Sun•Lab SnapShot

Solar Two Demonstrates Clean Power for the Future

The 10-megawatt Solar Two power tower pilot plant near Barstow, California, successfully completed operations in April 1999, having met essentially all of its objectives. It demonstrated the ability to collect and store solar energy efficiently and to generate electricity when needed by the utility and its customers. Based on the success of Solar Two, U.S. industry is actively planning the first commercial implementation of this technology.

Solar Two represents a new generation of solar energy technology, capable of producing clean, cost-effective, dispatchable electric power on a very large scale, without harmful pollutants or carbon emissions. Solar Two was conceived and built on the site of its predecessor, Solar One, by a consortium of U.S. utilities and industry and the Department of Energy (DOE). Over its three years of operation, Solar Two achieved its overall goal of demonstrating advanced molten-salt power tower technology developed over the past decade at a scale sufficient to allow follow-on commercialization of the technology. Plant operations successfully proved that solar energy could be collected efficiently over a broad range of operating conditions and that the low-cost energy storage system operated reliably and efficiently. This unique storage capability allowed solar energy to be collected when the sun was shining and high-value, dispatchable electric power to be generated at night or whenever demanded by the utility, even when the sun was not shining.

The next step...

In addition to validating the design and technical characteristics of molten-salt receiver and storage technology, Solar Two has also been successful in fostering commercial interest in power towers. Two of the project's key industry partners, the Boeing Company and Bechtel Corporation, are currently pursuing commercial solar power tower plant opportunities in Spain. Solar energy premiums and other incentives under review in Spain create an attractive market opportunity, providing the economic incentives needed to mitigate the initial high cost and risk of commercializing a new technology. The proposed Spanish project, "Solar Tres," would use all the proven molten-salt technology of Solar Two, scaled up by a factor of three. Boeing, Bechtel, and their Spanish partners are currently investigating design options, preparing cost estimates, and negotiating contract opportunities for a project start in 2000.

While Solar Two was a demonstration project, Solar Tres will be financed and built by industry (with no DOE cost-share) as a money-making venture. U.S. industry views this project as a springboard to near-term opportunities for numerous full-scale (greater than 50 megawatts) commercial power tower plants in Spain, in other worldwide markets, and eventually in the U.S. Southwest. This dispatchable, utility-scale solar power could be a major source of clean energy worldwide, offsetting as much as 4 million metric tonnes of carbon equivalent (MMTCE) over the next 10 years.

Still, much remains to be done. The risks of a large, capital-intensive plant demonstrating new technology remain high. With all the lessons learned from Solar Two, DOE's Concentrating Solar Power Program can play a vital role in providing the solar experience and expertise of Sun•Lab (Sandia National Laboratories and the National Renewable Energy Laboratory working together) to the Solar Tres consortium. An active partnership with U.S. industry will be critically important in assuring the success of this exciting renewable energy option. Among other things, Solar Two demonstrated the success that such a DOE/industry partnership can bring.

Concentrating Solar Power Program

In the beginning...

The Solar Two story really began when the United States became interested in alternatives to imported oil in the late 1970s as the global political situation threatened our energy supply. At that time, the DOE asked its national laboratories to explore sources of renewable energy, including innovative ideas for harvesting the power of the sun, the wind, and the heat of the earth. In the area of solar energy, the power tower concept was developed.

Solar One is Born

Engineers at Sandia National Laboratories in Albuquerque, New Mexico, and Livermore, California, studied this power tower concept and determined that the system held promise to generate electricity on a scale large enough to power entire cities. They proposed a test facility to investigate the concept and qualify components and systems for larger-scale evaluation at a pilot plant. As a result, the National Solar Thermal Test Facility (NSTTF) was built at Sandia in Albuquerque in 1976, followed soon after by the 10-megawatt Solar One pilot plant near Barstow, California.

Storage is the key to molten-salt power towers. These two tanks provide three full hours of storage at Solar Two.

The National Solar Thermal Test Facility

At the NSTTF, built at Sandia National Laboratories in Albuquerque in 1976, the 63-meter tall tower has 222 computer-controlled heliostats that can direct the sun into any of four test bays to produce a total thermal capacity of 5 megawatts. The facility has been used for six major power tower development programs, including development and qualification testing of the molten-salt technology used at Solar Two.

The major challenges facing researchers in making the concept work were first to develop very large mirrors that could accurately focus sunlight on the receiver as the sun moves across the sky. The receiver had to be able to handle the high solar fluxes (up to 1000 times the intensity of normal sunlight) and temperatures up to 565ºC. The heat then had to be stored to generate steam when power was needed. Testing at the NSTTF proved the concept was possible.

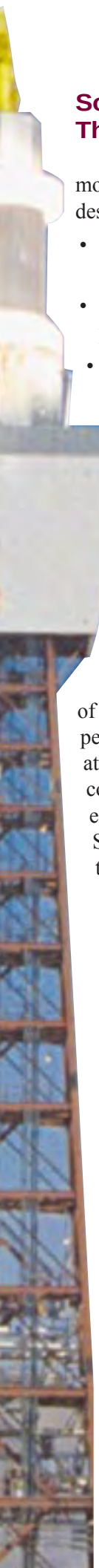
For Solar One, water was chosen as the heat-transport medium. The idea was to pump water up to the receiver to make steam, which was then brought down to the base of the tower to generate electricity or to thermally charge an enormous holding tank containing oil, rock, and sand.

By 1982, Solar One was ready to go into operation—with its field of 1,818 heliostats encircling and facing a tower rising 90 meters into the air and rated to produce 10 megawatts of power. The plant operated successfully until 1988, as planned, proving that power towers can produce electricity efficiently and reliably, operating with 96% availability during its final year. It generated more than 38,000 megawatt-hours during its lifetime and consistently ran at its 10-megawatt rating. Solar One did have deficiencies, however, including inefficiencies in its storage system and difficulties operating under intermittent cloud cover.

Solar One Begets Solar Two

Like the legendary phoenix, the idea for Solar Two (tower and receiver at right) arose from Solar One. This time, it was a matter of making improvements to a known and proven concept—and retrofitting the original plant to incorporate the improvements. Although the water/steam receiver concept worked, researchers knew that certain salts when melted could store the heat much more efficiently and cost-effectively. Thus, use of a large storage system would not only increase the value of produced power, but would actually decrease the overall cost as well. Much of the equipment at Solar One, including the large heliostat field, tower, and turbine, was reused, but a new receiver, storage system, control system, and connecting piping were required. The DOE and a consortium of utility and industry partners (see back page) shared the costs of the Solar Two effort.

The engineering, manufacturing, and construction of Solar Two lasted from 1992 into 1995, with initial startup and testing beginning in 1996. Solar Two operated from April 1996 to April 1999, when operations were completed, after having proven the promise of the concept.



Solar Two Performance... The Bottom Line

Solar Two's overall goal was to demonstrate advanced molten-salt power tower technology. To this end, its design objectives, developed early in the project, were to:

- Simulate the design, construction, and operation of the first commercial plants.
- Validate the technical characteristics of a molten-salt plant.
- Improve the accuracy of economic projections for commercial projects by increasing the database of system performance, and capital, operating, and maintenance costs.
- Collect, evaluate, and distribute information to foster interest in commercialization of power towers.
- Stimulate interest in forming a commercial consortium.

All of these objectives were successfully met during the project.

Over its three-year operating lifetime, daily operation of Solar Two became relatively routine, with various performance records broken on a fairly regular basis. Key attributes of solar power tower plants, including efficient collection and storage of the sun's energy and dispatch of electricity as needed by the utility grid, were confirmed. Specific technical accomplishments included demonstration of:

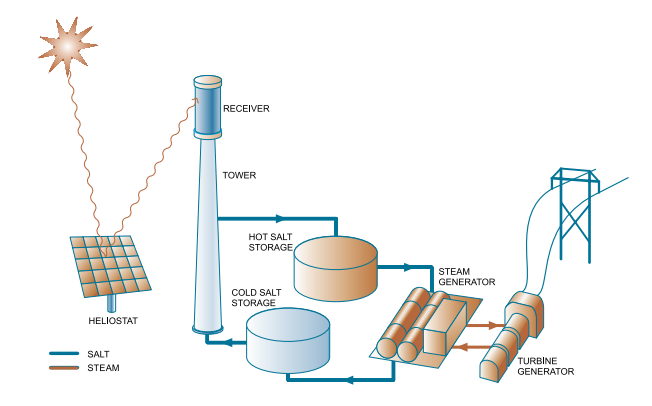
- **Dispatchability:** Using its unique and extremely efficient thermal storage system, Solar Two delivered electricity to the grid around the clock for 153 straight hours (nearly a full week), all from clean, renewable solar energy. The figure on the back page illustrates storage of energy during the day and generation of power after sunset, as compared to model predictions. The use of molten-salt storage has another important benefit in that it provides for simplified system operation because the collection of solar energy is isolated from electric energy production.
- **Power Output:** As plant performance and operations were optimized, daily net generation increased regularly, ultimately reaching a record 105 megawatt-hours. Over one 30-day period, Solar Two produced 1633 megawatt-hours, exceeding its one-month performance goal of 1500 megawatt-hours of power production. The plant also produced a record gross turbine power output of 11.6 megawatts.

continued on back page

Solar Two's receiver, atop a 90-meter tower, could absorb 800 times the normal intensity of the sun.

Molten-Salt Power Tower Technology

In a molten-salt power tower, sun-tracking heliostats can concentrate solar energy up to 1000 times onto a central, tower-mounted receiver. Molten nitrate salt, which is a clear liquid with properties like water at temperatures above its 240°C melting point, is pumped from a large storage tank to the receiver, where it is heated in tubes to temperatures of 565°C. The salt is then returned to a second large storage tank, where it remains until needed by the utility for power generation. At that time, the salt is pumped through a steam generator to produce the steam to power a conventional, high-efficiency steam turbine to produce electricity. The salt at 285°C then returns to the first storage tank to be used in the cycle again.

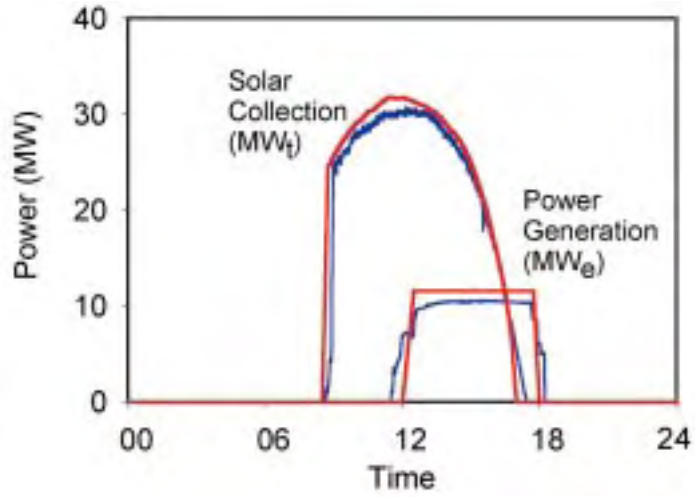


The Dispatchability Advantage

The major advantage of Solar Two is that the plant can produce power when the local utility needs it most—during peak demand periods in the afternoon and early evening, for example. Unlike most solar systems, which can produce power only when the sun shines, molten-salt power towers operate not only on sunny days, but also during cloudy periods and for up to 12 hours after sunset, if so desired. Solar Two, for example, could produce its full rated output of 10 megawatts for three hours after sunset.

The Environmental Factor

Power towers, like all solar technologies, have distinct advantages over conventional power plants in that they consume no fuel and do not pollute the environment. They use no more land than coal (including mining) or hydroelectric (including water storage) power plants. Solar Two has demonstrated that power towers can provide clean power without any emissions of green house gases or toxic chemicals. In the future, as many plants are built, power tower plants will be able to compete on a strictly economic basis with other, more conventional power-generation technologies. In the near-term, environmental benefits could play a major role in early deployments. For example, grants are available from national governments and international agencies (such as the Global Environment Facility) for solar technologies that can mitigate climate changes caused by carbon dioxide and other greenhouse gas emissions.



Example of predicted (red) and actual (blue) solar energy collection and power generation.

- **Reliability:** During one stretch in the summer of 1998, the plant operated for 32 of 39 days (four days down because of weather, one day because of loss of offsite power, but only two days down for maintenance).
- **Parasitic Power Use:** The electrical parasitic energy load—electricity required to run the plant, including power for the salt pumps and for the electric heat trace that prevented salt freezing in pipes—was reduced significantly, ultimately meeting the design goal regularly.
- **Efficiency:** The receiver efficiency was measured at 88% in low-wind conditions (and 86% in allowable operating winds), matching design specifications. Efficiency of the storage system was measured at greater than 97%, also meeting design goals.

Despite its many successes, operation of Solar Two was not without problems. There were numerous startup issues with components, including heat trace, piping, and the steam generator, that delayed routine operation of the plant for more than a year. In the end, essentially all of the issues were overcome with some combination of redesign and rework, improved operating procedures, or workarounds for fixes that could not be implemented at Solar Two. Only an issue with receiver startup in high winds could not be fully overcome during Solar Two operation, and even that problem is easily resolved with a minor design change in the next receiver.

Although testing at Solar Two has been completed, analysis of the data and overall plant evaluation continues. Extensive documentation of the project will be completed by September 2000, and key high-level reports will be available on the Sun♦Lab website as they are released. All the results are being incorporated into lessons-learned and design-basis documents, which will be key starting points for the design of Solar Tres and future plants by U.S. industry.

Solar Two Consortium

Participants: Arizona Public Service Company, Bechtel Corporation, California Energy Commission, Electric Power Research Institute, Idaho Power Company, Los Angeles Department of Water and Power, Pacificorp, Sacramento Municipal Utility District, Salt River Project, and Southern California Edison Company. Southern California Edison was the project manager, while Bechtel served as the engineering and construction manager. Boeing provided the receiver.

Contributors: Chilean Nitrate, Nevada Power, and South Coast Air Quality Management District

Industrial Contributors: Boeing/Rocketdyne, ABB Lummus, Gould Pumps, General Process Controls, Pitt-Des Moines, Raychem, and The Industrial Company

Government Partners: U.S. Department of Energy, Sandia National Laboratories, and the National Renewable Energy Laboratory

Just the Facts...

Solar Collectors:
- 1,818 Solar One heliostats (39 m^2 each)
- 108 new large-area heliostats (95 m^2 each)

Solar Receiver:
- 5.1-m diameter by 6.2-m high
- 32 25-mm diameter tubes in each of 24 panels
- 43-megawatt thermal rating with 800-sun peak-flux capability

Thermal Storage System:
- 2 12-m diameter by 8-m high storage tanks
- 1,400 tonnes of molten sodium/potassium nitrate salt

Steam Generator System:
- Separate preheater, evaporator, and superheater vessels
- 35.5-megawatt thermal rating at 100 bar and 538°C

Electric Power Generation System:
- Rankine-cycle non-reheat turbine from Solar One
- 10-megawatt net electric power rating

Project Cost - $58 million:
- Industry and Utility Cost Share - $32 million
- DOE Cost Share - $26 million

For on-line information about **Sun♦Lab,** please visit **http://www.eren.doe.gov/sunlab.** Information about the U.S. Department of Energy's Concentrating Solar Power Program can be found at **http://www.eren.doe.gov/csp.**

For more information on renewable energy or for additional copies of this brochure, contact the Energy Efficiency and Renewable Energy Clearinghouse (EREC): **1-800-DOE-EREC (363-3732).**

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