solar energy is absorbed by a working fluid (typically molten salt or air) and then used to generate steam to power a conventional turbine. The thermal energy can be effectively stored for hours, if desired, to allow electricity production during periods of peak need, even when the sun is not shining. The third type of CSP system, the **dish/engine system,** uses a parabolic dish concentrator to focus sunlight to a thermal receiver and a heat engine/generator (located at the focus of the dish) to generate power. More detailed descriptions of these technologies can be found in the literature [6,7].

Because of their thermal nature, each of these technologies can be "hybridized," or operated with fossil fuel as well as solar energy. Hybridization has the potential to dramatically increase the value of CSP technology by increasing its availability and dispatchability, decreasing its cost (by making more effective use of power generation equipment), and reducing technological risk by allowing conventional fuel use when needed.

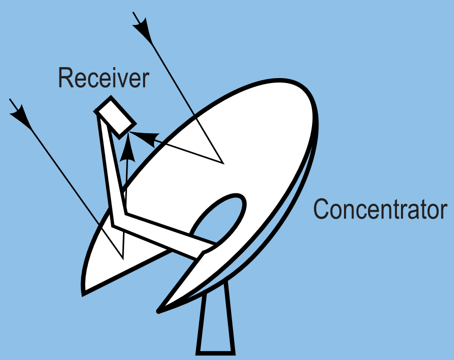
Typical solar-to-electric conversion efficiencies and annual capacity factors for the three technologies are listed in the table below. The values for parabolic troughs, by far the most mature technology, have been demonstrated commercially. Those for dish and tower systems are, in general, projections based on component and large-scale pilot plant test data and the assumption of mature development of current technology. While system efficiencies are important, they are, of course, only one factor in the ultimate measures of competitiveness—cost and value.



Trough System



Power Tower System



Dish/Engine System

Characteristics of Concentrating Solar Power Systems

System	*Peak Efficiency*	*Annual Efficiency*	*Annual Capacity Factor*
Trough	21%	10 to 12% (d) 14 to 18% (p)	24% (d) 25 to 70% (p)
Power Tower	23%	14 to 19% (p)	25 to 70% (p)
Dish/Engine	29%	18 to 23% (p)	25% (p)

(d) = demonstrated
(p) = projected, based on pilot-scale testing
Annual Capacity Factor refers to the fraction of the year the technology can deliver solar energy at rated power.

Trough Power Plants

With 354 MW of solar electric generating system (SEGS) parabolic trough power plants connected to the grid in Southern California since the mid-1980s, parabolic troughs represent the most mature CSP technology. To date, there are more than 110 plant-years of experience from the nine operating plants, which range in size from 14 to 80 MW. No new plants have been built since 1991 because declining fossil-fuel prices and reduced tax benefits in the United States resulted in unattractive near-term economic predictions for future plants. The nine plants are located at three sites in the Mojave Desert near Barstow, California: Daggett (SEGS I and II), Kramer Junction (SEGS III through VII), and Harper Lake (SEGS VIII and IX).

The performance of these power plants has continued to improve over their operational lifetime. The Kramer Junction site has achieved a 30% reduction in operation and maintenance (O&M) costs. This reduction is the result of major improvement programs for the collector design and the O&M procedures, carried out in collaboration between the Kramer Junction Company Operating Company and Sandia National Laboratories. In addition, key trough-component manufacturing companies have made advances in production techniques. For example, SOLEL in Israel has improved the absorber tubes, and Flabeg (the German reflector producer) has developed improved process know-how and system integration and is working to initiate new projects in the world's sunbelt. Numerous major consortia have responded to the recent Requests for Qualifications for CSP projects in Egypt and India, supported by the Global Environment Facility (GEF). Among them, firms like Bechtel and Duke Solar of the United States, SOLEL of Israel, the Abengoa Group and Gamesa of Spain, DSD of Germany, and BHEL and Larssen-Toubro of India have submitted qualified commitments for turnkey construction of parabolic trough plants. Independent power producer (IPP) developers and operators like BP Power, Duke Energy, ENEL, Iberdrola, Mahrubeni, and Union Fenosa, as well as renewable energy venture capital groups like Solar Millennium AG, provide some examples for the revived interest in this technology.

To further reduce costs, the following represent the expected next generation of trough technology:

- improvements in the collector field as a result of lower-cost designs and more durable receivers and collector structures;
- development of thermal energy storage systems suitable for solar-only deployment of the technology;
- continued improvements in the overall O&M of the systems;

A portion of the solar field at the Kramer Junction, California, power plant

- system cost reductions and efficiency improvements by substituting water for synthetic oil as the heat-transfer fluid;
- development of advanced solar/fossil hybrid designs, especially the coupling with combined-cycle power plants;
- development of innovative methods of concentrating solar energy on linear receivers. One concept under development in Australia is the Linear Fresnel Reflector that employs nearly flat mirrors located very close to the ground. This reduces concentrator wind loads and increases packing density, both of which could result in a lower-cost CSP system [8a].

These improvements are being implemented through ongoing research activities such as the German/Spanish Direct Solar Steam project [8b] where 26% levelized energy cost reduction is expected versus conventional oil trough systems, and the new USA Trough and EuroTrough projects [8c]. New receiver configurations and reflectors for trough applications are currently being developed and tested at Plataforma Solar de Almería in Spain. In Australia, advanced concepts are being pursued by the University of Sydney.

Ultimately, as larger (i.e., greater than 200 MW) and more advanced trough plants that include energy storage are deployed, power costs should be similar to clean coal-fired generation [9].

EuroTrough collector

SEGS troughs

The Kramer Junction trough plants have achieved a 30% reduction in operation and maintenance costs during the last five years.

Power Tower Plants

In more than 15 years of experiments worldwide, power tower plants have proven to be technically feasible in projects using different heat-transfer media (steam, air, sodium, and molten salts) in the thermal cycle and with different heliostat designs. U.S. and European industries (including Bechtel Corporation, the Boeing Company, Ghersa, and Inabensa) have expressed interest in commercializing second-generation power tower technology and have recently completed the operation of pilot plants.

At Barstow, California, the 10-MW Solar One plant successfully operated with steam as the receiver fluid from 1982 through 1988. Lack of a cost-effective energy storage system at Solar One led to the development of molten-salt technology and demonstration of the 10-MW Solar Two Pilot Plant (a retrofit of Solar One) from 1996 to 1999. Although a variety of technical issues were identified during testing, all problems were either solved at Solar Two or simple fixes were developed for implementation within the next plant. Solar Two successfully demonstrated a low-cost and highly efficient (97%) molten-salt energy storage system. It also demonstrated the feasibility of delivering utility-scale solar power to the grid 24 hours per day, if necessary [8d].

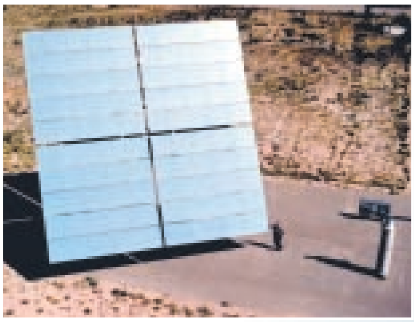
TSA Power Tower Testing at Plataforma Solar de Almería

In parallel, European activities have demonstrated the volumetric air receiver concept where the solar energy is absorbed on fine-mesh screens and immediately transferred to air as the working fluid. Energy is stored in a thermocline storage tank that is packed with ceramic pellets. Extensive validation of this concept was demonstrated at the 1-MW level by the Phoebus Technology Program Solar Air Receiver (TSA) tests conducted over the past several years in Almería, Spain.

Power tower efforts in the United States, Europe, and Israel are targeted to achieve electricity generation costs of less than 20¢/kWh for first commercial plants. These costs apply to solar-only plants with a capacity of at least 10 to 15 MW in high-insolation (2700 kWh/m^{2}yr) sites like the Mojave Desert; costs would be proportionately higher in regions of lower solar insolation. First commercial plants will incorporate the following improvements relative to the pilot plants:

- improvements in the heliostat field as a result of better optical properties, lower cost structures, and better control. New heliostat design activities include large-area heliostats, measuring 90 to 150-m^2 each, independently developed by Inabensa (Spain), Ghersa (Spain), and Advanced Thermal Systems (USA).
- improvements in system integration by reduction of parasitic loads, optimization of startup procedures, and better control strategies.
- improvements in solar/fossil hybridization schemes, especially the coupling with conventional combined-cycle power plants. One concept under investigation in Israel employs a secondary reflector on the tower top to direct the solar energy to ground level for collection in a high-temperature air receiver for use in a gas turbine. Coupling the output of a high-temperature solar system to a gas turbine could allow a higher efficiency than current steam turbine applications, faster startup times, lower installation and operating expenses, and perhaps a smaller, more modular system [10].

Ultimately, as power tower technology matures and larger (up to 200 MW), more advanced plants are deployed, power costs should be similar to clean coal-fired generation [9].



Advanced Thermal Systems 150-m^2 Heliostat

Inabensa 90-m^2 Heliostat

Solar Two

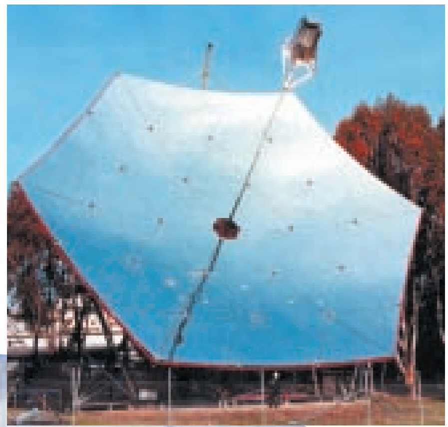
The Solar Two power tower demonstrated, via storage, the feasibility of delivering utility-scale solar power to the grid 24 hours per day.

Dish/Engine Power Plants

Several dish/engine prototypes have successfully operated during the last 10 years (including 7- to 25-kW units developed in the United States by Advanco, McDonnell Douglas Corporation, Cummins Engine Company, and others), but large-scale deployment has not yet occurred.

Currently in Spain, six units with a 9- to 10-kW rating are operating successfully. The German company Schlaich, Bergermann und Partner (SBP), working with the German companies Steinmüller (collector system) and SOLO Kleinmotoren GmbH (Stirling engine), developed these units. Three of these dishes have been continually operated with great success since 1992, accumulating more than 30,000 hours of operating experience. The new EuroDish development with the industrial engagement of SBP, Mero Raumstruktur GmbH & Co., SOLO, and the Abengoa/Inabensa Group [8e] will advance this concept. At the same time in the United States, two industrial teams (Stirling Energy Systems/Boeing Company and Science Applications International Corporation/STM Corp.) have installed several second-generation 25-kW dish/Stirling prototypes for extended testing and evaluation.

In addition, WGAssociates has demonstrated the first unattended, remote operation of an advanced-technology 10-kW dish/Stirling prototype (using the SOLO Kleinmotoren engine). These systems incorporate cost-reduction features, hybridization, and higher system reliabilities than previous prototypes to qualify them for mass production and commercialization.



Australian National University 400-m² Dish

SAIC/STM 25-kW Dish/Stirling System

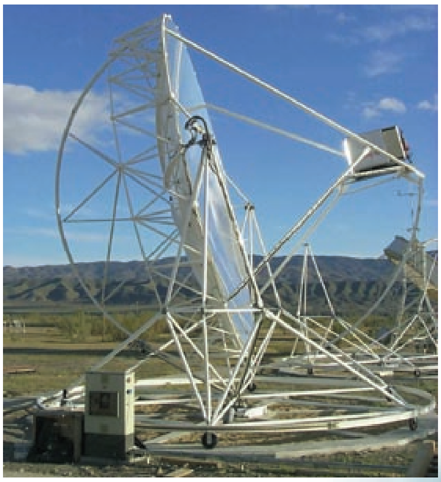
SES/Boeing 25-kw Dish/Stirling System

WGAssociates 10-kW dish/Stirling System

With the participation of a utility consortium, research and development work in Australia has demonstrated the 400-m^2, 50-kW "big dish" of the Australian National University in Canberra. Besides providing power on a kilowatt scale, this technology also has the capability of combining the thermal output of several dishes to supply a central multi-megawatt power plant.

In the market-introduction phase, pilot demonstrations of several tens of dish/Stirling units will compete in generation cost with photovoltaic systems of similar size. After successful demonstration and manufacturing scale-up, costs will drop to less than 15¢/kWh. This lower cost will be achieved through:

- improvements in mirrors and support structures, improvements in hybrid heat-pipe and volumetric receivers coupled to Stirling and Brayton engines, and development of control systems for fully automatic operation; and
- improvements in system integration by reduction of parasitic loads, optimization of startup procedures, better control strategies, and hybrid operation of the Stirling and Brayton engines.



10-kW EuroDish

Advanced Processes

While the above work is focused on production of electricity, longer term research is under way in Australia, Germany, Israel, Switzerland, and elsewhere aimed at production of solar fuels for a range of uses including both transportation and fuel cells for electricity production [11]. This work is targeted toward the thermochemical conversion of solar energy into chemical energy carriers (e.g., hydrogen, synthesis gas, and metals) to allow the efficient storage and transport of solar energy. While the ultimate goal is production of fuels from solar energy only, mid-term activities are also investigating novel techniques for hybrid solar/fossil chemical processes, which can upgrade the quality of fossil fuels (by the addition of solar energy), while providing a path from current technologies to a future of solar fuels. For example, the solar reforming of natural gas has been demonstrated at the 0.5-MW scale in Israel and Germany. In addition, more advanced processes for decarbonization of fossil fuels (to eliminate carbon dioxide discharge during combustion) and reduction of metals (as energy carriers) using coke or natural gas as chemical-reducing agents are being investigated in Switzerland, Israel, and elsewhere. Long-term success will require robust, efficient solar chemical processes, as well as cost-effective solar energy collection technologies resulting from large-scale implementation of solar electricity production.

These 9- to 10-kW Schlaich, Bergerman und Partner dishes are operating successfully at Plataforma Solar de Almería in Spain.

The Markets

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

Nevertheless, CSP technologies are capable of meeting the requirements of two major electric power markets: large-scale **dispatchable markets** comprised of grid-connected peaking and base-load power, and rapidly expanding **distributed markets** including both on-grid and remote/off-grid applications.

The attractive environmental attributes of CSP, combined with the inherent capability of the technology to meet dispatchable and distributed market needs, form a compelling argument for continued development of the technology. With appropriate commercialization strategies, CSP can begin penetrating the marketplace, even during this time of intense competition within the power industry.

Dispatchable Power Markets

Dispatchable power markets are dominated by fossil-fuel-fired electricity distributed over central utility grids. Power must be produced "on demand" in order to meet changing loads and command the highest value. Low life-cycle costs are the primary driver of investment decisions in this market, and advanced gas-fired and coal-fired plants represent the conventional technologies serving this market.

Using storage and hybridization capabilities, dispatchable trough and power tower technologies can address this market. They currently offer the lowest cost, highest value solar electricity available and have the potential to be economically competitive with fossil energy in the longer term. The lowest energy costs are generally achieved in the 100-MW and greater size range, although more modular designs (30 MW and below) are feasible and may offer advantages in some applications.

These technologies face a number of challenges in meeting developer, investor, and customer needs. With 110 plant-years of performance and reliability demonstrated at the SEGS plants, and with the recent demonstration of new power tower technologies, the most significant challenge in dispatchable applications is that the levelized energy cost is higher than competing conventional technologies. Fortunately, financial incentives are currently being offered in several countries that will help CSP get over the cost hurdle, as described later. In addition, technology development within the SolarPACES community will help reduce the capital cost of solar components and enable higher annual efficiency (both leading to lower, more competitive levelized energy cost).

CSP systems are candidates for dispatchable demonstrations in international markets supported by the Global Environment Facility (GEF) and other financial promoters. They are also competitive in the high-value green markets that are beginning to emerge worldwide. With continued development success and early implementation opportunities, we expect solar generation costs for large (greater than 100 MW) dispatchable CSP plants in high insolation regions to drop below 10¢/kWh by the time the first five CSP plants have been built (about 2005) and below 6¢/kWh by about 2010

Distributed Power Markets

The current emphasis in distributed power applications is to develop technologies that can operate reliably for loads ranging from several kilowatts to several megawatts. The majority of these applications are currently for remote power (such as water pumping and village electrification) where there is no utility grid. In these applications, diesel engine generators are the primary current competition. Also of growing interest to utilities are grid-connected applications in which the solar generator is sited at critical points on the transmission and distribution system, providing value not simply from the energy produced but also in postponing transmission and distribution infrastructure upgrades to meet load growth and in maintaining power quality. Small gas-turbine systems will also compete with CSP and other renewable energy technologies (for example, photovoltaic and wind) for this market. Key market criteria for distributed power applications are reliable unattended operations, minimal service requirements, and competition with the cost of alternatives.

The CSP technology appropriate for distributed applications is the dish/engine system. Each dish/engine module (10 to 50 kW, depending on the design) is an independent power system designed for automatic startup and unattended operation. Multiple dish/engine systems can be installed at a single site to provide as much power as required, and the system can readily be expanded with additional modules to accommodate future load growth. The systems can be designed for solar-only applications, can be easily hybridized with fossil fuels to allow power production without sunlight, or can be deployed with battery systems to store energy for later use. The high value of distributed power (more than 50¢/kWh for some remote applications) provides opportunities for commercial deployment early in the technology development.

There are several critical issues facing the development of dish/engine systems. The first and foremost is reliability, as measured by both mean time between failure and O&M costs. The second issue is system cost, which is currently less critical because commercial sales can occur in high-value markets at current costs as reliability and O&M are improved.

The future for distributed CSP applications is bright. The technology enhancements needed to achieve high reliability and reduce O&M costs are understood. As technology development proceeds, there will be numerous opportunities for field validations that will build on the high value of energy for remote applications and the low cost for system demonstration (because of the small module size). With continued development, market-introduction success and manufacturing scale-up, we expect distributed system costs will drop to 15¢/kWh within about five years and to below 10¢/kWh after 2010 (for production rates of several thousand units per year).

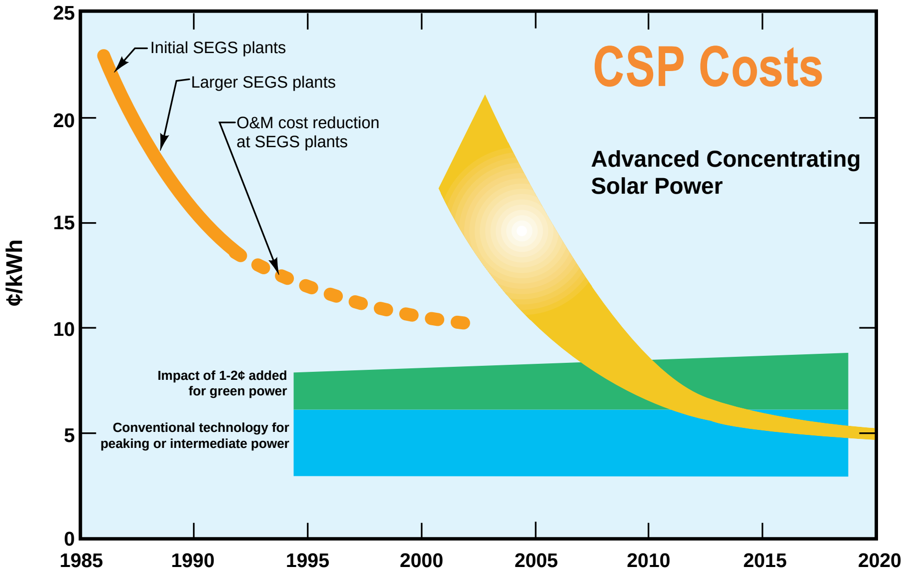
Past, Present, and Future CSP Electricity Costs

The electricity cost goals mentioned above for CSP technology are given historical context in the chart below. Electricity costs from current SEGS trough technology have been reduced by 50% during the last 15 years, and they are now 10 to 12¢/kWh for a large plant operating in a high solar resource region, such as a desert. To reduce costs further, technology improvements must be demonstrated to allow solar technology to progress down the advanced learning curve. For example, development of advanced trough technology and/or scale-up of the recently demonstrated power tower technologies are breakthroughs that should allow the continued drop of solar electricity costs into the competitive range. Power costs from initial "advanced technology" plants will be higher than today's plants because they will be smaller and less mature than today's SEGS technology. However, as the advanced technology is scaled up and matures, electricity costs should be significantly lower than today's plants. Until CSP enters the competitive green and conventional markets, significant monetary subsidies will be required to allow continued progress down the learning curve, as described in the next section.

Barriers and Near-Term Project Opportunities

Bringing a relatively new technology such as solar power plants into the marketplace requires attractive financial incentives to investors. From the viewpoint of profit and technical and financial risks, solar power is not yet adequately attractive to investors. For this reason, we have expanded our role in SolarPACES from one that historically focused on technology development to include nontechnical activities that address commercialization barriers and provide support for project development.

For example, taxation policy often stands in the way of solar project development. Recent studies in the United States have shown that if a CSP plant is taxed in the same way as an equivalent fossil-fuel plant, the solar plant will, because of its capital-intensive nature, pay much more tax per kilowatt-hour during its lifetime. In the international arena, taxation policies have killed the development of some solar projects because very high taxes would have been levied on imported solar components. These case studies have shown that taxation policy can affect the levelized electricity cost from the solar plant by as much as one-third. Resolving taxation issues can do as much for improving the economic competitiveness of CSP plants as will technological breakthroughs. The SolarPACES group is working with national decision makers, the European Commission, and organizations like the World Bank and the GEF to help understand the barriers to CSP market introduction, including tarriffs, tax equity, permitting, grid connection, and other power-sector reforms.



If solar technology is to achieve sustained market penetration, large projects (100 to 200 MW) must be developed. Without large projects, economies of scale and mass-production techniques (essential to lowering the cost of solar energy) cannot be achieved. The first step in realizing significant market-introduction plans is to develop initial project opportunities. SolarPACES is helping identify the most promising projects by sending experts to selected sunbelt countries. To date, SolarPACES "START" (Solar Thermal Analysis, Review and Training) teams and other experts have been instrumental in launching and/or supporting project feasibility studies for Australia [8a,8g], Brazil, Crete [12c], Egypt, India [8f], Mexico, Morocco, South Africa, and Spain

[12a,12b]. IPP-type projects employing solar trough and tower technology are in an advanced stage of development in at least six countries (Egypt, Greece, India, Mexico, Morocco, and Spain). These countries are targeted because financial incentives exist to reduce carbon dioxide emissions. For example, Spain is taking leadership in Europe's policy on climate protection, and has committed in Kyoto to obtain 12% of its primary energy needs from renewables by 2010. The national Spanish plan for the "Introduction of Renewable Energies in Spain" (Plan de Fomento de las Energías Renovables en España) establishes grant and production premium support for 200 MW of CSP plants in Spain. One 30- to 50-MW trough project (based on EuroTrough technology) and two new 10- to 15-MW power tower projects (one each based on Solar Two and TSA technology) will likely be implemented. Moving in a similar direction, the Italian parliament recently approved about $100 million to support CSP development and the implementation of a first 50-MW CSP plant in Italy. Egypt, Morocco, India, and Mexico are also currently developing projects that are sponsored by large grants (approximately $50 million each) from the GEF [9]. While the Request for Proposal in India foresees trough technology, the CSP technology used in Egypt, Morocco, and Mexico will be left to the bidder. In total, these projects, expected to be online by 2005, add up to an equivalent solar capacity of more than 150 MW.

The GEF and other organizations recognize the value in developing clean and sustainable CSP. What appeals to these organizations is that the embodied energy of a CSP plant is recovered after less than one-and-a-half years of plant operation and the power plant produces orders of magnitude less carbon dioxide per gigawatt hour on a life-cycle basis than competing fossil-fired plants [13]. Construction of CSP plants could thus help sunbelt countries meet carbon dioxide reduction goals, such as those of the 1997 Kyoto Climate-Change-Convention Protocol to reduce global warming. In addition, of all the renewable technologies available for large-scale power production today and for the next few decades, CSP is one of few with the potential to make major contributions of carbon-dioxide-free electricity at a reasonable price because it is built with commonly available materials (e.g., glass, concrete, steel, turbines) and is easy to scale-up. Furthermore, the majority of the plant-unique hardware (solar collectors, energy storage tanks, and power conversion units) can be built in the target countries with in-country labor. Solar photovoltaics cannot make these claims because of the high cost of cells and energy storage as well as the high cost of building special-purpose facilities to manufacture the solar cells [14].

Concluding Remarks

To fully exploit environmentally friendly CSP, broader cooperation between governments, nongovernment organizations, electric utilities, IPPs, and private industry is needed. Government support for research, technology development, and demonstration projects, though necessary, is insufficient. In addition, market incentives must be created to overcome barriers in the user and financial communities that exist because concentrating solar technologies are new and viewed as both risky and a possible threat to existing technologies and interests. Finally, the major investments needed to properly develop and market solar technology must be supported by stable, long-term regulatory policies, which can only be provided by legislative and governmental support.

The IEA/SolarPACES group is evaluating many of the technical and nontechnical issues discussed in this paper. For more information regarding ongoing projects, consult SolarPACES' annual reports [5] and its website at www.solarpaces.org.

Concentrating Solar Power Testing Facilities

Weizmann Institute of Science in Rehovot, Israel

The National Solar Thermal Test Facility in Albuquerque, New Mexico, USA

Plataforma Solar de Almería in Almería, Spain

References

1. SolarPACES, *Entering the 21st Century: IEA/SolarPACES Strategic Plan*, March 2000, and *Program of Work 1999-2002,* November 1999.

2. G. Kolb and C. Tyner, "Solar Thermal Electricity," *IEA Workshop on the Mitigation of Greenhouse Gas Emissions,* Paris, France, September 15–16, 1997.

3. M. Becker, W. Meinecke, M. Geyer, F. Trieb, M. Blanco, M. Romero, and A. Ferrière, "Solar Thermal Power Plants," *The Future for Renewable Energy, Prospects and Directions*, edited by EUREC-Agency, James & James Science Publishers, London, 2000 and 2001 update (in preparation).

4. M. Becker, M. Macias, and J. Ajona, "Solar Thermal Power Stations," *The Future for Renewable Energy, Prospects and Directions,* Edited by EUREC-Agency, James & James Science Publishers, London, 1996. ISBN 1-873936-70-2.

5. W. Grasse, editor, *SolarPACES Annual Reports, 1996 – 1999.*

6. U.S. Department of Energy and Electric Power Research Institute, *Renewable Energy Technology Characterizations*, EPRI TR-109496, December 1997. May be downloaded from www.eren.doe.gov/utilities/techchar.html.

7. C. Winter, R. Sizmann, L. Vant-Hull, editors, "Solar Power Plants," Springer-Verlag, Berlin, Germany, 1991. ISBN 3-540-18897-5.

8. [8a] D. Burbidge, D. Mills, G. Morrison (pp. 21–26), [8b] E. Zarza, K. Hennecke (pp. 65–70), [8c] E. Lüpfert, W. Schiel, E. Zarza, R. Osuna, P. Nava (pp. 45–50), [8d] J. Pacheco, H. Reilly, G. Kolb, C. Tyner (pp. 1–11), [8e] P. Heller, A. Baumuller, W. Schiel, (pp. 33–38), [8f] S. Garg (pp. 51–56), and [8g] S. Kaneff (p. 83), *Proceedings of the 10th SolarPACES International Symposium on Solar Thermal Concentrating Technologies,* Sydney, Australia, March 8–10, 2000.

9. Enermodal Engineering, Ltd., *Cost Reduction Study for Solar Thermal Power Plants,* Final Report, Prepared by Enermodal Engineering Ltd. in association with Marbek Resource Consultants Ltd. by contract of World Bank/GEF, Washington D.C., May 5, 1999.

10. A. Segal and M. Epstein, "The Reflective Solar Tower as an Option for High Temperature Central Receivers," *Proceedings of the 9th SolarPACES International Symposium on Solar Thermal Concentrating Technologies,* Font-Romeu, France, June 22–26, 1998, and *Journal de Physique IV*, Vol. 9, pp. 53–58, 1999.

11. A. Steinfeld, "Recent Research Developments in Solar Thermochemical Processing," *Recent Research Developments in Chemical Engineering,* Vol. 4, pp. 95–101, 2000, Transworld Research Network. ISBN: 81-86846-63-8.

12. [12a] W. Gould, A. Zavoico, W. Collier, I. Grimaldi, [12b] R. Osuna, V. Fernandez, M. Romero, M. Marcos, and [12c] G. Brakmann, *Energex 2000: Proceedings of the 8th International Energy Forum,* Las Vegas, Nevada, July 23–28, 2000.

13. F. Kreith, P. Norton, and D. Brown, "A Comparison of CO_2 Emissions from Fossil and Solar Power Plants in the United States," *Energy,* Vol. 15, No. 12, pp. 1181–1198, 1990.

14. M. Geyer, and V. Quaschning, "Solar Thermal Power – The Seamless Solar Link to The Conventional Power World," *Renewable Energy World*, Vol. 3 No. 4, pp. 184–196, July/August 2000.

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