Parabolic Trough Power Plant System Technology

A parabolic trough solar power plant uses a large field of collectors to supply thermal energy to a conventional power plant. Because they use conventional power cycles, parabolic trough power plants can be hybridized—other fuels can be used to back up the solar power. Like all power cycles, trough power plants also need a cooling system to transfer waste heat to the environment.

Parabolic trough power plant technologies include:

- Direct steam generation
- Fossil-fired (hybrid) backup
- Operation and maintenance
- Power cycles
  - Steam Rankine
  - Organic Rankine
  - Combined
- Wet and dry cooling

Power Cycles

There are a number of different power cycles that can be used for parabolic trough power plants. And there are a number of options for how to integrate solar energy into the power cycle.

The SEGS IV parabolic trough power plant in Kramer Junction, California.
Credit: Sandia National Laboratories

Steam Rankine Cycle

All of the SEGS (solar electric generating system) plants and most new projects are planning to use steam Rankine power cycles. These power plants have power cycles very similar to those used for many coal, nuclear, or natural gas-fired steam power plants.

The 80-MWe SEGS plants use a regenerative reheat steam turbine cycle that has a gross steam cycle efficiency approaching 38% with high-pressure steam conditions of 100bar, and 370°C. The power cycle uses a solar steam generator in place of the conventional boiler fired by natural gas, coal, or waste heat from nuclear fission. Otherwise the power cycle is very similar with the following components:

- A surface condenser
- Multiple low-pressure and high-pressure feedwater heaters
- Deaerator
- Wet cooling towers.

Solar energy is used to generate the high-pressure steam and als
(or thermal energy storage system) supplies the hot, heat transfe
heat transfer fluid passes through a series of shell-in-tube heat ex
pressure steam that runs the Rankine steam turbine. The cold hea
solar field (or thermal energy storage system).

For standard overhaul, workers remove a 30-MWe steam turbine from the SEGS V power plant in Kramer Junction, California.

Organic Rankine Cycle

The organic Rankine cycles (ORCs) use an organic fluid—such as butane or pentane—instead of water like a steam Rankine cycle.

Organic Rankine cycles are also typically much simpler in design. They are often used for applications with a lower resource temperature, such as for geothermal power plants. Also, many organic Rankine cycles operate at lower pressures, which reduces the capital cost of components.

This single-stage, 5-MWe organic Rankine cycle turbine operated on butane at the Mammoth Hot Springs geothermal power plant in California.

For small power plants—ranging in size from 100 kWe to 10 MWe—the organic Rankine cycle has some advantages. One advantage is that many of the working fluids in organic Rankine cycle systems can be condensed at or above atmospheric pressures. This eliminates the need for maintaining a vacuum in the condenser.

For more information, see our publications on parabolic trough organic Rankine cycles.

Combined-Cycle Systems

It's possible to integrate solar steam into the Rankine bottoming cycle of a combined-cycle parabolic trough power plant. This type of plant is called an integrated solar combined cycle system (ISCCS).

A combined-cycle system uses solar heat for steam generation and gas turbine waste heat for preheating/superheating the steam. It can approximately double steam turbine capacity. However, when solar energy isn't available, the steam turbine must run at part load, which reduces efficiency.

Adding thermal energy storage could help double the solar contribution. And the cost for increasing steam turbine size for a combined-cycle power plant is substantially lower than the cost of a stand-alone Rankine cycle power plant.

Several new projects using an integrated solar combined cycle system are under development.

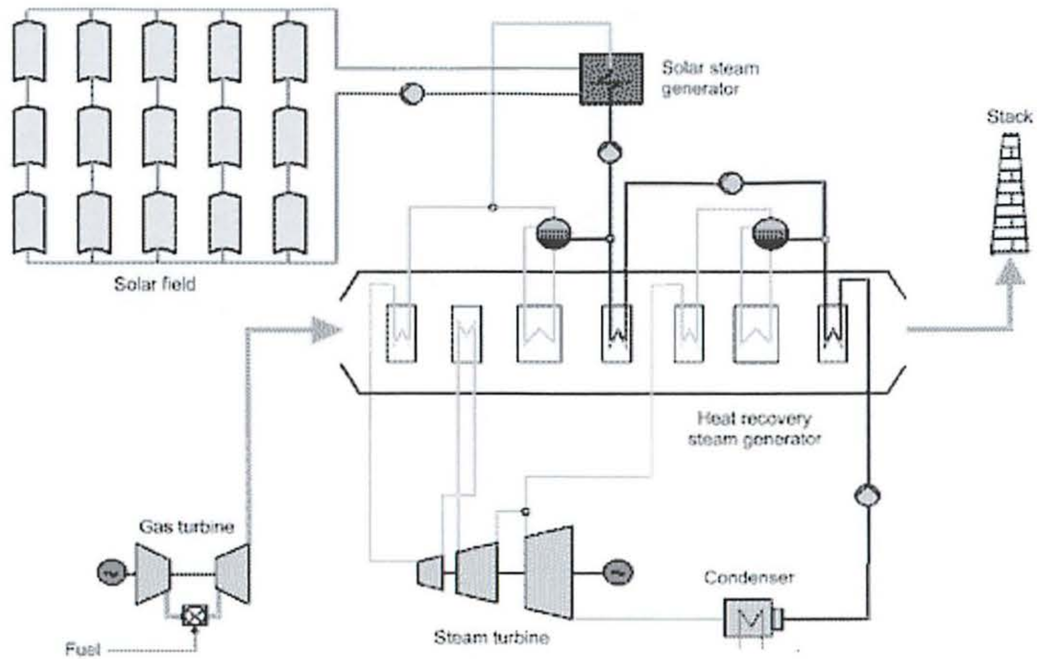

Figure 1. ISCCS process flow schematic. *Credit: FlagSol*

For more information, see our publications on integrated solar combined cycle systems.

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Fossil-Fired (Hybrid) Backup

Because parabolic trough power plants use conventional power cycle technologies, fossil-fired boilers or heaters usually can be integrated to enable power plant operation at full-rated output during periods of low solar radiation, such as overcast days and at night.

Most existing parabolic trough power plants have hybrid backup capability. They can operate using 100% solar input, 100% natural gas input, or any combination in between. Typically the fossil backup efficiency is much lower than for a modern combined-cycle power plant. So the fossil fuel is typically only used for backup during the utility's peak demand periods.

Although the SEGS (solar electric generating system) plants initially operated 25% of the time on fossil fuel, currently they only produce a few percent of their annual output from natural gas.

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Direct Steam Generation

Another option under consideration for future parabolic trough plants is the possibility of generating steam directly in the solar field. This eliminates the need for an intermediate heat transfer fluid and steam-generation heat exchangers. It also should allow the solar field to operate at higher temperatures, resulting in higher power cycle efficiencies and lower fluid pumping parasitics.

Ceimat and DLR (German Aerospace Center) are currently testing direct steam generation (DSG) at the Plataforma Solar de Almeria in Spain. They must address a number of technical issues. But direct steam generation is still one of the most promising opportunities for future cost reductions.

For more information, see our publications on parabolic trough direct steam generation.

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Wet and Dry Cooling

Historically, parabolic trough power plants have used wet cooling towers. But now they can be designed to use dry cooling technology for reducing water consumption. Utilization of dry cooling usually only requires a modest increase in electricity cost.

The SEGS (solar electric generating system) plants use approximately 800-1000 gallons of water per MWh generated. With wet cooling, the cooling tower represents approximately 90% of a Rankine parabolic trough power plant's raw water consumption. The other 10% of water consumption includes the steam cycle makeup cycle (8%) and mirror washing (2%).

For more information, see our publications on parabolic trough power plant wet, dry, and hybrid cooling.

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Operation and Maintenance

The operation and maintenance (O&M) of a parabolic trough power plant is very similar to conventional steam power plants that cycle on a daily basis.

Parabolic trough power plants typically require the same staffing and labor skills to operate and maintain them 24-hours per day. However, they require additional O&M requirements to maintain the solar fields.

Initial plants required a substantial number of mechanics, welders, and electricians to maintain immature solar technology. Modern parabolic trough solar technology is much more robust and requires minimal preventive or corrective maintenance. The one exception is mirror washing.

The high-pressure demineralized water

Experience has shown that solar field mirrors must be washed frequently during the summer. But the increase in solar output pays for the cost of labor and water. Current power plants may wash mirrors weekly during the peak solar times of the year. It's usually only necessary every few months during the winter.

system—called Mr. Twister—has sprayers that spin as they move down when washing the mirrors.

For more information, see our publications on parabolic trough power plant operation and maintenance.

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Content Last Updated: April 10, 2007

2006 Parabolic Trough Technology Workshop

The Parabolic Trough Technology Workshop was held on February 14-1 Nevada. It had three goals:

- Exchanging technical information
- Collaborating on SolarPaces projects: receiver testing and dry co
- Gathering industry input on laboratory R&D directions.

The workshop featured presentations on the following topics:

- Power plant project developments
- Receiver testing
- Concentrator testing
- Thermal energy storage
- Wet and dry cooling
- Power plant design

The following documents are available as Adobe Acrobat PDFs. Downlo

Attendee List: (PDF 31 KB)

Parabolic Trough Power Plant Project Developments

ENEA Activities on CSP (Concentrating Solar Power) Technologi
Presentation Posted with Permission: (PDF 1.8 MB)
Presenter/Author: Maccari, A. (ENEA GmbH)

APS 1-MWe & Solargenix 64-MWe Nevada Solar One Project Sta
Presentation Posted with Permission: (PDF 827 KB)
Author: Gee, R. (Solargenix)
Presenter: Price, H. (NREL)

Need for Regulatory Revisions to Successfully Secure, CSP (Con Projects in the US: Lessons from Spain
Presentation Posted with Permission: (PDF 2.8 MB)
Presenter/Author: Aringhoff, R. (Solar Millennium)

Western Governors' Association, Clean and Diversified Energy I Report
Presentation Posted with Permission: (PDF 309 KB)
Presenter: Kearney, D. (Kearney & Associates)

Status and Strategic Next Steps of Global Market Initiative for C Power)

Presentation Posted with Permission: (PDF 1.2 MB)
Presenter/Author: Aringhoff, R. (Solar Millennium)

SEIA (Solar Energy Industry Association) — R&D Committee
Presentation Posted with Permission: (PDF 164 KB)
Presenter/Author: Marker, A. (Schott Research and Development)

Also see our publications on parabolic trough technology research and (

Parabolic Trough Receiver Testing

Parabolic Trough Receiver Testing, Thermal Loss Tests
Presentation Posted with Permission: (PDF 722 KB)
Presenter: Lüpfert, E. (German Aerospace Center DLR)

Hydrogen Problem
Presentation Not Posted
Presenter/Author: Benz, N. (Schott Solar Thermal Business Unit)

Parabolic Trough Receiver Infrared Camera Field Test Results
U.S. Department of Energy Presentation: (PDF 553 KB)
Presenter/Author: Price, H. (NREL)

Trough Receiver Heat Loss Testing
NREL Presentation: (PDF 645 KB)
Presenter/Author: Lewandowski, A.
Other Authors: Feik, C.; Hansen, R.; Phillips, S.; Bingham, C.; Netter, :
Meglan, B.; Wolfrum, E.

Also see our publications and resources on parabolic trough receivers.

Parabolic Trough Concentrator Testing

Parabolic Trough Optical Performance Analysis Techniques
Presentation Posted with Permission: (PDF 2.0 MB)
Presenter/Author: Lüpfert, E. (German Aerospace Center DLR)

Parabolic Trough VSHOT Optical Characterization in 2005-2006
U.S. Department of Energy Presentation: (PUBS PROCESS)
Author: Wendelin, T. (NREL)
Presenter: Lewandowski, A. (NREL)

Practical Field Alignment of Parabolic Trough Concentrators
Presentation Posted with Permission: (PDF 995 KB)
Author: Diver, R. (Sandia National Laboratories)
Presenter/Author: Brosseau, D. (Sandia National Laboratories)

Also see our publications and resources on parabolic trough concentrat(

Parabolic Trough Thermal Energy Storage

Assessment of Thermal Energy Storage for Parabolic Trough Sol

Presentation Posted with Permission: (PDF 209 KB)
Presenter/Author: Kearney, D. (Kearney & Associates)

Thermal Storage Concept for a 50 MW Trough Power Plant in Sp
Presentation Posted with Permission: (PDF 1.5 MB)
Presenter/Author: Nava, P. (FlagSol GmbH)

Inorganic Molten Salt Thermal Storage R&D
U.S. Department of Energy Presentation: (PDF 332 KB)
Presenter/Author: Brosseau, D. (Sandia National Laboratories)

APS 1-MWe Parabolic Trough Thermocline Storage Design and M
U.S. Department of Energy Presentation: (PDF 519 KB)
Presenter/Author: Brosseau, D. (Sandia National Laboratories)

TRNSYS Modeling of 1 MWe Saguaro Plant
Presentation Posted with Permission: (PDF 267 KB)
Presenter/Author: Kolb, G. (Sandia National Laboratories)

Proposed Bench-Scale Tests to Investigate Recovery from Salt F Fields
Presentation Posted with Permission: Sandia National Laboratories (PDF
Presenter/Author: Kolb, G. (Sandia National Laboratories)

ENEA Activities on CSP (Concentrating Solar Power) Technologi
Presentation Posted with Permission: (PDF 1.8 MB)
Presenter/Author: Maccari, A. (ENEA GmbH)

Concrete and Phase-Change TES (Thermal Energy Storage)
Presentation Posted with Permission: (PDF 2.1 MB)
Presenter/Author: Tamme, R. (German Aerospace Center DLR)

Also see our publications on parabolic trough thermal energy storage.

Parabolic Trough Power Plant — Dry and Wet Cooling

Cooling for Parabolic Trough Power Plants: Overview
U.S. Department of Energy Presentation: (PDF 272 KB)
Presenter/Author: Price, H. (NREL)

Heat Rejection for Trough Rankine Cycles
Presentation Posted with Permission: (PDF 51 KB)
Presenter/Author: Kelly, B. (Nexant Inc.)

Hybrid Wet/Dry Cooling for Power Plants
NREL Presentation: (PDF 1.1 MB)
Presenter/Author: Kutscher, C.

Also see our publications available on dry, wet and hybrid cooling.

Parabolic Trough Power Plant Design

Large Plant Studies

Presentation Posted with Permission: (PDF 959 KB)
Presenter/Author: Kelly, B. (Nexant Inc.)

Also see our publications on parabolic trough power plant systems.

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factories. Some 45,000 people commute there every day, many from south-central Los Angeles. Plans are afoot to add a server farm and a bleach factory. Local officials are delighted with the two new prospects for the same reason that most cities would frown on them: they will use enormous amounts of electricity.

Vernon is part of a patchwork of small cities in the metropolis that remain independent because Los Angeles lacks the power to swallow them. Three others are also dedicated to industry, though not with the same single-mindedness. Far from fighting a losing battle, they are a large part of the reason southern California has remained a centre of industry. Despite its glitzy image, metropolitan Los Angeles sustains more manufacturing jobs than the entire state of Michigan.

One reason industry holds on is that doing business in Vernon is cheap. Larry Kosmont, an independent analyst, reckons most heavy industry would be better off there than elsewhere in Los Angeles, or even in Houston or Las Vegas. Taxes are low, and would be much lower were it not for the state. Vernon has its own gas-fired power station and sells electricity for about 20% less than elsewhere in the area. Power is a big source of profits, which is why the city is keen to lure energy-hungry firms. It wants to start building a big new power station later this year.

What most strikes business owners is the efficiency of the place. Ben Swett of Windowbox.com, a gardening-supply company, says Vernon's bureaucrats spend just days, or even hours, on a permit application that would take months in the city of Los Angeles. Vernon's health and fire inspectors, though finicky, are a small team, which means businesses routinely deal with the same people. The police force keeps crime, and thus insurance rates, to a minimum. Brett Willberg, who runs an ice factory, says he has never bothered to fix the electric gate in front of his operation, which does not close.

Vernon caters so diligently to the needs of businesses because it does not have to balance their demands with those of residents. Only about 90 people live in Vernon, many of them cops and fire-fighters. Most rent their homes from the city for a pittance—a one-bedroom flat costs $147 per month. They are the city's electorate and, in theory, the pool from which mayors and local politicians are drawn.

It does not sound like a recipe for a functioning democracy, because it isn't. The mayor has held power for 34 years. Contested elections are almost unknown. The last was in 2006, when three outsiders moved into a house just before the deadline and petitioned to stand for city offices. Their electricity was abruptly cut off and their home declared unfit for habitation. The outsiders got ten votes out of 68 cast. That was a surprise: they had expected just eight. Bill Schneider of the Chamber of Commerce says the shenanigans during the election worried him—because of the risk that another regime might take over. "What outsiders miss is that the damn place works well," says Lonnie Kane, who runs a clothing firm with his wife, Karen.

Most of Vernon's companies find it useful to be so close to the centre of Los Angeles. The rendering plants pick up cooking fat from local fast-food joints and meat from supermarkets. Mr Willberg keeps costs down by being close to the delis and liquor shops that are big users of ice. Eric Bender, who is about to submit plans for the server farm, will not have to lay much fibre-optic cable. Mr Kane's clothing firm needs to be near designers.

Many cities used to have places like Vernon. Think of Manchester's warehouses or Manhattan's meat-packing district, now converted into clubs and trendy lofts. This is a shame. Smelly, noisy businesses sustain a wider range of jobs than the cafés and cultural centres that most cities try so hard to lure. And all the businesses that exist in Vernon have to exist somewhere. None of which, admittedly, is much comfort when the wind changes. ■

Solar energy

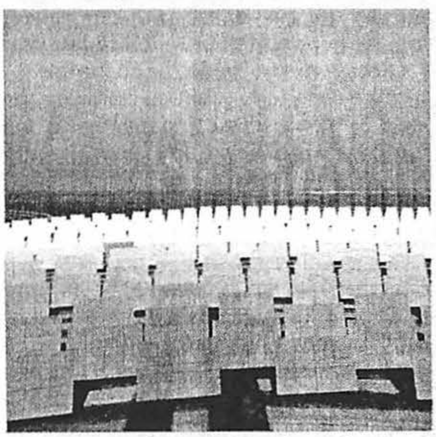
The power of concentration

A new type of power plant harnesses the sun—and taxpayers

ON FEBRUARY 22nd, at an event featuring film stars, astronauts and technology gurus, Acciona, a Spanish conglomerate, is due to inaugurate a new power plant a few miles from Las Vegas. In fact, the plant has been running since last June. But the technology it uses, known as "concentrating solar power" (CSP), is hot right now, as the Hollywood luminaries might put it.

Acciona's new plant, called "Nevada Solar One", can generate up to 64 megawatts (MW)—enough, it says, to power more than 14,000 homes. The Solar Energy Industries Association (SEIA) says that more CSP plants, with a total capacity of 4,000MW, are in the pipeline and have signed contracts to sell their future output. An 11MW plant opened in Spain last year (pictured). New Energy Finance, a research firm, estimates that 2,000MW of capacity is in the works in Europe.

As their name suggests, CSP plants generate electricity by concentrating the sun's rays, usually to boil water. The resulting steam drives turbines similar to those found at power plants that run on coal or natural gas. There are several different designs. The Nevada plant uses long curved mirrors, called parabolic troughs, to focus light on a tube of fluid running just above them. The Spanish plant uses a forest of smaller mirrors to focus light on a tower in their midst. Other concepts involve long flat mirrors and devices resembling satellite dishes.



Solar power, but not as we know it

Solar power, of course, does not produce climate-changing greenhouse gases. But it also excites utilities because it generates the most power just when it is needed: on hot, sunny days when people turn on air conditioners. And CSP provides a way around the main drawbacks of solar power from photovoltaic cells. Unlike them, it does not involve expensive silicon wafers. And some designs provide power round the clock, not just when the sun is shining, by storing energy in the form of molten salt.

Even so, CSP is still not as cheap as coal- or gas-fired plants. America's CSP boom is driven by state laws requiring utilities to generate a certain share of their power from renewable sources, and by generous federal tax breaks, which offset as much as 45% of development costs, according to SEIA. In Spain, meanwhile, utilities must pay an extra €0.25 ($0.37) per kilowatt-hour on top of the market price for power from CSP.

America's tax breaks are due to run out at the end of the year, and without them, says Rhone Resch of SEIA, no more CSP plants will be built there. But in the long run, he argues, costs should come down. And if fossil-fuel prices continue to increase and American powerplants have to start paying for their greenhouse-gas emissions, CSP might just achieve "grid parity" with the wholesale power price. That really would be an excuse for a party.

number of people affected was particularly large—at least double the total employed by the more visible brand-name carmakers. Among the commitments made by China in 2001 when it joined the WTO was an agreement to open up to foreign suppliers. But in 2006 it increased the tariff on car parts from 10% to 25% (the same as the rate charged on imported foreign-made vehicles) if the parts comprised more than 60% of the finished car's value.

This made it much harder for foreign firms to compete with China's own low-cost suppliers. Imports have since grown at only a fraction of the rate of the domestic industry, and many foreign partsmakers have responded by setting up shop in China. But this means job losses back home, and is bitterly resented in America, Canada and parts of Europe.

Whether the WTO decision will provide much relief is questionable. An appeal seems inevitable. Meanwhile the Chinese industry is growing, and big foreign suppliers feel that they need to establish their own operations in China now in order to remain competitive, rather than wait for a political settlement. The tariffs are expected to go in a few years anyway, once China's carmakers start building fancier vehicles that need sophisticated foreign technology, says Rodger Baker of Stratfor.com, a research firm.

The decision will still resonate, however. Within China, it may mean that the bureaucrats in charge of implementing WTO commitments will find it easier to get things done. The WTO decision also draws attention to China's increasingly fractious trade relationships, which are the source of a growing number of anti-dumping actions, including one targeting car tyres, which was filed on February 8th. Most importantly, it shows China's potential vulnerability before the WTO. "Victory in this case will whet the appetite of foreign competitors and their governments to bring more," says Lester Ross, a lawyer at WilmerHale, based in Beijing.

That is because the Chinese government has not just intervened on behalf of partsmakers. It has erected barriers to protect many other industries, for example by imposing elaborate registration and certification requirements for imported food, cosmetics, chemicals and pharmaceuticals. These do not apply to local firms, which is just the kind of preferential treatment that could fall foul of WTO rules.

China was eager to join the WTO on the basis that membership of a large, multilateral organisation would enhance its ability to compete with other big countries. But its odd, state-dominated economy makes it particularly sensitive to verdicts of this kind. This month's result may not help the car-parts firms in America, Canada and Europe, but it is good news for foreign firms in other protected industries. ■

Wal-Mart

Always low prices

NEW YORK

As the American economy turns down, Wal-Mart is looking up

"WE know the economy will be a critical factor this year," said Lee Scott, the boss of Wal-Mart, as the world's biggest retailer released its quarterly results on February 19th. Wal-Mart's prospects do indeed reflect those of the economy at large—but not in the way you might expect. With America tipping towards recession, Wal-Mart is doing much better than in the past couple of years when the economy was booming. Sales increased by 8.3% compared with the same period last year, to a record $106.3 billion. Mr Scott concluded that in a volatile economy Wal-Mart was "well positioned to succeed".

The secret of Wal-Mart's meteoric rise over the past five decades has been its obsession with low prices. It got into trouble in 2005-07 when it focused less on "always low prices" (its longstanding motto) and more on expansion. Sales growth, productivity and profits fell, while Target and other upmarket rivals snatched market share. Wal-Mart, the biggest private employer, became a favourite public whipping boy because of its health-care, gender and labour policies. In February last year Mr Scott's job was said to be on the line.

"We used to be quite negative on the stock, because the company threw too much money at new stores," says Gregory Melich, a retail analyst at Morgan Stanley, an investment bank. Wal-Mart has over 7,100 stores worldwide and more than 4,000 in America. Last summer Mr Melich upgraded his verdict on Wal-Mart, because he saw a "big strategic shift": it reduced its capital expenditure to $14 billion for the fiscal year, from $18 billion the year before, slowing its expansion to spruce up existing shops instead. It opened far fewer new shops in January than in previous years.

The economic downturn is another boost for the recovery of the Bentonville behemoth, as cost-conscious consumers defect (or return) to the cheapest of the big retailers. Prices for oil and many foods are at record highs, but Wal-Mart can pass some inflation on to shoppers without losing its low-price leadership. And it is in the right line of business in hard times. Its biggest strength is grocery sales, which are not slowing down, and are unlikely to, since they are essential purchases.

Other retailers are in a far harder spot. Home Depot, America's number two retailer, is in its sixth quarter of falling sales. The home-improvement market has been badly hit by the subprime-mortgage meltdown. Fashion retailers are in trouble, since most people think they can put off buying clothes. Ann Taylor, a fashion retailer, says it will close 117 of its 921 stores over the next three years.

Even so, analysts predict that overall, retailing will escape a recession this year. They forecast 3% growth (excluding cars and petrol) compared with 4% last year. Retailers with international reach gain from the weak dollar. Wal-Mart's operations abroad, which represent one-quarter of sales, grew by 18.8% in the past three months. The American government's fiscal-stimulus package of up to $168 billion will give retailers an extra $15 billion or so, and Wal-Mart is likely to get the lion's share. In tune with the times, the firm with always low prices changed its slogan last year to a new variation on the theme: "Save money. Live better." ■

Business in America

Where there's muck

VERNON, CALIFORNIA

The city of Vernon highlights the tenacity of manufacturing in California

YOU can usually tell which way the wind is blowing in Vernon. One smell emanates from Farmer John's, a large slaughterhouse and meat-packing plant. Another more acrid one comes from Baker Commodities, where cooking fat and animal carcasses are rendered. Such enterprises seem increasingly out of place just across Interstate 10 from downtown Los Angeles, with its ever-multiplying luxury flats. But Jim Andreoli, who runs the rendering plant, has no plans to move. "There is nowhere else for us to go," he says.

For the past 102 years Vernon has fought what its administrator, Eric Plesch, wryly calls a "losing battle" for industry in the old-fashioned sense of the word. Just five square miles (13 square kilometres) in size, the city is packed with metal-stampers, plastic-moulders and sausage ▸▸

Advanced Heat Transfer and Thermal Storage Fluids

Dan Blake, Luc Moens, Dan Rudnicki, Mary Jane Hale,
Professor Ramana Reddy,
and Greg Glatzmaier

not downloaded

nrel.gov/csp/troughnet/pdfs

Goals and Objectives

- The goal is to find a heat transfer and thermal storage fluid with a usable liquid range from near 0 to above 400 °C that will meet the cost and performance requirements of parabolic trough systems.
- The near term objective (FY03) is to identify a fluid with the potential for service up to 300 °C.

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What are Parabolic Trough Collectors?

The parabolic trough is the most advanced of the concentrator systems. This technology is used in the largest grid connected solar-thermal power plants in the world. One such complex in the U.S. uses parabolic troughs. The Kramer Junction companies operate and maintain five 30-megawatt Solar Electric Generating Systems (SEGS). These SEGS comprise 150 to 354 megawatts of installed parabolic trough solar thermal electric generating capacity located in California's Mojave desert. The combined California facilities produce more than 99% of the commercially available solar generated electric power in the U.S.

A parabolic trough collector has a linear parabolic-shaped reflector that focuses the sun's radiation on a linear receiver located at the focus of the parabola. The collector tracks the sun along one axis from east to west during the day to ensure that the sun is continuously focused on the receiver. Because of its parabolic shape, a trough can focus the sun at 30 to 100 times its normal intensity (concentration ratio) on a receiver pipe located along the focal line of the trough, achieving operating temperatures over 400 degrees Celcius.

A collector field consists of a large field of single-axis tracking parabolic trough collectors. The solar field is modular in nature and is composed of many parallel rows of solar collectors aligned on a north-south horizontal axis. A working (heat transfer) fluid is heated as it circulates through the receivers and returns to a series of heat exchangers at a central location where the fluid is used to generate high-pressure superheated steam. The steam is then fed to a conventional steam turbine/generator to produce electricity. After the working fluid passes through the heat exchangers, the cooled fluid is recirculated through the solar field. The plant is usually designed to operate at full rated power using solar energy alone, given sufficient solar energy. However, all plants are hybrid solar/fossil plants that have a fossil-fired capability that can be used to supplement the solar output during periods of low solar energy. The Luz plant is a natural gas hybrid.

What are Flat Plate Collectors?

Flat Plate Collectors are the most common type of solar water heating systems for residential and commercial applications. Flat plate collectors are similar to a car's radiator, except that instead of moving heat away from a car's engine, through the airstream of the car's radiator, a flat plate collector collects the solar energy of the sun and transfers it to the home. A flat plate collector is made up of one or more dark metal plates, that are covered with a sheet of glass, which absorbs the solar energy of the sun and converts that solar energy into heat, in the form of hot water. The solar heat can be transferred either air or water (or other fluids in more sophisticated flat plate collector systems). Flat plate collector systems are used comfort heating of a home or commercial building in the winter and for domestic hot water production throughout the year. Flat plate collectors usually heat water to temperatures ranging from 150° to 200° F (66° to 93° C). The efficiency of flat plate collectors varies from manufacturer to manufacturer, and system to system, but usually ranges from as low as 20% to as high as 80%.

What is Direct Solar Steam?

Direct Solar Steam is also referred to as "Direct Steam Generation." For a number of years it has been proposed that parabolic-trough systems will benefit in both performance and cost from generation of steam directly in the solar field, eliminating the expensive heat transfer fluid, the thermodynamic disadvantages of an intermediate heat transport system between the solar field and power block, and the HTF-to-steam heat exchangers. Although there are both pros and cons to this approach, it has generally been viewed positively by LUZ and the current trough development community. An important prototype development is currently under way at several location with one to two rows of collectors. Because some flow-instability studies

INDUSTRIAL SOLAR TECHNOLOGY U.S. TROUGH PROGRAM

Putting the Sun to Work

Development and Testing of the Focal Point Power Trough (FPPT): An Advanced Parabolic Trough Concentrator

ASES Solar2006
July 12, 2006

NREL Contract RCX-4-44440
"USA Trough: Near-Term Component/Subsystem Development"

Industrial Solar Technology Corporation

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Serious Megawatts

India Building Large-Scale Solar Thermal Capacit

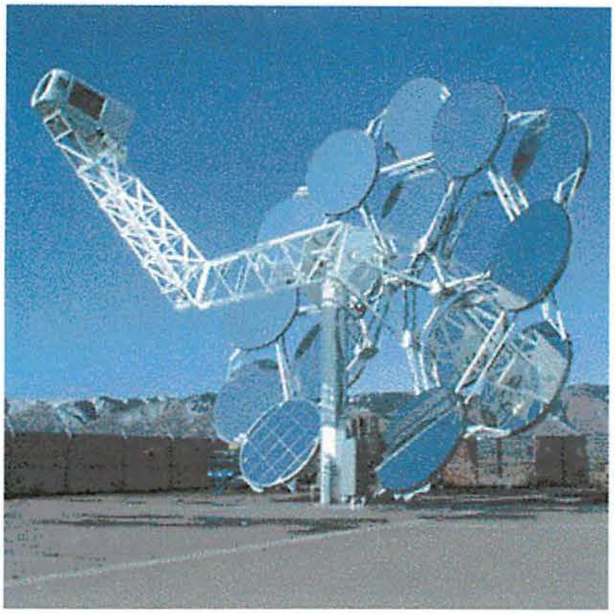
By Gordon Feller
October 2, 2002
Rajastan, India

**Parabolic Trough A
Brighton, Colorado,
photo: US D.O.I**

Editor's Note: Just as on a small scale, hybrid engines stretch a gallon of gas, in the same manner a hybrid power plant can stretch its own supply of fossil fuel. In India, a huge new power station using hybrid systems is close to completing their financing and breaking ground in the sunny state of Rajasthan. This fossil fuel / solar hybrid will produce a whopping 140 megawatts of electric power, and 40 of those megawatts will be produced from a field of solar thermal parabolic troughs. Not as glamorous as photovoltaics, but still much more cost-effective, parabolic systems use mirrors to focus sunlight that i a thermal media (gas, steam) to drive a turbine generator. The project de below is projected to go in at about US $1 million per megawatt, which is with conventional fuels. Read on...

India's power sector has a total installed capacity of app 102,000 MW of which 60% is coal-based, 25% hydro, ar balance gas and nuclear-based. Power shortages are est about 11% of total energy and 15% of peak capacity rec and are likely to increase in the coming years. In the next 10 years, anotl MW of capacity is required. The bulk of capacity additions involve coal the supplemented by hydroelectric plant development. Coal-based power invc environmental concerns relating to emissions of suspended particulate mɛ sulfur dioxide (SO2), nitrous oxide, carbon dioxide, methane and other gɛ other hand, large hydroplants can lead to soil degradation and erosion, lo wildlife habitat and species diversity and most importantly, the displacem people. To promote environmentally sound energy investments as well as mitigate the acute shortfall in power supply, the Government of India is p

C at the receiver, and achieve the highest efficiencies for converting solar energy to electricity in the small-power capacity range.



Parabolic dish collector with a mirror-like reflectors and an absorber at the focal point
[Courtesy of SunLabs - Department of Energy]

Parabolic trough system

Parabolic troughs are devices that are shaped like the letter "u". The troughs concentrate sunlight onto a receiver tube that is positioned along the focal line of the trough. Sometimes a transparent glass tube envelops the receiver tube to reduce heat loss.

Parabolic troughs often use single-axis or dual-axis tracking. In rare instances, they may be stationary. Temperatures at the receiver can reach 400 °C and produce steam for generating electricity. In California, multi-megawatt power plants were built using parabolic troughs combined with gas turbines.

Parabolic trough system
[Courtesy of SunLabs - Department of Energy]

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calcination

Solar Tubular Reformer with Molten-Salt Thermal Storage - Design Modification of the Reactor Tube and Testing

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2006

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National Renewable Energy Laboratory

Innovation for Our Energy Future

A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

Concentrating Solar Deployment System (CSDS)
A New Model for Estimating U.S. Concentrating Solar Power Market Penetration

Nate Blair, Walter Short, Mark Mehos, Donna Heimiller

National Renewable Energy Laboratory

NREL is operated by Midwest Research Institute . Battelle

CSDS Model
(Concentrating **S**olar **D**eployment **S**ystem**)**

A multi-regional, multi-time-period model of capacity expansion in the electric sector of the U.S. focused on renewables.

Designed to estimate market potential of solar energy in the U.S. for the next 20 – 50 years under different technology development and policy scenarios

Concentrating Solar Deployment Systems (CSDS) – A New Model for Estimating U.S. Concentrating Solar Power Market Potential

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CSDS (based on WinDS) is a computer model of expansion of generation and transmission capacity in the U.S. electric sector spanning the next 50 years. It minimizes system-wide costs of meeting loads, reserve requirements, and emission constraints by building and operating new generators and transmission in each of 26 two-year periods from 2000 to 2050. The CSDS model is focused on addressing the market issues of greatest significance to renewables – specifically issues of transmission and resource variability.

CSDS attempts to examine these issues primarily by using a much higher level of geographic disaggregation than other models. Other models (such as the NEMS model used by the U.S. Energy Information Agency) have only a few regions in the US (13 in the case of NEMS). These models have to make assumptions about the cost of transmission and resource variability on the electric grid. With a high level of geographic disaggregation, CSDS can model these distance effects directly within the model instead of making assumptions. CSDS uses 358 different regions in the entire United States. Much of the data inputs to CSDS are tied to these regions and derived from a detailed GIS model/database of the renewable resources, transmission grid, and existing plant data. The geographic disaggregation of solar resources allows CSDS to calculate transmission distances and the benefits of dispersed solar plants supplying power to a demand region.

In the United States, the viable solar resource areas are located primarily within the southwestern states. Therefore, in the model, only regions within the southwest are allowed to build CSP plant. Note that the entire country is still modeled and conventional generation and other renewables are built as needed outside this region.

Similarly to the models breakdown of wind resource into five classes, the solar resource appropriate for CSP systems has also been broken into five classes that are defined by the annual average direct normal radiation ranging from 6.75 KW/m2/day to 8.06 kW/m2/day. Additionally, there are a variety of exclusions applied to the solar resource areas.

Linear programs, such as WinDS and CSDS, work by minimizing an objective function while subject to constraints. The cost minimization that occurs is subject to over seventy types of constraints including transmission line access, physical resources, load constraints, and emission and policy constraints. The CSDS objective function is a minimization of all the costs of the US electric sector including the present value of the installation cost and anticipated O&M costs of both generation and transmission capacity, fuel costs, emission penalties and many more.

CURRENT CSP SYSTEM ASSUMPTIONS

Ideally, the model would compete solar-only, trough with storage, dishes, solar towers, etc. in an economically optimum portfolio. However, this first stage of development limits the situation to a single technology (parabolic trough Rankine cycle similar to the SEGS plants installed in California) with a pre-selected thermal storage level of six hours. These factors, combined with an assumed scale of 100 MW plant size, determine the initial cost and performance characteristics. The NREL CSP analysis tool, Excelergy[1], is a Microsoft Excel based performance and financing tool for parabolic trough systems with current costs and performance assumptions. The basic plant configuration, operating and financial assumptions and performance by solar class were based on Excelergy.

The storage assumption greatly simplifies the treatment of resource variability and allows an assumption of dispatchability.

BASE CASE ASSUMPTIONS AND RESULTS

In this analysis, the Base Case is a business-as-usual case that relies heavily on the Reference Case scenario of the US Energy Information Agency Annual Energy Outlook for

[1] Price, H. (2003). Parabolic Trough Solar Power Plant Simulation Model: Preprint. 12 pp.; NREL Report No. CP-550-33209.

2005[2] for inputs that fall outside the scope of WinDS. This includes electricity demand, fossil fuel prices, existing federal energy policies, and the cost and performance of non-renewable electric generating technologies.

With these Base Case inputs, CSDS projects that solar power will provide about 55 GW of capacity in 2050, far larger than today's 350 MW (see top slice of graph in Figure 4). Although this growth is largely attributable to improvements in the cost and performance of solar power plants, there are many other drivers.

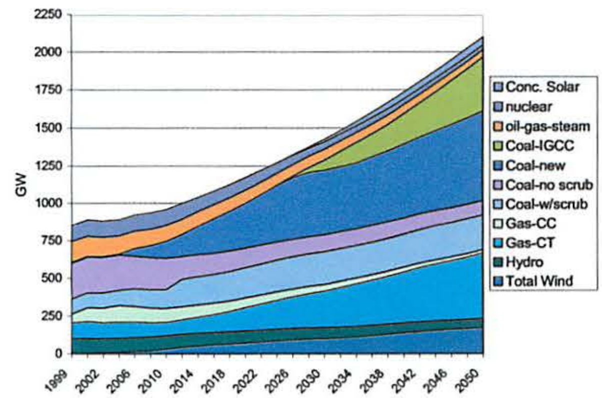

Figure 4: National Capacity for the CSDS Base Case

Another interesting question of deployment, which can be answered by CSDS, is where the future CSP capacity will be located. Based on the GIS inputs to CSDS, transmission, siting issues and load location and load growth, the model selects the economically best sites for each period to add new capacity. Figure 7 shows the location of CSP capacity in 2050. Expectedly, these are locations throughout the southwest with class 5 solar resource as well as locations that are close to large electric load growth (such as in southern California).

Figure 7: Projected CSP Capacity (MW) by region in 2050

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[2] United States DOE, EIA, "Annual Energy Outlook 2005", January 2005, DOE/EIA-0383(2005)

Figure 8 maps where the power produced by the capacity is shipped and used to meet load. Notice that CSP generation is shipped significantly outside of the area in which the capacity is built.

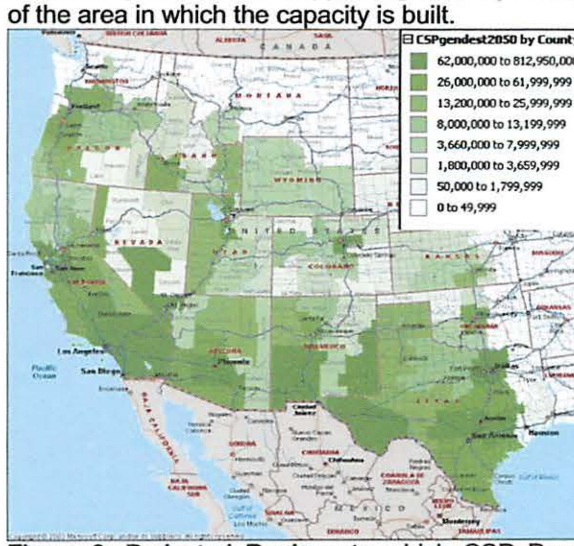


Figure 8: Projected Regions to which CSP Power (MWhr) is shipped.

SENSITIVITY CASES FOR FEDERAL POLICIES

The real power of this model is to examine the impact of various policies on the penetration of CSP into the U.S. electric market. To date, we have examined three federal policies:

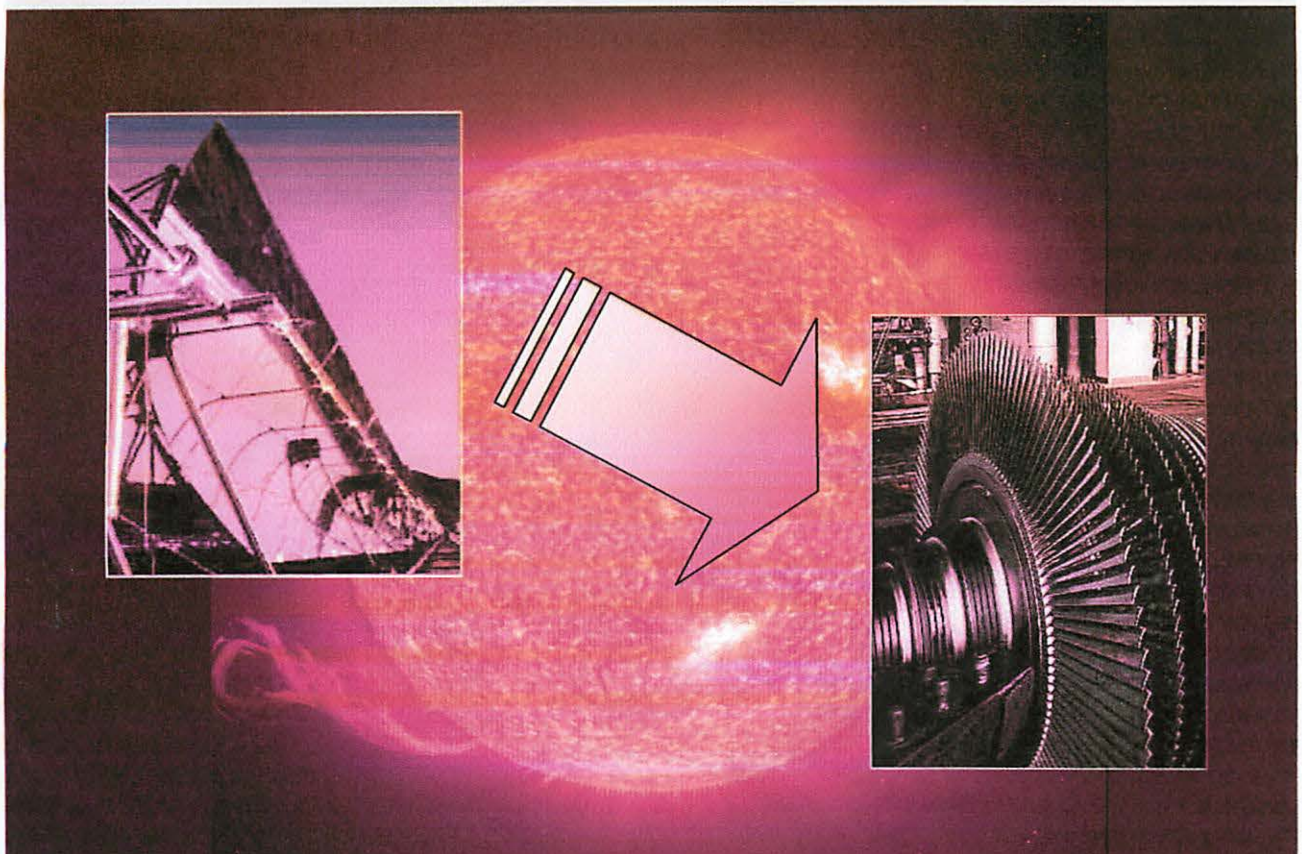
- Continued Federal R&D Spending on CSP
- Extension of the Investment Tax Credit (ITC) to 2012 and 2020
- Extension of the Production Tax Credit (PTC) to 2012 and 2020

The results of these analyses are published elsewhere but demonstrate that a lack of R&D significantly limits penetration, an extension of the 30% ITC significantly enhances near-term penetration and using a wind-like PTC instead of an ITC does not enhance market growth until CSP costs have declined in the future.

CONCLUSIONS

- A tool has been developed to model the future capacity growth of CSP trough systems that incorporates detailed information about resource data, transmission and load.
- CSDS can give an idea of the location of future CSP deployment and CSP generation wheeling.
- CSDS is capable of examining the possibilities of a high-penetration CSP vision.
- This tool can be used to examine a variety of future federal and state policy impacts as well as technology and competitive market impacts.

CONCENTRATING SOLAR POWER NOW



SOLAR ENERGY DRIVES CONVENTIONAL POWER PLANTS

Concentrating solar collectors produce high temperature heat to operate steam and gas turbines, combined cycles or stand alone engines for electricity or for combined heat and power.

DAY AND NIGHT POWER SUPPLY

Thermal storage systems allow for night-time solar power generation. Fuels like oil, gas, coal or biomass can additionally be used to deliver electricity whenever required.

LOW COST SOLAR ELECTRICITY

With costs ranging from 10 to 15 ct/kWh, concentrating solar power still requires support, but co-firing and special schemes of finance yield affordable power already today.

SOLUTIONS FOR POWER AND WATER

Process heat from combined generation can be used for seawater desalination, thus helping to reduce the threat of freshwater scarcity in many arid countries.

LARGE POTENTIAL FOR SUSTAINABLE DEVELOPMENT

The concentrating solar power potential exceeds the world electricity demand by more than 100 times.

The Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

DLR
Deutsches Zentrum für Luft- und Raumfahrt e.V.
German Aerospace Center

Federal Ministry for Economic Cooperation and Development

PRINCIPLES AND POTENTIAL OF CONCENTRATI

HOW CAN THE SUN DRIVE A POWER PLANT?

In a simple way: the solar radiation can be collected by different Concentrating Solar Power (CSP) technologies to provide high temperature heat (bottom right). The solar heat is then used to operate a conventional power cycle, such as a steam or gas turbine, or a Stirling engine.

Solar Power Towers (top left) and Parabolic Trough Power Plants (top centre) as well as Parabolic Dish Engines (top right) are the current CSP technologies. Parabolic trough plants with 354 MW of presently installed capacity have been in commercial operation for many years. Power Towers and Dish Engines have been tested successfully in a series of demonstration projects.

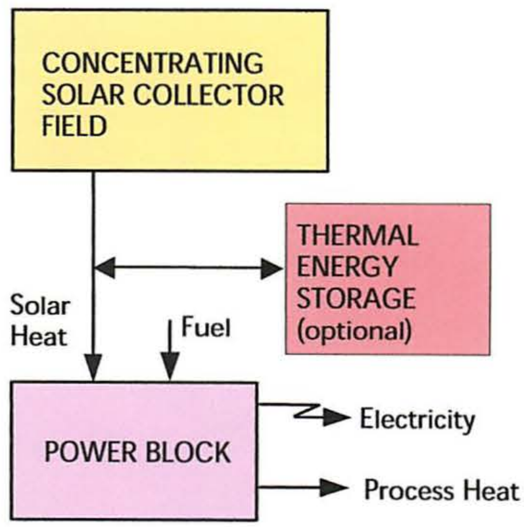
Solar heat collected during daytime can be stored in concrete, molten salt, ceramics or phase-change media. At night, it can be extracted from the storage to run the power block.

Fossil and renewable fuels like oil, gas and biomass can be used for co-firing the plant, thus providing additional power for base or peak load demand.

Combined generation of electricity and heat by CSP is particularly interesting, as the high value solar input energy is used with the best possible efficiency, exceeding 85 %.

Process heat from combined generation can be used for industrial applications, district cooling or sea water desalination.

CSP is one of the best suited technologies to help, in an affordable way, mitigate climate change as well as to reduce the consumption of fossil fuels. Therefore, CSP has a large potential to contribute to the sustainable generation of power.



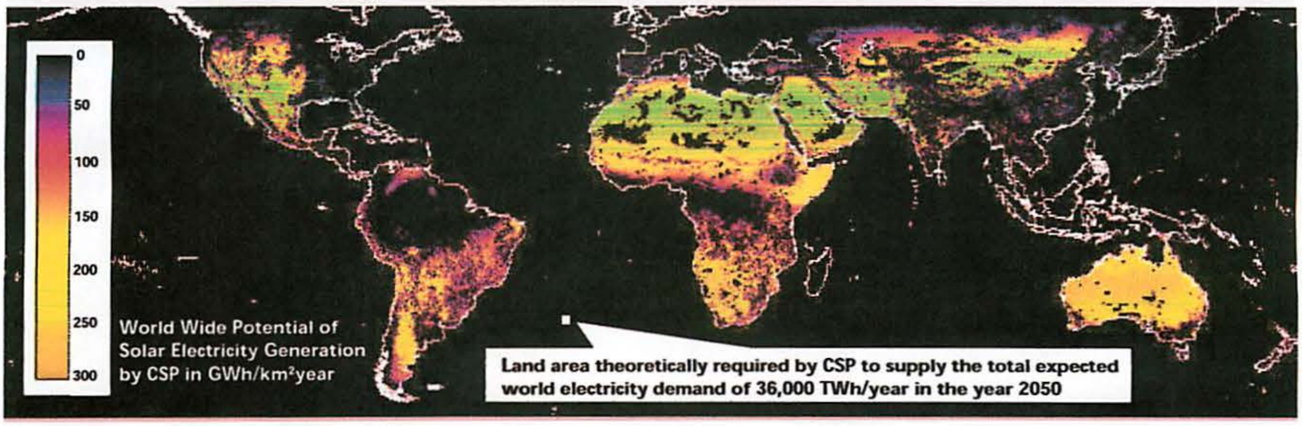
Principle of a concentrating solar power system for electricity generation or for combined heat and power generation

Please note:

Cost data within this brochure is given in Euro or Euro-cents.

Title photograph of the sun is courtesy of SOHO/EIT. SOHO is a project of international cooperation between ESA and NASA.

NG SOLAR POWER

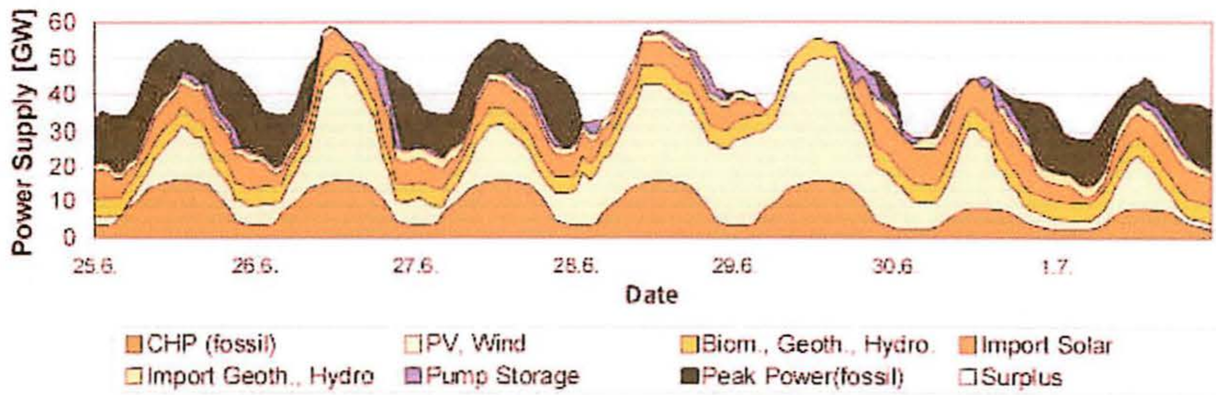


CSP HELPS TO MEET THE IPCC GOALS

In many regions of the world, every square kilometre of land can produce as much as 200-300 GWh/year of solar electricity using CSP technology (top). This is equivalent to the annual production of a conventional coal or gas fired 50 MW power plant or - over the total life cycle of a CSP system - to the energy contained in 16 million barrels of oil. The exploitation of less than 1 % of the total CSP potential would suffice to meet the recommendations of the Intergovernmental Panel on Climate Change (IPCC) for a long-term stabilisation of the climate. At the same time, concentrating solar power will become economically competitive with fossil fuels.

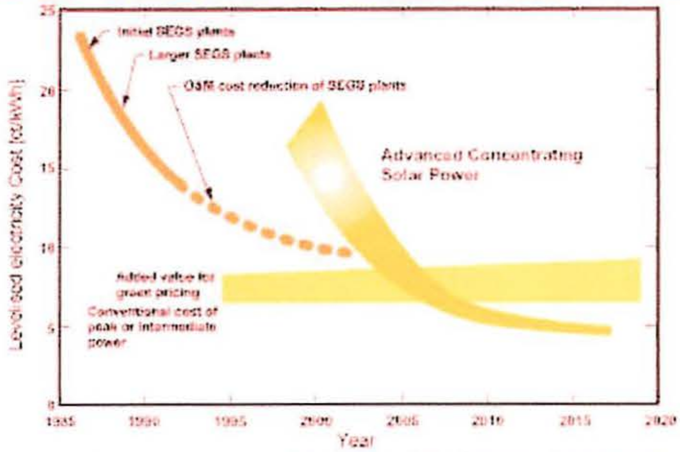
INTERNATIONAL SOLAR ENERGY ALLIANCES

The large solar power potential in the southern countries will only be used to a small extent, if it is restricted by the regional demand and by the local technological and financial resources. But if solar electricity is exported to regions with less solar energy resources, a much greater part of the potential of the sunbelt countries could be harvested for the protection of the global climate. Some countries like Germany already consider the perspective of solar electricity imports from North Africa and Southern Europe as a contribution to the long-term sustainable development of their power sector (bottom).



Time series of load and power generation in Germany in the year 2050 in a scenario assuming environmental and economical sustainability. Import of solar electricity will have the important role of filling the gap between the electricity demand and the supply from national renewable power sources. CHP: combined heat and power.

WHY CONCENTRATING SOLAR POWER ?



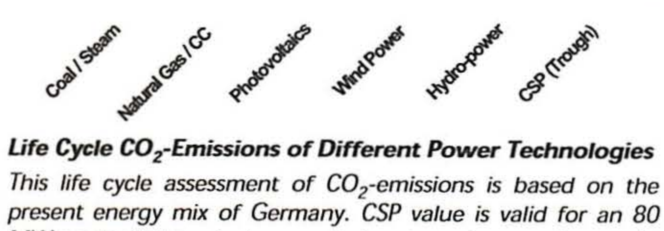
Cost perspectives of CSP until 2020. Source: SolarPaces

ECONOMIC SUSTAINABILITY

The history of the Solar Electricity Generating Systems (SEGS) in California shows impressive cost reductions achieved up to now, with electricity costs ranging today between 10 and 15 ct/kWh. However, most of the learning curve is still ahead (top). Advanced technologies, mass production, economies of scale and improved operation will allow to reduce the solar electricity cost to a competitive level within the next 10 - 15 years. This will reduce the dependency on fossil fuels and thus, the risk of future electricity cost escalation. Hybrid solar-and-fuel plants, at favourable sites, making use of special schemes of finance, can already deliver competitively priced electricity today.

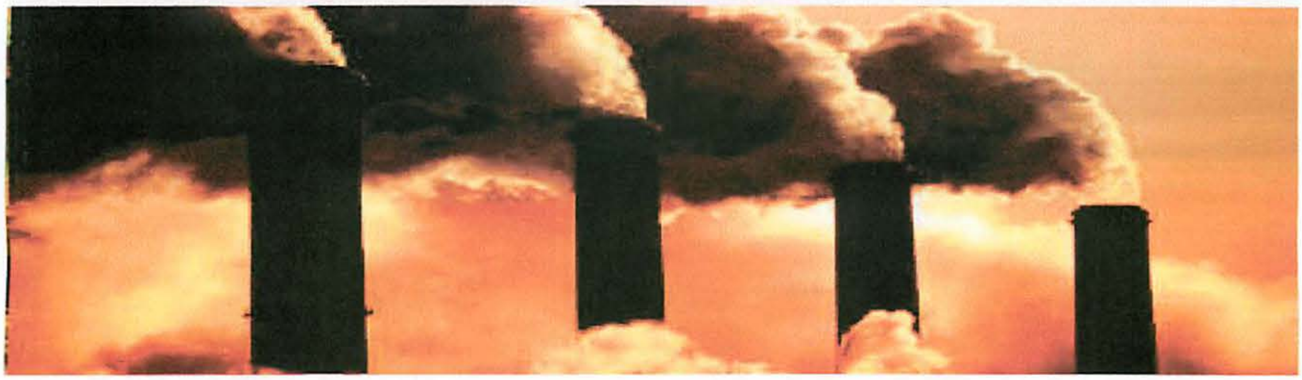
ENVIRONMENTAL SUSTAINABILITY

Life cycle assessment of emissions (bottom) and of land surface impacts of the concentrating solar power systems shows that they are best suited for the reduction of greenhouse gases and other pollutants, without creating other environmental risks or contamination. For example, each square meter of collector surface can avoid 250-400 kg of CO_2-emissions per year. The energy payback time of the concentrating solar power systems is in the order of only 5 months. This compares very favourably with their life span of approximately 25- 30 years. Most of the collector materials can be recycled and used again for further plants.



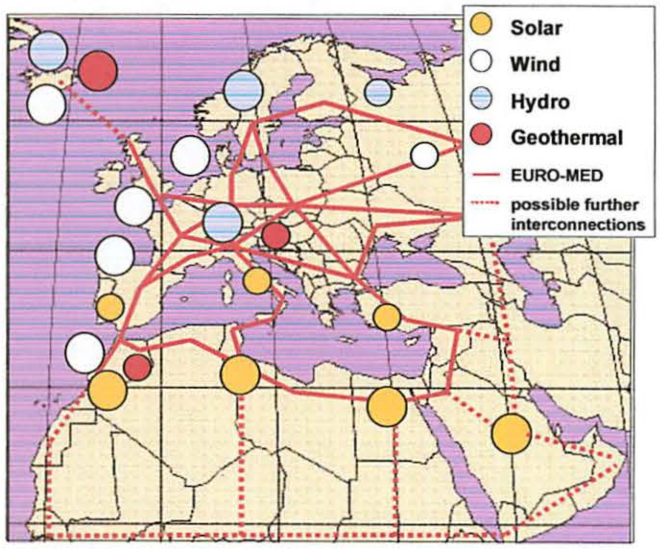
Life Cycle CO_2-Emissions of Different Power Technologies

This life cycle assessment of CO_2-emissions is based on the present energy mix of Germany. CSP value is valid for an 80 MW parabolic trough steam cycle in solar only operation mode. PV and CSP in North Africa. CC: Combined Cycle. Source: DLR.

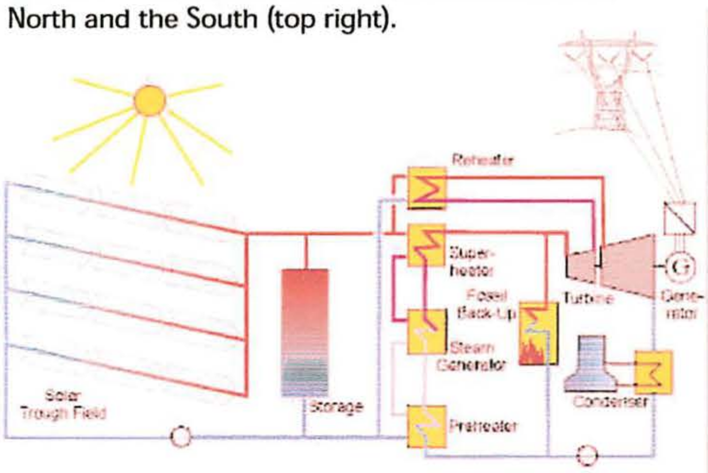


SOCIAL SUSTAINABILITY

CSP systems supply electricity and process heat like any conventional power plant (bottom). Their integration into the grid does not require any measures for stabilisation or backup capacity. On the contrary, they can be used for these purposes, allowing for a smooth transition from today's fossil fuel based power schemes to a future renewable energy economy. Large electricity grids such as a Euro-Mediterranean Power Pool via High Voltage Direct Current Transmission will in the medium term allow for an intercontinental transport of renewable electricity. The existing power line from Spain to Morocco could already be used for this purpose. This concept will help to stabilise the political and economic relations between the countries of the North and the South (top right).



Vision of a Euro-Mediterranean grid interconnecting sites with large renewable electricity resources



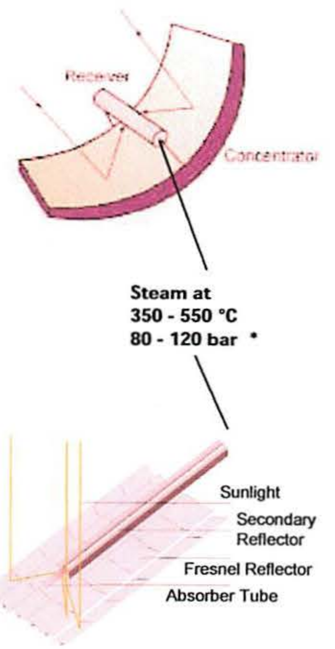
Sketch of a Parabolic Trough Steam Cycle Plant

In sunbelt countries, CSP will reduce the consumption of fossil energy resources and the need for energy imports. The power supply will be diversified with a resource that is distributed in a fair way and accessible by many countries. Process heat from combined generation can be used for seawater desalination and help, together with of a more rational use of water, to address the challenge of growing water scarcity in many arid regions. Thus, CSP will not only create thousands of jobs and boost economy, but will also effectively reduce the risks of conflicts related to energy, water and climate change.

CSP TECHNOLOGIES - THE STATE OF THE ART

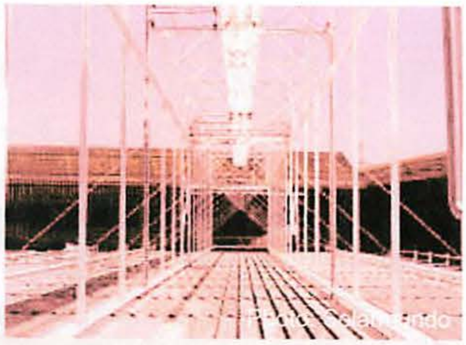
PARABOLIC TROUGH SYSTEMS

Steam cycle power plants with up to 80 MW capacity using parabolic trough collectors have been in commercial operation for more than fifteen years (top). A total of nine plants with 354 MW of installed power are feeding the Californian electric grid with 800 million kWh/year at a cost of about 10-12 ct/kWh. The plants have proven a maximum efficiency of 21 % for the conversion of direct solar radiation into grid electricity.



A European consortium has developed the next collector generation, the EUROTROUGH, which aims to achieve better performance and cost by enhancing the trough structure (bottom left). The new collector will be tested in 2003 under real operating conditions in the Californian solar thermal power plants within the PARASOL project funded by the German Federal Ministry for the Environment. While the plants in California use a synthetic oil as heat transfer fluid in the collectors, efforts to achieve direct steam generation within the absorber tubes are under way in projects sponsored by the European Commission in order to reduce the costs further.

Another option under investigation is the approximation of the parabolic troughs by segmented mirrors according to the principle of Fresnel (bottom right). Although this will reduce the efficiency, it shows a considerable potential for cost reduction. The close arrangement of the mirrors requires less land and provides a partially shaded, useful space below.



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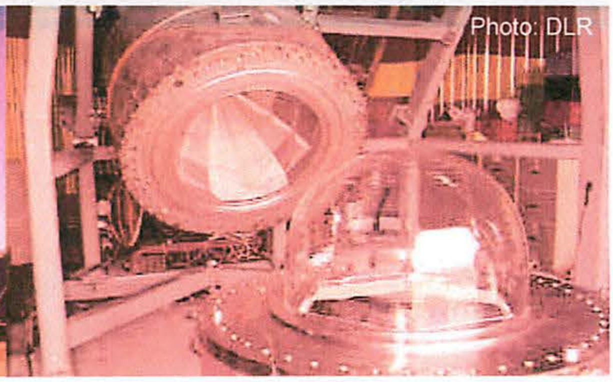
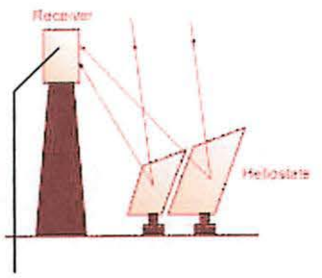
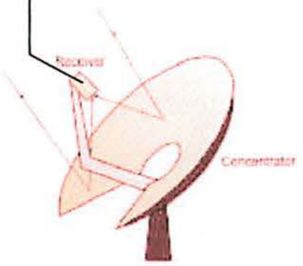




Air or Helium at
600 - 1200 °C
1 - 20 bar *



* range of the present state of the art and expected future achievements

SOLAR TOWER SYSTEMS

Concentrating the sunlight by up to 600 times, solar towers are capable of heating air or other media to 1200 °C and higher (top left). The hot air may be used for steam generation or - making use of the full potential of this high-temperature technology in the future - to drive gas turbines. The PS10 project in Sanlucar, Spain, aims to build a first European steam cycle pilot plant with 10 MW of power. For gas turbine operation, the hot air must pass through a pressurised solar receiver with a solar window (top right). Combined cycle power plants using this method will require 30 % less collector area than equivalent steam cycles. At present, a first prototype to demonstrate this concept is built within the European SOLGATE project with three receiver units coupled to a 250 kW gas turbine.

PARABOLIC DISH ENGINES

Parabolic dish concentrators are relatively small units that have a motor-generator in the focal point of the reflector. The motor-generator unit may be based on a Stirling engine (bottom right) or a small gas turbine. Their size typically ranges from 5 to 10 m of diameter or 5 to 25 kW of power, respectively. Like all concentrating systems, they can additionally be powered by fossil fuel or biomass, providing firm capacity at any time. Because of their size, they are particularly well suited for decentralised power supply and remote, stand-alone power systems. Within the European project EURO-DISH, a cost effective 10 kW Dish-Stirling engine for decentralised electric power generation is being developed by a European consortium with partners from industry and research (bottom left).

http://www.sbp.de
http://www.dlr.de/TT/solartherm/solargasturbine
http://www.klst.com/projekte/eurodish

INITIATING CSP PROJECTS

STEP 1: BASIC PROJECT INFORMATION

The initial step of a CSP project is to identify the basic investment opportunities. First evaluation can be started e.g. by regional authorities with eventual support from CSP experts to assess general information on the market chances, capacity requirement, cost level, revenues, availability of finance, national policies, the level of political risks, the solar irradiation level, possible project implementation structures and the general availability of sites. If the outcome is promising, partners for a project company and sources of finance for project development must be agreed.

STEP 2: PROJECT ASSESSMENT

A pre-feasibility study will include solar energy resource assessment, a preliminary conceptual design of the plant and technical and economic performance modelling for several project alternatives. It will yield a first estimate of the levelised electricity cost and of the economic perspectives of the project. The study will give the general project outlines like administrative requirements, expected environmental impacts, viable schemes of finance and a project implementation structure. This phase will yield a pre-selection and recommendation for the most promising sites. The study will be the basis for the decision about the continuation of the project.

STEP 3: PROJECT DEFINITION

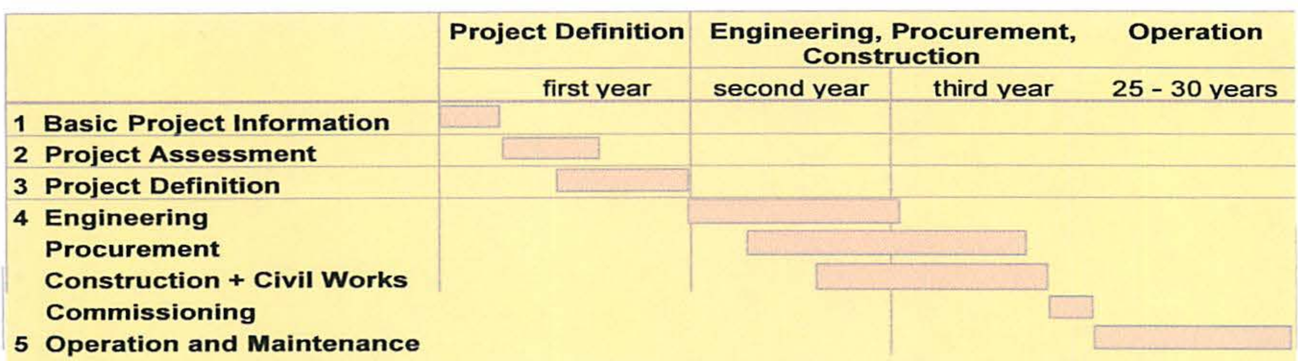
A feasibility study will analyse the most promising project configuration identified in the pre-feasibility phase, going into detail in resource assessment, thermodynamic and economic performance calculations, and specifying major equipment and investment estimates based on budgetary quotes. Usually, an environmental impact study is included. As a result, the project site will be selected and the necessary land will be reserved or purchased by the project company. The study will be the basis for a construction bid and for the related Engineering, Procurement and Construction (EPC) contract, as well as for all the legal and administrative requirements to start the project.

STEP 4: ENGINEER-PROCURE-CONSTRUCT

A consortium bidding for the EPC contract should consist of the construction company, power block supplier, solar plant supplier and an engineering company, all of whom will be experienced in CSP technology. The basis for this phase is a reliable scheme of finance (next page) that allows for electricity costs equivalent to the expected revenues. Due to the fact that fuel is substituted by capital goods, a long term power purchase agreement is a major pre-requisite for the realisation of CSP plants. The final activity of this phase is the grid connection and commissioning of the plant.

STEP 5: OPERATION AND MAINTENANCE

Operation of the CSP plants is expected to last over an economic life cycle of 25 to 30 years.



FINANCING

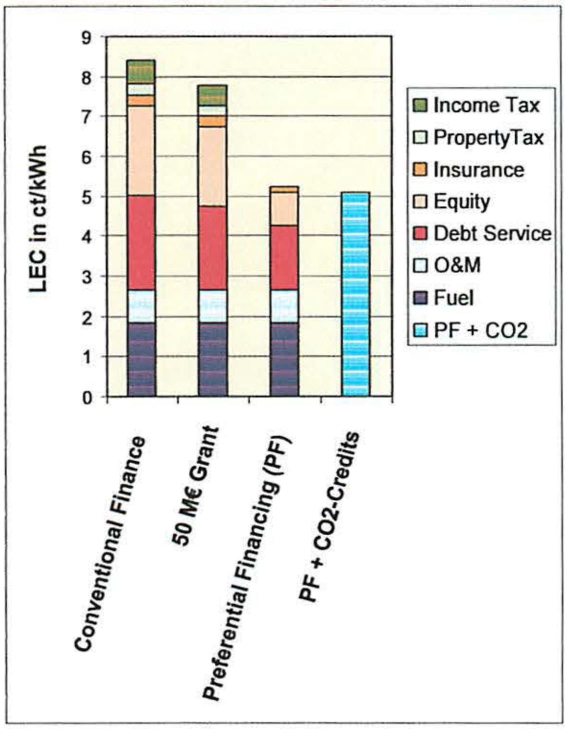
Solar collectors increase the initial investment and the related capital cost in comparison to fuel-fired power plants. Interests for extra debt and equity, insurance costs, taxes and custom duties have to be paid, extra land has to be purchased and extra staff has to be employed. In contrast to that, fuels are purchased without any interest or insurance rates, and are often free of custom duties and taxes or even subsidised by the government.

Therefore, CSP requires start-up finance to enter the market and to follow the learning curve. This can be achieved by an instrument such as the Spanish Renewable Energy Act expected to become operational for CSP by the end of 2002, that will grant a revenue of 15 ct/kWh for CSP plants with maximum 50 MW of power and operated in solar-only mode. For developing countries, a grant by the Global Environmental Facility (GEF) of approximately 50 M€ per plant is expected to be applied to projects in Mexico, Morocco, India and Egypt.

In order to achieve affordable costs today, a combination of financial mechanisms including public-private risk sharing must reduce the capital cost. In addition to the GEF-grant and to CO_2-Credits from the Clean Development Mechanism, all stakeholders of a CSP project including host countries, banks, investors, insurers and suppliers are encouraged to contribute to start-up financing by adapting their profit expectations to the learning curve.

Private participation in start-up finance will require an international public-private-partnership over the whole phase of market introduction in order to reduce the project related risks for all stakeholders to a minimum.

During an executive conference on CSP organised by BMU, GEF and KfW in Berlin in June 2002, the "Berlin Declaration" was issued by an international group of stakeholders that agreed to jointly develop a long term strategy for the market introduction, and to discuss different innovative models of finance in order to start a series of CSP projects.



Example of a fictitious hybrid CSP start-up project showing the effects of several strategies of finance on the levelised electricity cost LEC (Source: DLR)

General calculation parameters: Hybrid 200 MW parabolic trough steam cycle power plant in medium load, solar share 45 %, annual electricity 1000 GWh/y, investment 425 M€, discount rate 3.5 % (real), economic life 25 years, fuel cost 12 €/MWh, avoided CO_2 310,000 t/y.

Parameters for conventional financing and (in brackets) ideal parameters for preferential start-up financing (PF): Debt interest rate 8 %/y (4 %/y), internal rate of return of equity 20 %/y (8 %/y), insurance rate 1% (0.5 %) of Inv./y, property tax 1.5 % (0 %) of Inv./y, income tax 38 % (0 %) of Inc./y, custom duty 5 % (0 %) of direct investment, production overhead 10 % (5 %), grant 0 M€ (50 M€), CO_2-Credit 0 €/t (5 €/t), risk management private (private & public).

http://www.bmu.de
http://www.solarpaces.org/csp_docs.htm
http://www.en-consulting.com/csp

THE MISSION OF GERMANY

CSP TECHNOLOGY FOR THE WORLD MARKET

German companies are among the world leading technology providers and project developers of concentrating solar power (top). The parabolic trough plants in California, the EUROTROUGH, the EURODISH, the PS10 power tower, and lately, the pressurised air receiver SOLGATE have been developed and produced with major participation of German companies and research centres, most of them represented in the European Solar Thermal Power Industry Association ESTIA. With financial support from the German Federal Ministry for Economic Cooperation and Development (BMZ) and the GEF, the first concentrating solar power plant in India will be set up in Mathania, Rajastan.

50 % RENEWABLE ENERGY SHARE IN 2050

The energy policy target for Germany is to reach a 50% renewable energy share by the year 2050, including national resources and renewable electricity imports (centre). The instruments to reach this goal range from the Renewable Energy Sources Act to the political and financial support of research and development of renewables, among many other initiatives. The German Federal Ministry for the Environment (BMU) encourages the development of a long-term strategy for CSP market introduction, finance and market expansion.

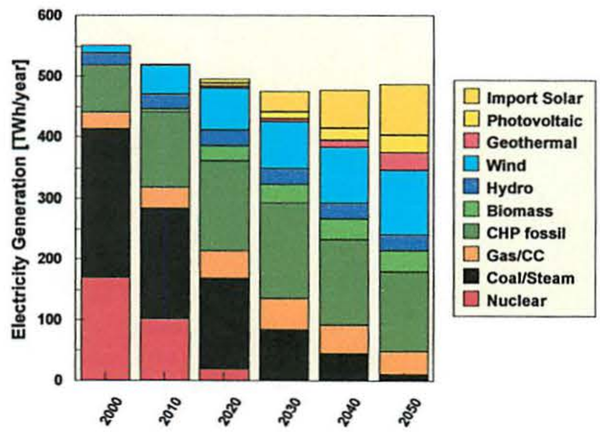
R&D FOR COST REDUCTION

Since the present cost of CSP technologies is a major barrier to their commercialisation, the Federal Ministry for the Environment, with 10 million Euro plus 7 million Euro of industrial contributions, is funding research and development in order to reduce costs and bring CSP into the position to successfully enter the market. Germany has been active in many international research and development activities of the European Commission (bottom) and within the International Energy Agency's SolarPaces Programme.

This brochure was created within the German Future Investment Programme (ZIP) in co-operation of BMU and DLR.

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

CSP projects under development



Electricity supply within a sustainable energy scenario for Germany. After 2030 electricity will increasingly be employed for the generation of hydrogen for the transportation sector

Direct steam generating parabolic trough test facility at the Plataforma Solar, Almeria, Spain

For more information and to obtain an extended version of this brochure, please contact:

Federal Ministry for the Environment (BMU)
Referat Z II 7
D-11055 Berlin
Germany

OVERVIEW OF SOLAR THERMAL TECHNOLOGIES

Introduction

There are three solar thermal power systems currently being developed by U.S. industry: parabolic troughs, power towers, and dish/engine systems. Because these technologies involve a thermal intermediary, they can be readily hybridized with fossil fuel and in some cases adapted to utilize thermal storage. The primary advantage of hybridization and thermal storage is that the technologies can provide dispatchable power and operate during periods when solar energy is not available. Hybridization and thermal storage can enhance the economic value of the electricity produced and reduce its average cost. This chapter provides an introduction to the more detailed chapters on each of the three technologies, an overview of the technologies, their current status, and a map identifying the U.S. regions with best solar resource.

Parabolic Trough systems use parabolic trough-shaped mirrors to focus sunlight on thermally efficient receiver tubes that contain a heat transfer fluid (Figure 1). This fluid is heated to 390°C (734°F) and pumped through a series of heat exchangers to produce superheated steam which powers a conventional turbine generator to produce electricity. Nine trough systems, built in the mid to late 1980's, are currently generating 354 MW in Southern California. These systems, sized between 14 and 80 MW, are hybridized with up to 25% natural gas in order to provide dispatchable power when solar energy is not available.

Cost projections for trough technology are higher than those for power towers and dish/engine systems due in large part to the lower solar concentration and hence lower temperatures and efficiency. However, with 10 years of operating experience, continued technology improvements, and O&M cost reductions, troughs are the least expensive, most reliable solar technology for near-term applications.

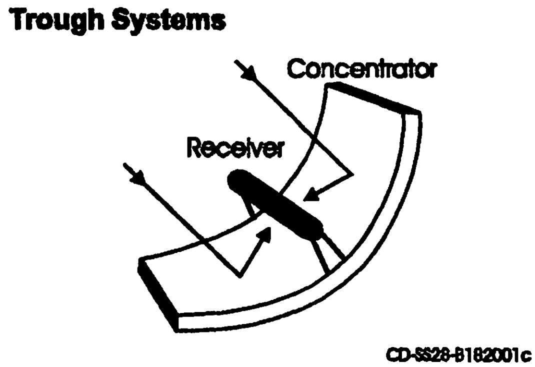


Figure 1. Solar parabolic trough.

Power Tower systems use a circular field array of heliostats (large individually-tracking mirrors) to focus sunlight onto a central receiver mounted on top of a tower (Figure 2). The first power tower, Solar One, which was built in Southern California and operated in the mid-1980's, used a water/steam system to generate 10 MW of power. In 1992, a consortium of U.S. utilities banded together to retrofit Solar One to demonstrate a molten-salt receiver and thermal storage system.

The addition of this thermal storage capability makes power towers unique among solar technologies by promising dispatchable power at load factors of up to 65%. In this system, molten-salt is pumped from a "cold" tank at 288°C

(550°F) and cycled through the receiver where it is heated to 565°C (1,049°F) and returned to a "hot" tank. The hot salt can then be used to generate electricity when needed. Current designs allow storage ranging from 3 to 13 hours.

"Solar Two" first generated power in April 1996, and is scheduled to run for a 3-year test, evaluation, and power production phase to prove the molten-salt technology. The successful completion of Solar Two should facilitate the early commercial deployment of power towers in the 30 to 200 MW range.

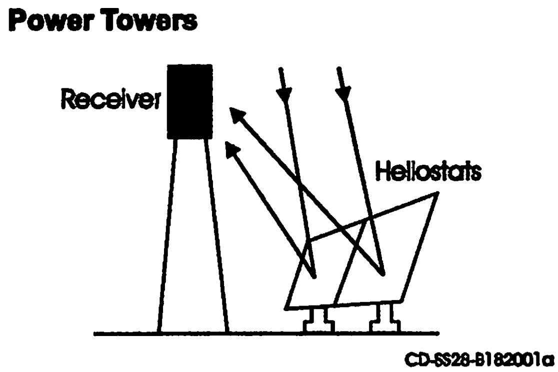


Figure 2. Solar power tower.

Dish/Engine systems use an array of parabolic dish-shaped mirrors (stretched membrane or flat glass facets) to focus solar energy onto a receiver located at the focal point of the dish (Figure 3). Fluid in the receiver is heated to 750°C (1,382°F) and used to generate electricity in a small engine attached to the receiver. Engines currently under consideration include Stirling and Brayton cycle engines. Several prototype dish/engine systems, ranging in size from 7 to 25 kW_e have been deployed in various locations in the U.S. and abroad.

High optical efficiency and low startup losses make dish/engine systems the most efficient (29.4% record solar to electricity conversion) of all solar technologies. In addition, the modular design of dish/engine systems make them a good match for both remote power needs in the kilowatt range as well as hybrid end-of-the-line grid-connected utility applications in the megawatt range. If field validation of these systems is successful in 1998 and 1999, commercial sales could commence as early as 2000.

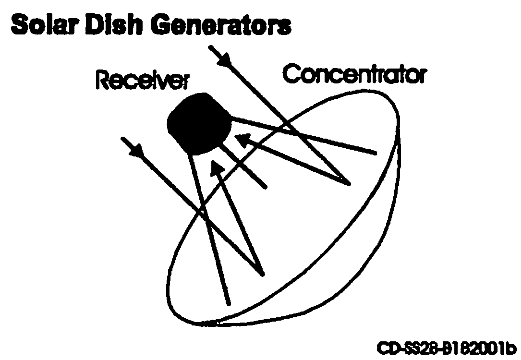


Figure 3. Solar dish/engine system.

OVERVIEW OF SOLAR THERMAL TECHNOLOGIES

Technology Comparison

Table 1 below highlights the key features of the three solar technologies. Towers and troughs are best suited for large, grid-connected power projects in the 30-200 MW size, whereas, dish/engine systems are modular and can be used in single dish applications or grouped in dish farms to create larger multi-megawatt projects. Parabolic trough plants are the most mature solar power technology available today and the technology most likely to be used for near-term deployments. Power towers, with low cost and efficient thermal storage, promise to offer dispatchable, high capacity factor, solar-only power plants in the near future. The modular nature of dishes will allow them to be used in smaller, high-value applications.

Towers and dishes offer the opportunity to achieve higher solar-to-electric efficiencies and lower cost than parabolic trough plants, but uncertainty remains as to whether these technologies can achieve the necessary capital cost reductions and availability improvements. Parabolic troughs are currently a proven technology primarily waiting for an opportunity to be developed. Power towers require the operability and maintainability of the molten-salt technology to be demonstrated and the development of low cost heliostats. Dish/engine systems require the development of at least one commercial engine and the development of a low cost concentrator.

Table 1. Characteristics of solar thermal electric power systems.

	Parabolic Trough	Power Tower	Dish/Engine
Size	30-320 MW*	10-200 MW*	5-25 kW*
Operating Temperature (°C/°F)	390/734	565/1,049	750/1,382
Annual Capacity Factor	23-50%*	20-77%*	25%
Peak Efficiency	20%(d)	23%(p)	29.4%(d)
Net Annual Efficiency	11(d')-16%*	7(d')-20%*	12-25%*(p)
Commercial Status	Commercially Available	Scale-up Demonstration	Prototype Demonstration
Technology Development Risk	Low	Medium	High
Storage Available	Limited	Yes	Battery
Hybrid Designs	Yes	Yes	Yes
Cost			
$/m^2	630-275*	475-200*	3,100-320*
$/W	4.0-2.7*	4.4-2.5*	12.6-1.3*
$/W$_p$ †	4.0-1.3*	2.4-0.9*	12.6-1.1*

* Values indicate changes over the 1997-2030 time frame.

† $/W$_p$ removes the effect of thermal storage (or hybridization for dish/engine). See discussion of thermal storage in the power tower TC and footnotes in Table 4.

(p) = predicted; (d) = demonstrated; (d') = has been demonstrated, out years are predicted values

Cost Versus Value

Through the use of thermal storage and hybridization, solar thermal electric technologies can provide a firm and dispatchable source of power. Firm implies that the power source has a high reliability and will be able to produce power when the utility needs it. Dispatchability implies that power production can be shifted to the period when it is needed. As a result, firm dispatchable power is of value to a utility because it offsets the utility's need to build and operate new power plants. This means that even though a solar thermal plant might cost more, it can have a higher value.

OVERVIEW OF SOLAR THERMAL TECHNOLOGIES

Solar Thermal Power Cost and Development Issues

The cost of electricity from solar thermal power systems will depend on a multitude of factors. These factors, discussed in detail in the specific technology sections, include capital and O&M cost, and system performance. However, it is important to note that the technology cost and the eventual cost of electricity generated will be significantly influenced by factors "external" to the technology itself. As an example, for troughs and power towers, small stand-alone projects will be very expensive. In order to reduce the technology costs to compete with current fossil technologies, it will be necessary to scale-up projects to larger plant sizes and to develop solar power parks where multiple projects are built at the same site in a time phased succession. In addition, since these technologies in essence replace conventional fuel with capital equipment, the cost of capital and taxation issues related to capital intensive technologies will have a strong effect on their competitiveness.

Solar Resources

Solar resource is one of the most important factors in determining performance of solar thermal systems. The Southwestern United States potentially offers the best development opportunity for solar thermal electric technologies in the world. There is a strong correlation between electric power demand and the solar resource due largely to the air conditioning loads in the region. Figure 4 shows the direct normal insolation for the United States.

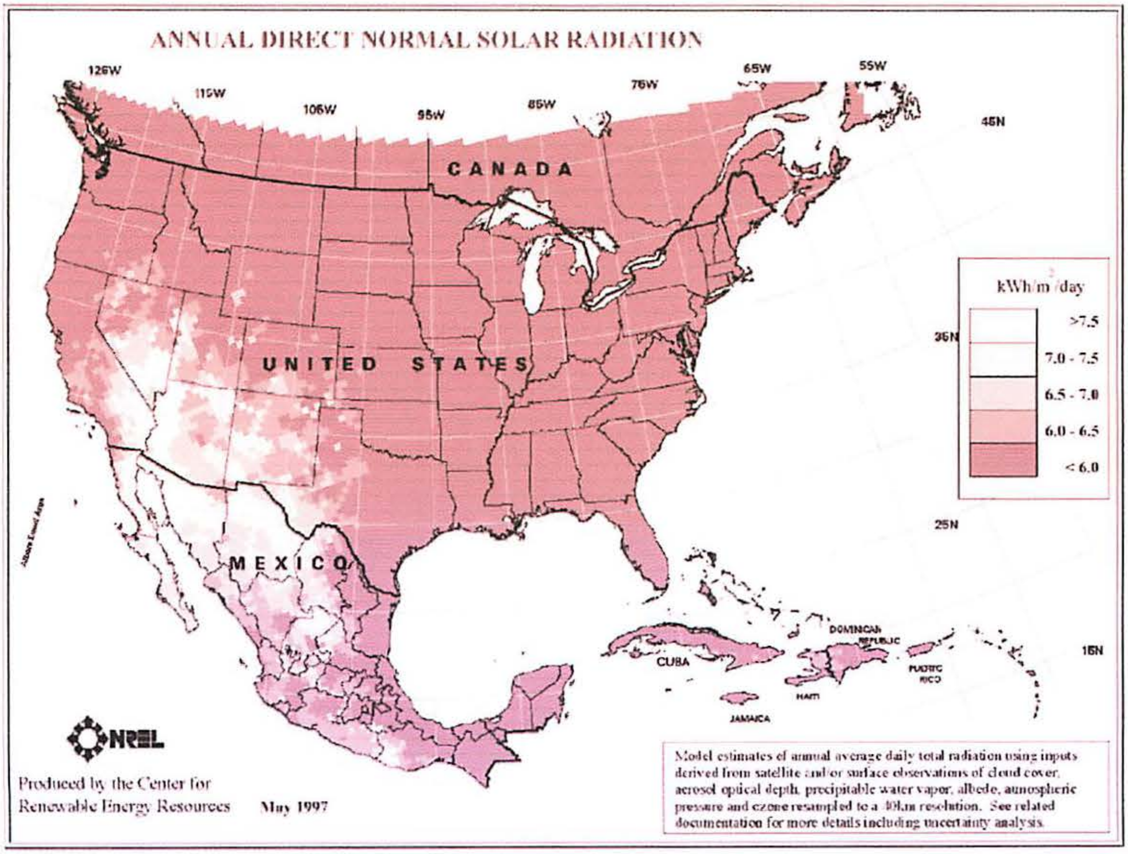


Figure 4. Direct normal insolation resource.

OVERVIEW OF SOLAR THERMAL TECHNOLOGIES

Summary

Solar thermal power technologies are in different stages of development. Trough technology is commercially available today, with 354 MW currently operating in the Mojave Desert in California. Power towers are in the demonstration phase, with the 10 MW Solar Two pilot plant located in Barstow, CA., currently undergoing at least two years of testing and power production. Dish/engine technology has been demonstrated. Several system designs are under engineering development, a 25 kW prototype unit is on display in Golden, CO, and five to eight second-generation systems are scheduled for field validation in 1998. Solar thermal power technologies have distinct features that make them attractive energy options in the expanding renewable energy market worldwide. Comprehensive reviews of the solar thermal electric technologies are offered in References 1 and 2.

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2. Holl, R.J., Status of Solar-Thermal Electric Technology, Electric Power Research Institute: December 1989. Report GS-6573.

3. Mancini, T., G.J. Kolb, and M. Prairie, "Solar Thermal Power", Advances in Solar Energy: An Annual Review of Research and Development, Vol. 11, edited by Karl W. Boer, American Solar Energy Society, Boulder, CO, 1997, ISBN 0-89553-254-9.

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Colorado solar tech shows promise

By Steve Raabe
Denver Post Staff Writer

Article Last Updated: 12/06/2006 10:44:02 AM MST

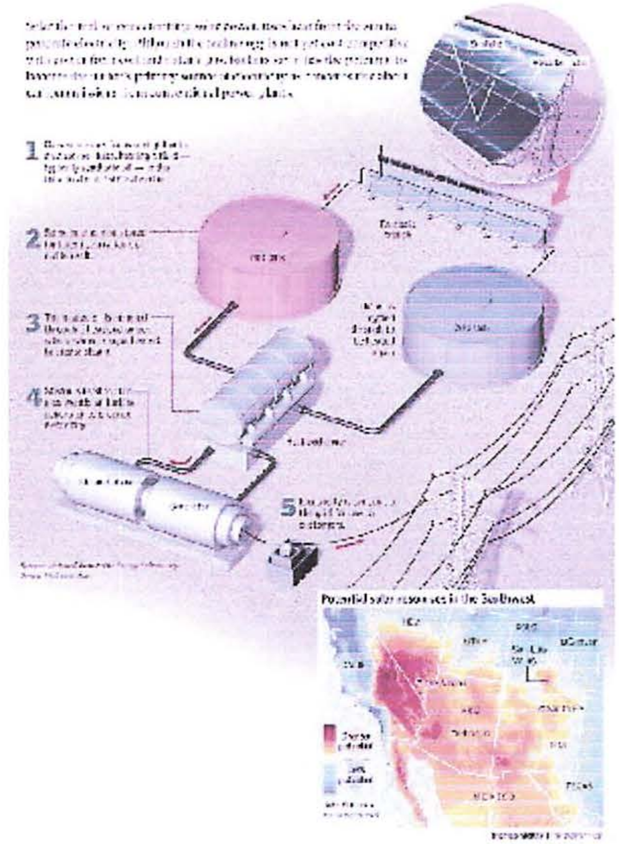
Colorado's sun-drenched San Luis Valley is being eyed for a solar-power technology that advocates say could revolutionize American electrical generation.

Think rooftop-mounted, solar-electric panels but on a much larger scale and with a technological twist that makes it cheaper and more efficient than conventional photovoltaic panels.

Known as solar thermal or concentrating solar power, the technology uses mirrors to focus sunlight. The generated heat then drives power-producing turbines.

Concentrating solar is viewed by its backers as a utility-scale resource that could one day supplant coal- and natural- gas-fired power plants as the nation's chief source of electricity.

"It's a very promising technology," said Mark Mehos, a scientist at the Golden- based National Renewable Energy Laboratory who heads one of the nation's top



(CLICK TO ENLARGE)

concentrating-solar-power research efforts. "I have no doubt that in five to 10 years, it will be cost-competitive with (natural- gas-fired) plants."

Photovoltaic arrays cost roughly 20 to 24 cents

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per kilowatt hour, compared with 13 to 16 cents for concentrating solar power, according to Mehos. Natural-gas power costs an average of eight to 10 cents, while coal runs about four cents.

Renewable-energy advocates say coal's low cost doesn't reflect the expected future costs of taxes on carbon emissions.

As technology improves, costs for concentrating solar will come down, Mehos said, making the process competitive first with natural-gas-fired power and eventually with coal- fired electricity.

But the higher costs of solar thermal make it unpalatable to Stan Lewandowski, general manager of the Intermountain Rural Electric Association, which serves 130,000 Colorado members.

"With solar installations or wind power, our big deal is cost," he said. "I think coal has a limited future, but at the present time it's the cheapest source, and it will get us through until the next technological breakthrough."

NREL researchers have rated the San Luis Valley in south-central Colorado as having the state's best solar exposure.

"We would love to put projects in the San Luis Valley," said John O'Donnell, president of Ausra Inc., the U.S. unit of Sydney, Australia-based Solar Heat and Power.

The only thing holding back a serious bid, he said, is the high cost - roughly $1 million a mile - of building new transmission lines to carry the power to populated areas.

In addition to its higher production costs and need for expensive new transmission lines, solar thermal could face local public opposition because of the broad swaths of land needed to generate large amounts of power.

A 100-megawatt plant - enough to serve about 40,000 households - would cost roughly $325 million and cover 500 acres of land with solar collectors.

The San Luis Valley's ample sunshine already has attracted one power project being developed by Colorado's biggest electric utility, Xcel Energy, and its partner, SunEdison LLC. However, the team will use photovoltaic panels, which convert sunlight directly to electricity - a different approach than solar thermal.

Xcel Energy said it is talking with other Southwestern power companies about collaborating on a major solar-thermal facility whose costs and generated power would be shared by the participants.

"We're in very preliminary discussions," said Mark McGree, Xcel's director of resource planning and bidding. "Primarily, it's a cost issue. We know it works, but we don't know if the cost structure works with today's materials and technology."

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Despite its current higher costs than gas and coal, solar thermal is being used at a 354-megawatt power plant in California's Mojave Desert and in smaller facilities in Arizona and Nevada.

Increasing concern about carbon-dioxide emissions from fossil-fuel generators has led California's three largest utilities to enter into development agreements for an additional 2,250 megawatts of concentrating solar power.

Spain has launched several solar-thermal projects, and the process has enough promise that several European countries are discussing the notion of building transmission lines under the Mediterranean Sea to carry solar power from North Africa.

"Concentrating solar power is clearly the answer," said Tom McKinnon, an energy researcher and professor of chemical engineering at the Colorado School of Mines. "It's just a no-brainer that we should be building CSP instead of coal plants."

While wind power also emits no carbon dioxide, solar thermal carries an advantage over wind because its heat can be stored to generate energy when the sun isn't shining - an attractive feature for utilities.

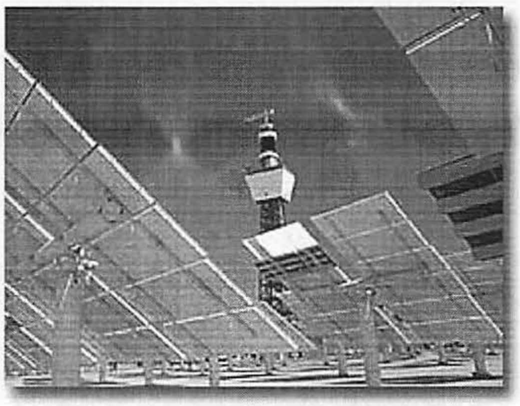
"Storage is what makes the difference," McKinnon said. "If the power is dispatchable, it becomes a lot more valuable to utilities."

Staff writer Steve Raabe can be reached at 303-954-1948 or sraabe@denverpost.com .

CSP Technologies Overview

Technology Overview

Concentrating solar power plants produce electric power by converting the sun's energy into high-temperature heat using various mirror configurations. The heat is then channelled through a conventional generator. The plants consist of two parts: one that collects solar energy and converts it to heat, and another that converts heat energy to electricity.

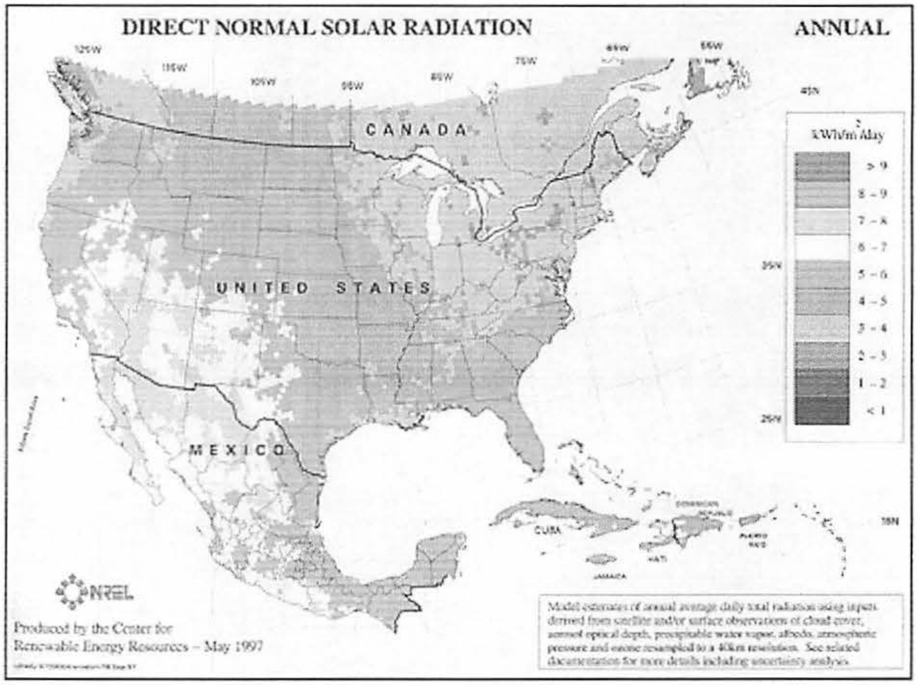


By collecting solar energy during daylight hours and storing it in hot molten salt, concentrating solar power technologies like power towers give utilities an alternative method for meeting peak loads. (Warren Gretz)

Concentrating solar power systems can be sized for village power (10 kilowatts) or grid-connected applications (up to 100 megawatts). Some systems use thermal storage during cloudy periods or at night. Others can be combined with natural gas and the resulting hybrid power plants provide high-value, dispatchable power. These attributes, along with world record solar-to-electric conversion efficiencies, make concentrating solar power an attractive renewable energy option in the Southwest and other sunbelt regions worldwide.

The Solar Resource

The solar resource for generating power from concentrating solar power systems is plentiful. For instance, enough electric power for the entire country could be generated by covering about 9 percent of Nevada—a plot of land 100 miles on a side—with parabolic trough systems.



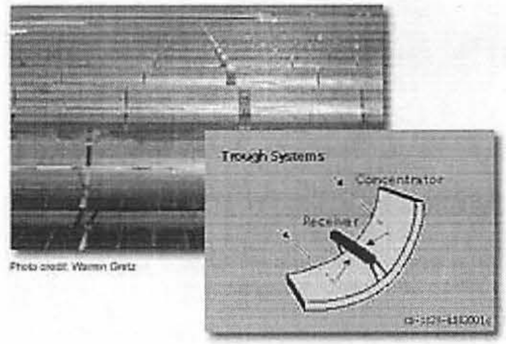
The solar resources for generating power from concentrating solar power systems is plentiful. For instance, enough electric power for the entire country could be generated by covering about 9 percent of Nevada – a plot of land 100 miles on a side – with parabolic trough systems.

The amount of power generated by a concentrating solar power plant depends on the amount of direct sunlight. Like concentrating photovoltaic concentrators, these technologies use only direct-beam sunlight, rather than diffuse solar radiation.

The southwestern United States potentially offers the best development opportunity for concentrating solar power technologies in the world. There is a strong correlation between electric power demand and the solar resource due largely to air conditioning loads in the region. In fact, the Solar Electric Generating System plants operate for nearly 100% of the on-peak hours of Southern California Edison.

How Does It Work?
There are three kinds of concentrating solar power systems—troughs, dish/engines, and power towers—that are classified by how they collect solar energy.

Trough systems:
The sun's energy is concentrated by parabolically curved, trough-shaped reflectors onto a receiver pipe running along the inside of the curved surface. This energy heats oil flowing through the pipe, and the heat energy is then used to



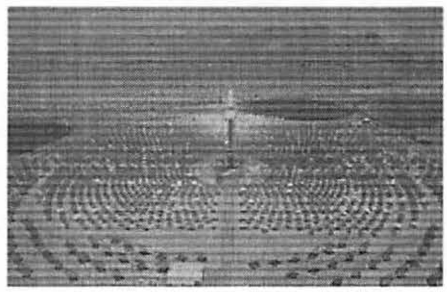
generate electricity in a conventional steam generator.

A collector field comprises many troughs in parallel rows aligned on a north-south axis. This configuration enables the single-axis troughs to track the sun from east to west during the day to ensure that the sun is continuously focused on the receiver pipes. Individual trough systems currently can generate about 80 megawatts of electricity.

Trough designs can incorporate thermal storage—setting aside the heat transfer fluid in its hot phase—allowing for electricity generation several hours into the evening. Currently, all parabolic trough plants are "hybrids," meaning they use fossil fuel to supplement the solar output during periods of low solar radiation. Typically a natural gas-fired heat or a gas steam boiler/reheater is used; troughs also can be integrated with existing coal-fired plants.

For more information, see the following documents:
Technology Characterization: Solar Parabolic Trough (PDF Format 303KB)
Solar Trough Power Plants (HTML Format; PDF Format 230KB)
Parabolic Trough Roadmap (PDF Format 1053KB)

Power tower systems:



What is a Power Tower and How Does it Work?
A power tower converts sunshine into clean electricity for the world's electricity grids. The technology utilizes many large, sun-tracking mirrors (heliostats) to focus sunlight on a receiver at the top of a tower. A heat transfer fluid heated in the receiver is used to generate steam, which, in turn, is used in a conventional turbine-generator to produce electricity. Early power towers (such as the Solar One plant) utilized steam as the heat transfer fluid; current designs (including Solar Two, pictured) utilize molten nitrate salt because of its superior heat transfer and energy storage capabilities. Individual commercial plants will be sized to produce anywhere from 50 to 200 MW of electricity.

What are the Benefits of Power Towers?
Solar power towers offer large-scale, distributed solutions to our nation's energy needs, particularly for peaking power. Like all solar technologies, they are fueled by sunshine and do not release greenhouse gases. They are unique among solar electric technologies in their ability to efficiently store solar energy and dispatch electricity to the grid when needed — even at night or during cloudy weather. A single 100-megawatt power tower with 12 hours of storage needs only 1000 acres of otherwise non-productive land to supply enough electricity for 50,000 homes. Throughout the sunny Southwest, millions of acres are available with solar resources that could easily produce solar power at the scale of hydropower in the Northwest U. S.

What is the Status of Power Tower Technology?

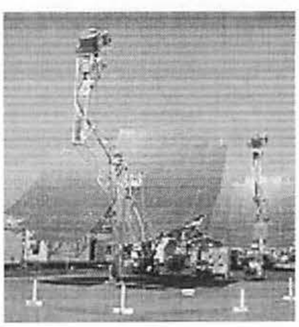
Power towers enjoy the benefits of two successful, large-scale demonstration plants. The 10-MW Solar One plant near Barstow, CA, demonstrated the viability of power towers, producing over 38 million kilowatt-hours of electricity during its operation from 1982 to 1988. The Solar Two plant was a retrofit of Solar One to demonstrate the advantages of molten salt for heat transfer and thermal storage. Utilizing its highly efficient molten-salt energy storage system, Solar Two successfully demonstrated efficient collection of solar energy and dispatch of electricity, including the ability to routinely produce electricity during cloudy weather and at night. In one demonstration, it delivered power to the grid 24 hours per day for nearly 7 straight days before cloudy weather interrupted operation.

The successful conclusion of Solar Two sparked worldwide interest in power towers. As Solar Two completed operations, an international consortium, led by U. S. industry including Bechtel and Boeing (with technical support from Sandia National Laboratories), formed to pursue power tower plants worldwide, especially in Spain (where special solar premiums make the technology cost-effective), but also in Egypt, Morocco, and Italy. Their first commercial power tower plant is planned to be four times the size of Solar Two (about 40 MW equivalent, utilizing storage to power a 15MW turbine up to 24 hours per day).

This industry is also actively pursuing opportunities to build a similar plant in our desert Southwest, where a 30 to 50 MW plant would take advantage of the Spanish design and production capacity to reduce costs, while providing much needed peaking capacity for the Western grid. The first such plant would cost in the range of $100M and produce power for about 15¢/kWh. While still somewhat higher in cost than conventional technologies in the peaking market, the cost differential could be made up with modest green power subsidies and political support, jump-starting this technology on a path to 7¢/kWh power with the economies of scale and engineering improvements of the first few plants. It would, at that point, provide clean power as economically as more conventional technologies.

For more information, see the following documents:
Technology Characterization: Solar Power Towers (PDF Format 303KB)
Solar Two Demonstrates Clean Power for the Future (HTML format; PDF format 557KB)

Dish/engine systems:
What is a Solar Dish-Engine System?
A Solar Dish-Engine System is an electric generator that "burns" sunlight instead of gas or coal to produce electricity. The major parts of a system are the solar concentrator and the power conversion unit. Descriptions of these subsystems and how they operate are presented below.

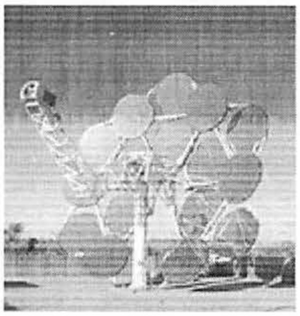


The Boeing/Stirling

THE DISH, which is more specifically referred to as a concentrator, is the primary solar component of the system. It collects the solar energy coming directly from the sun (the solar energy that causes you to cast a shadow) and concentrates or focuses it on a small area. The resultant solar beam has all of the power of the sunlight hitting the dish but is concentrated in a small area so that it can be more efficiently used. Glass mirrors reflect ~92% of the sunlight that hits them, are relatively inexpensive, can be cleaned, and last a long time in the outdoor environment, making them an excellent choice for the reflective surface of a solar concentrator. The dish structure must track the sun continuously to reflect the beam into the thermal receiver.

Energy Systems DECC project will evaluate the performance of the "critical" parts of the Stirling engine and develop the next-generation of the 25 kW Dish-Stirling System.

THE POWER CONVERSION UNIT includes the thermal receiver and the engine/generator. The thermal receiver is the interface between the dish and the engine/generator. It absorbs the concentrated beam of solar energy, converts it to heat, and transfers the heat to the engine/generator. A thermal receiver can be a bank of tubes with a cooling fluid, usually hydrogen or helium, which is the heat transfer medium and also the working fluid for an engine. Alternate thermal receivers are heat pipes wherein the boiling and condensing of an intermediate fluid is used to transfer the heat to the engine.



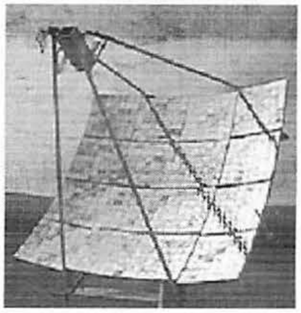
This Science Application International Corporation/STM Power Inc. 25 kW Dish-Stirling System is operating at a Salt River Project site in Phoenix, AZ.

The engine/generator system is the subsystem that takes the heat from the thermal receiver and uses it to produce electricity. The most common type of heat engine used in dish-engine systems is the Stirling engine. A Stirling engine uses heat provided from an external source (like the sun) to move pistons and make mechanical power, similar to the internal combustion engine in your car. The mechanical work, in the form of the rotation of the engine's crankshaft, is used to drive a generator and produce electrical power.

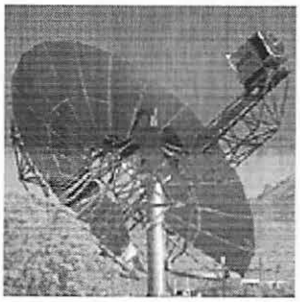
In addition to the Stirling engine, microturbines and concentrating photovoltaics are also being evaluated as possible future power conversion unit technologies. Microturbines are currently being manufactured for distributed generation systems and could potentially be used in dish-engine systems. These engines, which are similar to (but much smaller than) jet engines, would also be used to drive an electrical generator. A photovoltaic conversion system is not actually an engine, but a semi-conductor array, in which the sunlight is directly converted into electricity.

What are the markets for Solar Dish-Engine Systems?
Solar dish-engine systems are being developed for use in emerging global markets for distributed generation,

green power, remote power, and grid-connected applications. Individual units, ranging in size from 9 to 25 kilowatts, can operate independent of power grids in remote sunny locations to pump water or to provide electricity for people living in remote areas. Largely because of their high efficiency and "conventional" construction, the cost of dish-engine systems is expected to compete in distributed markets.



This small photovoltaic solar dish conversion system is being developed by Concentrating Technologies, LLC.

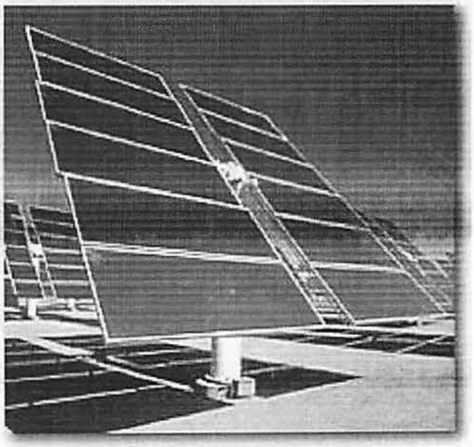


The Advanced Dish Development System is a 10 kW water pumping system developed by WG Associates for use by Native Americans in the southwest U.S.

Opportunities are emerging for the deployment of dish-engine systems in the Southwest U.S. Many states are adopting green power requirements in the form of "portfolio standards" and renewable energy mandates. While the potential markets in the U.S. are large, the size of developing worldwide markets is immense. The International Energy Agency projects an increased demand for electrical power worldwide more than doubling installed capacity. More than half of this is in developing countries and a large part is in areas with good solar resources, limited fossil fuel supplies, and no power distribution network. The potential payoff for dish-engine system developers is the opening of these immense global markets for the export of power generation systems.

For more information, see the following documents:
Technology Characterization: Solar Dish Engine (PDF Format 888KB)
Solar Dish/Engine Systems (PDF Format 200KB)

Business and Market Opportunities
With one of the best direct normal insolation resources anywhere on earth, the southwestern states are poised to reap large and as yet largely uncaptured economic benefits from this important natural resource. California, Nevada, Arizona, and New Mexico are each exploring policies that will nurture the development of their solar-based industries.



Experience gained with Solar Two has established a foundation on which

industry can develop its first commercial plants.
(Joe Flores, Southern California Edison)

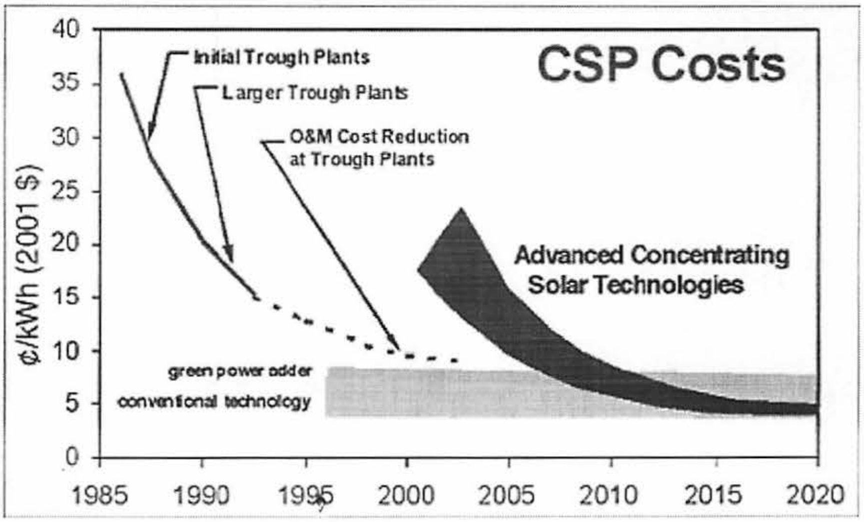
In addition to the concentrating solar power projects under way in this country, a number of projects are being developed in India, Egypt, Morocco, and Mexico. In addition, independent power producers are in the early stages of design and development for potential parabolic trough power projects in Greece (Crete) and Spain. Given successful deployment of one or more of these initial markets, additional project opportunities are expected in these and other regions.

One key competitive advantage of concentrating solar energy systems is their close resemblance to most of the power plants operated by the nation's power industry. Concentrating solar power technologies utilize many of the same technologies and equipment used by conventional central station power plants, simply substituting the concentrated power of the sun for the combustion of fossil fuels to provide the energy for conversion into electricity. This "evolutionary" aspect—as distinguished from "revolutionary" or "disruptive"—results in easy integration into today's central station-based electric utility grid. It also makes concentrating solar power technologies the most cost-effective solar option for the production of large-scale electricity generation.

Analysts predict the opening of specialized niche markets in this country for the solar power industry over the next 5 to 10 years. The U.S. Department of Energy estimates that by 2005 there will be as much as 500 megawatts of concentrating solar power capacity installed worldwide.

For more information, see the following document:
Markets for Concentrating Solar Power (HTML Format; PDF Format 82KB)

What Does It Cost?
Concentrating solar power technologies currently offer the lowest-cost solar electricity for large-scale power generation (10 megawatt-electric and above). Current technologies cost \$2–\$3 per watt. This results in a cost of solar power of 9¢–12¢ per kilowatt-hour. New innovative hybrid systems that combine large concentrating solar power plants with conventional natural gas combined cycle or coal plants can reduce costs to \$1.5 per watt and drive the cost of solar power to below 8¢ per kilowatt hour.



Advancements in the technology and the use of low-cost thermal storage will allow future concentrating solar power plants to operate for more hours during the day and shift solar power generation to evening hours. Future advances are expected to allow solar power to be generated for 4¢–5¢ per kilowatt-hour in the next few decades.

For more information about how concentrating solar power technologies compare financially with one another, see page 3 of "Overview Of Solar Thermal Technologies" (PDF Format 296KB).

For more information about how concentrating solar power technologies compare financially with other renewable energy electricity technologies, see page 3 of "Project Financial Evaluation" (PDF Format 34KB).

Staff may be slashed at Golden energy lab

By Mike Soraghan
Denver Post Washington Bureau

WASHINGTON — President Bush's proposed cuts in energy conservation programs mean the National Renewable Energy Laboratory in Golden — where 800 people work on solar power, wind power and other alternatives — will lose one-third to one-half of its workforce, officials said Monday.

Oil drilling and other energy development fared better Monday as Bush released the details of his spending plan for the country.

Bush's interior secretary, Gale Norton, proposed increasing funding for energy development on Bureau of Land Management lands by $15 million. And her plan assumes the government will raise $1.2 billion a year — beginning in 2004 — from oil leases in the Arctic National Wildlife Refuge in Alaska. Congress currently prohibits any such sales.

U.S. Rep. Mark Udall, D-Colo., said it makes no sense for Bush to declare an energy crisis, then cut conservation programs like those at Golden's NREL.

"There's no balance," Udall said. "In an energy crisis, the quickest way to provide more supply is to conserve what you have."

But Energy Secretary Spencer Abraham called renewable energy a failed effort.

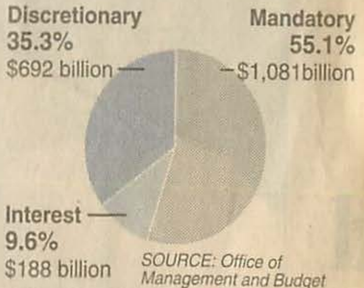
"For those who will argue that we should just spend more money now on existing energy programs, let me say this: Continuing and expanding programs that have been in place as we drifted to the edge of an energy crisis does not appear to be a wiser course of action," Abraham said.

The release of Bush's detailed plan provides a baseline for horse trading in Washington that will finally determine what happens to myriad government programs. The budget must now be worked on by both houses of Congress, then sent back to the White House. It lays out

Please see COLORADO on 10A

The Bush plan

The budget breaks down spending into discretionary and mandatory. Discretionary is what the president and Congress must decide to spend. Mandatory includes Social Security, Medicare and Medicaid.



SOURCE: Office of Management and Budget

AP

Budget details spending for Colorado

COLORADO from Page 1A

in great detail where the Bush administration wants to put its money. In Colorado, it gives an early picture of what kind of government spending the state might expect.

■ The Animas-La Plata dam project got $20 million. The Ute tribes and Four Corners water districts pushing for the dam had hoped for about $30 million, but a spokesman for Sen. Ben Nighthorse Campbell, R-Colo., said Bush's proposal is actually $1 million more than he had asked for in legislation last year.

■ Colorado would get an extra $6.8 million for parks and open-space acquisition under Bush's proposed increase in the Land and Water Conservation Fund for land acquisition, Norton's most touted program. Norton said the increase in the Land and Water Conservation Fund "fulfills President Bush's commitment to investing in America's natural resources," adding that the Interior Department is seeking to give state governments more flexibility in spending the money. The amount of money available for federal land acquisition would be cut by $60 million to make room for new programs aimed at paying private landowners to preserve wildlife habitat.

■ The budget commits $7.6 million to developing plans for the monuments designated by President Clinton.

■ Funding for the cleanup at the Rocky Flats nuclear bomb plant increased $9.2 million, or 1.5 percent, which Abraham said keeps the project on a "fast track" for finishing in 2006.

■ The National Institute of Standards and Technology's Boulder facility got no money to build new buildings. Udall said the buildings are outdated and Clinton had set aside $40 million for construction in the upcoming budget.

■ A wind-energy facility in Boulder County would have its budget cut from $40 million to $20 million.

■ The budget for the Department of the Interior, which has 5,610 employees in Colorado, predicts elimination of 500 to 1,700 jobs nationwide. A senior official said they were most likely at the U.S. Geological Survey.

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Implementation of 3-Port Condensing Wave Rotors in R718 Cycles

The use of a novel 3-port condensing wave rotor is suggested to enhance the turbocompression in a refrigeration cycle that works only with water (R718) as a refrigerant. Although the implementation of such a wave rotor essentially reduces the size and cost of R718 units, their efficiency may also be increased. The condensing wave rotor employs pressurized water to pressurize, desuperheat, and condense the refrigerant vapor, all in one dynamic process. The underlying phenomena of flash evaporation, shock wave compression, desuperheating, and condensation inside the wave rotor channels are described in a wave and phase-change diagram. The thermodynamic process is shown in pressure-enthalpy and temperature-entropy diagrams. Based on the described thermodynamic model, a computer program was generated to evaluate the performance of R718 baseline and wave-rotor-enhanced cycles. The effect of some key parameters on the performance enhancement is demonstrated as an aid for optimization. A performance map summarizes the findings. It shows optimum wave rotor pressure ratio and maximum relative performance improvement of R718 cycles by using the 3-port condensing wave rotor.
[DOI: 10.1115/1.2131886]

Keywords: 3-port condensing wave rotor, water as a refrigerant, R718, refrigeration, shock wave, flash evaporation, wave rotor technology

Introduction

There has been a tremendous effort by the refrigeration and air-conditioning industry to find the best substitute for chlorofluorocarbon (CFC) refrigerants [1,2]. The search for new and environmentally benign refrigerants has renewed interest in technologies that use natural refrigerants, such as water (R718). Considering all pros and cons of natural refrigerants already described in previous studies [3,4], water can be considered as an attractive refrigerant because of its following advantages:

- It has no global warming potential (GWP=0).
- It has no ozone depletion potential (ODP=0).
- It is nontoxic, nonflammable, easy to handle, and inert to the environment (minimizes safety precautions).
- It has no risk of future restrictions due to refrigerant environmental impact.
- It has no disposal problem after use.
- It works with very low pressure differences, reducing safety precautions.
- It has high theoretical coefficient of performance (COP), competitive with CFCs depending on the evaporatoration temperature [5,6].
- The system working with water as a refrigerant can use direct heat exchangers for evaporation and condensation. Therefore, R718 systems can obtain very high COP [7].
- Tap water, treated waste water, or coarsely filtered river water can be used directly as make-up water (warehousing bulky refrigeration canisters is not required).
- Chiller systems, coupled with a closed cooling tower loop, allow for diminished water treatment.
- Turbochillers using water as a refrigerant have shown to be inherently much less noisy than conventional compression chiller systems.

Despite the above attractive features, there are a few challenges of using water as a refrigerant compared to traditional refrigerants. At the triple point, the vapor pressure of water is only 611 Pa, which is <1% of the atmospheric pressure. The low operating pressures of water-vapor refrigeration systems combined with the steep vapor pressure curve of water requires compression systems that can handle large-volume flows while still delivering high-pressure ratios [8–11]. This states challenges for the compressor design. Although single-stage turbo compressors commonly deliver large-volume flows with mostly insufficient pressure ratios, positive displacement compressors can obtain high-pressure ratios but only for relative small-volume flows. A technical compromise has been the use of multistage turbocompressors with intercooler [12].

Water Refrigeration Cycles. Figure 1 pictures the schematic of a two-stage R718 turbochiller with direct condensation and evaporation, two high-performance centrifugal compressors, and an intercooler. Figure 2 is a schematic thermodynamic model for the actual system. R718 units can be comprised of three directly interlinked cycles: (i) a cooling water cycle that condenses the superheated vapor from the compressor and releases the thermal energy to the ambient through a heat exchanger device, mostly a cooling tower; (ii) a chilled water cycle that absorbs thermal energy from the heat source and transfers it to the refrigerant by phase change; and (iii) a refrigerant cycle or the core cycle that consists of four components: compressor, expansion device, condenser, and evaporator. Cooling towers can be direct (open-circuit) or indirect (closed-circuit) heat rejection equipment. In the direct type, cooling water is exposed directly to the atmosphere. The warm cooling water is sprayed over a fill that increases the contact area, and air is blown through the fill. The majority of heat removed from the cooling water is due to partial evaporation of the cooling water requiring a permanent replenishment. The re-

Contributed by the Advanced Energy Systems Division of ASME for publication in the Journal of Energy Resources Technology. Manuscript received April 2, 2004; final manuscript received September 28, 2005. Review conducted by Srinivas Garimella.

Materials that could increase the efficiency of concentrating solar power are shown in a slide Thursday in Golden. *RJ Sangosti, The Denver Post*

Solar thermal draws grants

The promising technology, also known as concentrating solar power, attracts dollars from the Energy Department to two area firms and Golden's NREL.

By Steve Raabe *The Denver Post* / 30Nov07 1C

Two Denver-area solar-energy firms and a research lab have garnered the lion's share of $12.4 million in federal grants awarded Thursday to speed alternative-energy advancements.

Four grants from the U.S. Department of Energy totaling $2.5 million are going to Lakewood-based Abengoa Solar Inc., formerly known as Solucar, and SkyFuel Inc. of Arvada, both developers of a solar-power technology that analysts say could change the future of generating electricity.

In addition, the Golden-based National Renewable Energy Laboratory is receiving $4 million from the DOE to help push the solar technologies and other clean-energy programs toward commercialization.

The concentration of funding in metro Denver underscores the region's growing role in renewable energy, experts said.

"We're extremely pleased," said Ken May, division director of Abengoa Solar, a subsidiary of Seville, Spain-based energy giant Abengoa SA.

Abengoa got three of the DOE's 12 awards, for a total of $2 million, for projects to increase the efficiency of concentrating solar power — a technology that uses acres of mirrors to reflect and concentrate the sun's heat to generate electricity.

A fourth award of $435,000 to SkyFuel also will be used to advance concentrating-solar-power technology.

SkyFuel, based in Albuquerque but with its research-and-development unit in Arvada, hopes to use the enhanced technology in a proposed

SOLAR » 5C

SOLAR: Challenge for technology is competitiveness

«FROM 1C

1,000-megawatt concentrating-solar-power plant in the San Luis Valley that could become one of the world's largest when fully built. The plant could supply power for about 500,000 homes.

Storage is the key

Both of the firms are working on ways to store solar heat so that power can still be generated after sunset.

"Obviously, that's what Xcel Energy and the other utilities want — thermal storage so they can get the power whenever they need it," said Randy Gee, chief technology officer of SkyFuel.

The main drawback of wind and solar power has been their intermittent nature. Concentrating solar power, also known as solar thermal, is more dependable, said Mark Mehos, a research chief at the National Renewable Energy Laboratory.

He said the technology is proven and in place at a handful of power plants in the U.S. The challenge now, he said, is to make it more efficient and reduce its costs enough to be competitive with "clean coal" power generation.

Already, Mehos said, solar thermal's 30 percent federal tax credit allows it to compete in cost with natural-gas-fired generation.

"The goal is to make it competitive without that tax incentive," Mehos said.

A concentrating-solar-power prototype dish/engine system is in place at the National Renewable Energy Laboratory in Golden. *Warren Getz, NREL*

The federal grants issued Thursday stemmed from a request for proposals to energy firms earlier this year. Combined with investments from the companies and laboratories, the research programs will total $13.8 million.

Steve Raabe: 303-954-1948 or sraabe@denverpost.com

Energy Services BULLETIN

Print-friendly version

Energy Services

Western Area Power Administration

Vol. 23, No. 5
October 2004

In this issue

TOPICS from the POWER LINE Find solar technology and finance information online

Editor's note: The Energy Services Bulletin features real answers to real questions posed to our staff at the Energy Services Power Line. We hope you find it useful.

Question:
We are currently working on gathering some solar data. Do you have any information or resources on the following topics:

- Projected efficiency improvements for solar technologies, photovoltaic and concentrating solar (including dishes, troughs and power towers); and projected years for achieving those goals with continued research and development.
- Capital cost information for solar technologies mentioned above.

Answer:
The Power Line did an extensive search on emerging solar technologies and costs, and came up with several excellent resources that you should find useful.

U.S. DOE Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Program gives an overview on developing solar technologies. Within this site, Photovoltaic Systems Technology Development addresses technology status and costs in a general way.

Check out Concentrating Solar Power and Sun Lab, a joint program of Sandia and National Renewable Energy Laboratories, focusing on activities in the area of concentrating solar power. Research and Development Advances in Concentrating Solar Power looks at technology improvements and costs.

An overview of equipment costs and business and market opportunities also can be found here. In addition, there is

Resources

- U.S. DOE Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Program
- U.S. DOE EERE Photovoltaic Systems Technology Development
- Concentrating Solar Power and Sun Lab
- Research and Development Advances in Concentrating Solar Power
- Sun Lab costs and business and market opportunities
- Sun Lab CSP markets
- SolarPACES
- U.S. DOE Trough Technology Roadmap
- *The Commercial Path Forward for CSP Technologies*
- *Due-Diligence Study of Parabolic Trough and Power Tower Technologies*
- *Parabolic Trough Solar Power for Competitive U.S. Markets*
- *Green Power and Market Research News*
- Western's Renewables Web page

People

- Randy Manion

Submit a story idea

cold
- Calendar of events

information about markets for CSP including capital costs on troughs, power towers and solar dishes or engines.

SolarPACES is the International Energy Agency's program for CSP economics and financing. Information specific to CSP plant costs is available at this site.

A U.S. DOE planning process produced the Trough Technology Roadmap. Technology roadmapping is a needs-driven planning process that helps identify, select and develop technology alternatives to satisfy a set of product needs.

Reports and presentations look at financial side of solar

Papers and presentations that examine the financial aspects of solar technologies are also available online. *The Commercial Path Forward for CSP Technologies*, by Frederick Morse of Morse Associates, Inc., discusses the steps needed to bring the technology to market. Morse is a consultant for government agencies and utilities on the application of and markets for renewable energy.

Due-diligence Study of Parabolic Trough and Power Tower Technologies, by Hank Price for the National Renewable Energy Laboratory, is a PowerPoint presentation that includes capital costs for specific projects.

Presented at the 1999 conference, Renewable and Advanced Energy Systems for the 21st Century, *Parabolic Trough Solar Power for Competitive U.S. Markets* looks at what is necessary for large-scale parabolic trough solar powerplants to compete with U.S. state-of-the-art fossil power technology in a competitive U.S. power market.

Finally, Western's Renewable Energy Program Manager Randy Manion can provide technical support and expert contacts. E-mail him or call 720-962-7423. Manion also produces the *Green Power and Market Research News*, a newsletter about these and other renewable technologies for Western. It is available on-line at or by e-mail. Western's Renewables Web page also lists several resources.

Equipment loan program

Technical questions

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Renewable Energy Gets Boost

Local renewable energy projects recently received a boost from Tri-State Generation and Transmission Association, which supplies electricity to 18 of Colorado's 22 electric cooperatives.

In June, Tri-State authorized the country's first program to provide incentives for local projects that develop renewable energy resources. Under this aggressive program, Tri-State will offer renewable performance payments to its members to support a variety of community-based renewable energy programs.

The board also added a number of new incentives to Tri-State's long-standing Energy Efficiency Credits program and endorsed new emergency load management and control practices. These programs will assist consumers in reducing their energy costs and support electric system reliability when energy is in short supply.

"Tri-State supports renewable energy and is committed to helping member electric systems develop their locally available renewable resources by providing some of the necessary cash flow during a project's early years," said Ken Anderson, Tri-State's newly appointed executive vice president and general manager. "Rural communities are rich in solar, wind, biomass, small hydropower and geothermal resources, and with financial support, we can help our members invest in local renewable energy projects that support our rural economies."

In the Energy Efficiency Credits program electric co-op member-owners are eligible for payments after purchasing and installing certain high-efficient water heaters, heating and cooling systems, lighting and electric motors.

In 2007, Tri-State paid $1.4 million in EEC incentive payments to consumers who made qualifying energy-saving choices. Added to the list of eligible products are certain Energy Star heat pumps and air-conditioners, refrigerators and freezers, equipment for certain member load control programs and light emitting diode (LED) lighting strips.

As part of Tri-State's demand response and load control efforts, its board also sanctioned a new emergency and operational load management program. This measure will identify member consumers, especially businesses, willing to have their electricity interrupted when the electricity supply is low. As power supplies become increasingly in short supply across the West, such programs can help ensure electric system reliability.

"Combined, all these efforts are part of our continuing effort to further develop our balanced generation portfolio," said Anderson.

PROPOSALS SOUGHT FOR LARGE-SCALE SOLAR PROJECT BY COLORADO CO-OP

Tri-State Generation and Transmission in Westminster has joined three other utilities to seek proposals for a solar parabolic trough generation facility in New Mexico.

This technology utilizes a series of trough-shaped mirrors to focus sunlight onto an oil-filled tube and then uses the hot oil to generate steam. The steam is used to turn a generator and produce electricity.

If viable proposals are submitted and the project moves ahead, it should be generating electricity by 2011.

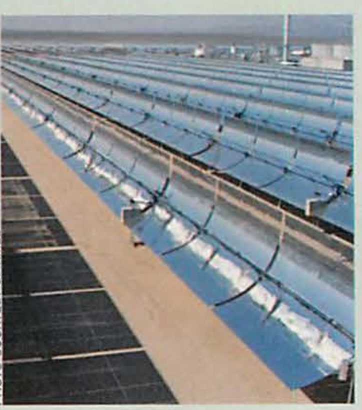

PHOTO COURTESY OF RMEL

Researchers Find New Future Power

Floor vibrations, sewage and sludge and tap water are all possible sources of tomorrow's energy.

The next time the floor vibrates beneath your feet, think of it as renewable energy in the making. A London architectural firm has a proposal for capturing the energy produced when thousands of people walk through a large structure such as a shopping mall. Plans are under way to build an energy-harvesting staircase with small hydraulic generators embedded in the floor. It is estimated that each footstep can generate 3 to 5 watts of power. Multiply that by tens of thousands of walkers each day and you could generate some serious energy.

Not quite so nice but equally serious is a proposal at Mississippi State University to transform sludge and wastewater collected from a sewage treatment facility into a feedstock for producing "biodiesel." The researchers recently received a $200,000 grant to further their studies.

In Canada, a team of researchers believes it has discovered a new way of generating electricity for small electronics by using pressurized, flowing water. The new method harnesses the natural electrokinetic properties of a liquid by pumping it through tiny microchannels. This technology could provide a new power source for devices such as mobile phones and MP3 players, charging them by pumping water to high pressure.

All of these potential future power sources are renewable and may be part of the solution to the crisis the electric industry is facing today.

Ratepayers United of Colorado

Coloradoans for Clean Energy (CO-force)

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Concentrating Solar Power Ready to Replace Fossil Fuels, Say Colorado Ratepayers

Submitted by dziskin on Wed, 2006-12-20 22:11. News

FOR IMMEDIATE RELEASE

Concentrating Solar Power Ready to Replace Fossil Fuels, Say Colorado Ratepayers

DENVER, August 18, 2006 – For the first time ever, utility ratepayers in Colorado have asked that incentives to burn coal for electric power be replaced with solar power. Concentrating solar power (CSP) produces steam with mirrors that gather sunlight. By storing some of the heat, CSP runs generating plants day and night. A new form of CSP that is directly cost competitive with fossil fuel combustion is now entering commercial deployment, according to the testimony submitted Friday at the Colorado Public Utilities Commission (PUC).

"The Southwestern United States has superb solar resources, with more energy than Saudi Arabia waiting to be tapped," said John S. O'Donnell, the expert witness who submitted the testimony on Concentrating Solar Power. "This solar power can directly replace the burning of fossil fuels to heat water and produce steam," said O'Donnell.

Dan Friedlander, an individual in the Colorado PUC case said, "We all need to be concerned about future costs of coal and carbon regulations, because ratepayers will be footing the bill, especially here in Colorado. Coal burning exposes us to rate increases and the dangers of planetary heating. Generating our power with sunlight instead of coal is the safest, soundest, and cheapest choice."

Alison Burchell, a geologist and spokesperson for Ratepayers United of Colorado, said, "We talk about carbon capture as if it's a ready solution to critical planetary warming. But trying to bury the massive amounts of CO_2 emitted from coal plants is like burying a mountain range – it will be difficult and, at the least, very expensive. If we build CSP plants instead, we avoid paying for the coal and its transportation and the monumental backend costs to bury its exhaust."

Ratepayers United of Colorado recommends that policies outlined in the Western Governor's Association January 2006 Solar Task Force Report be aggressively implemented.

"Ratepayers in Colorado are being asked to pay premium prices for our utilities to burn more coal, and to accept uncertainty about future electric costs and massive environmental costs," said Friedlander. "Instead we should develop our abundant solar resources and meet all our power needs securely. Building solar infrastructure is the best use of our money now, and the best legacy we can leave future generations."

Testimony Submitted 8/18/06 by Ratepayers United to CoPUC

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This is an excerpt from EERE Network News, a weekly electronic newsletter.

October 29, 2008

Ausra Opens its First Concentrating Solar Power Plant in California

The Ausra technology employs flat mirrors that direct sunlight onto an overhead tube, in which water is boiled into steam. *Credit:* Ausra, Inc.

The 5 megawatt (MW) Kimberlina Solar Thermal Energy Plant in Bakersfield, California, is the first to use Ausra's innovative technology that replaces trough-shaped solar mirrors with a series of narrow, flat mirrors, which mimic the performance of a solar trough at a lower cost. The power plant is also the first of its kind to be built in California in more than 20 years, with the previous plant being the Solar Energy Generating System (SEGS) near Barstow, which employs solar troughs. But while the SEGS plant heats oil that is used to boil water in a separate boiler, the Ausra technology focuses the sun's heat onto pipes that carry water, which is boiled directly into steam. The steam can then be used for either power production or as process steam in a factory. See the Ausra press release.

The Kimberlina plant will also be seen as a crucial demonstration of the Ausra technology before the company develops its Carrizo Plains solar power plant, a 177-MW facility for which the company holds a power purchase agreement with Pacific Gas and Electric Company (PG&E). Ausra intends to build the facility in central California and to start producing power in 2010. Ausra and PG&E have also committed to developing 1,000 MW of concentrating solar power (CSP) over the next five years, and Ausra's technology is also slated for a 300-megawatt CSP plant planned for Florida. But Ausra seems confident, as it opened a manufacturing facility in Las Vegas, Nevada, this summer to produce the reflectors, absorber tubes, and other key components used in its CSP plants. See the Ausra press release and the article from the October 3, 2007, edition of this newsletter on Ausra's other CSP commitments.

Printable Version

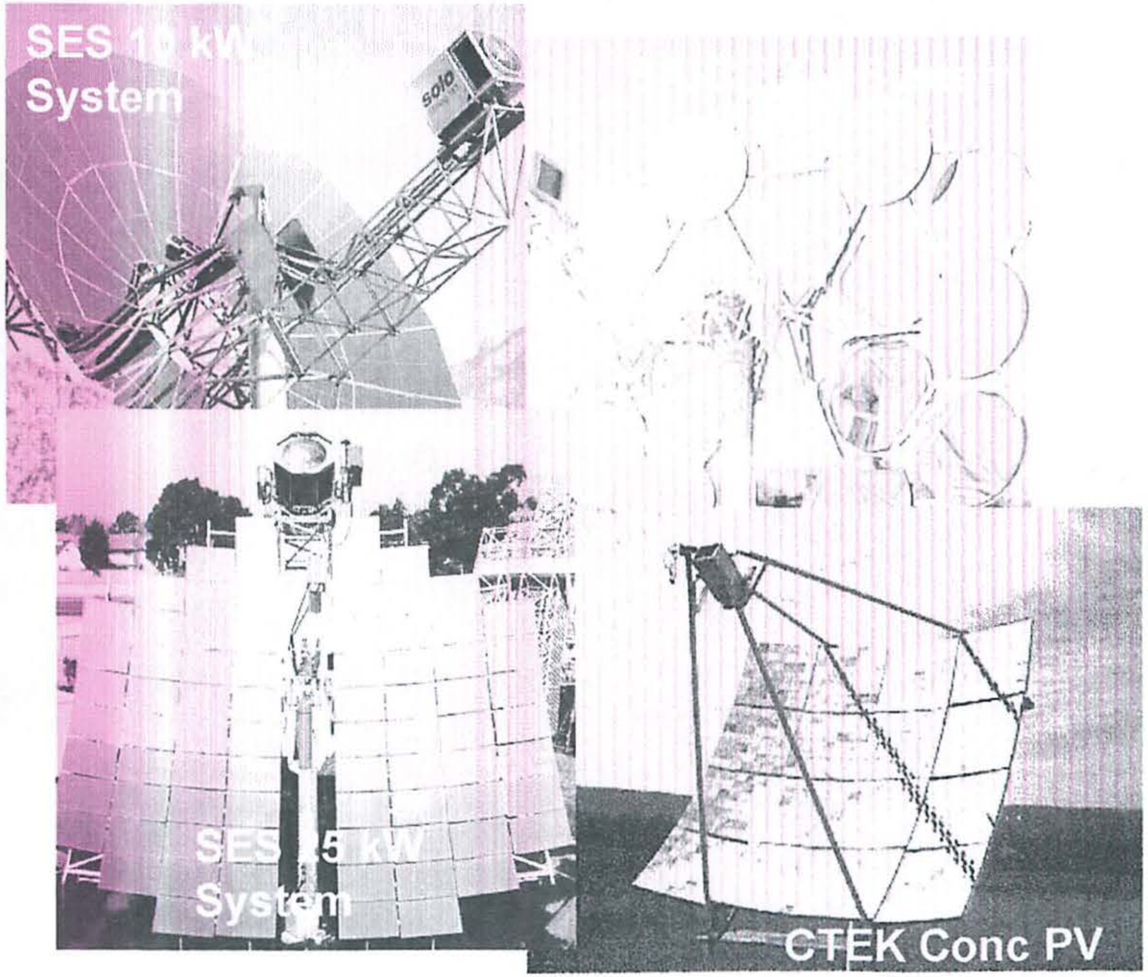
Concentrating Solar Power Dish Systems

Dr. Thomas R. Mancini
Solar Thermal Program Manager
Sandia National Laboratories

Renewable Energy Opportunities in Algeria

October 23, 2003

What are Dish Systems?



Characterized by:

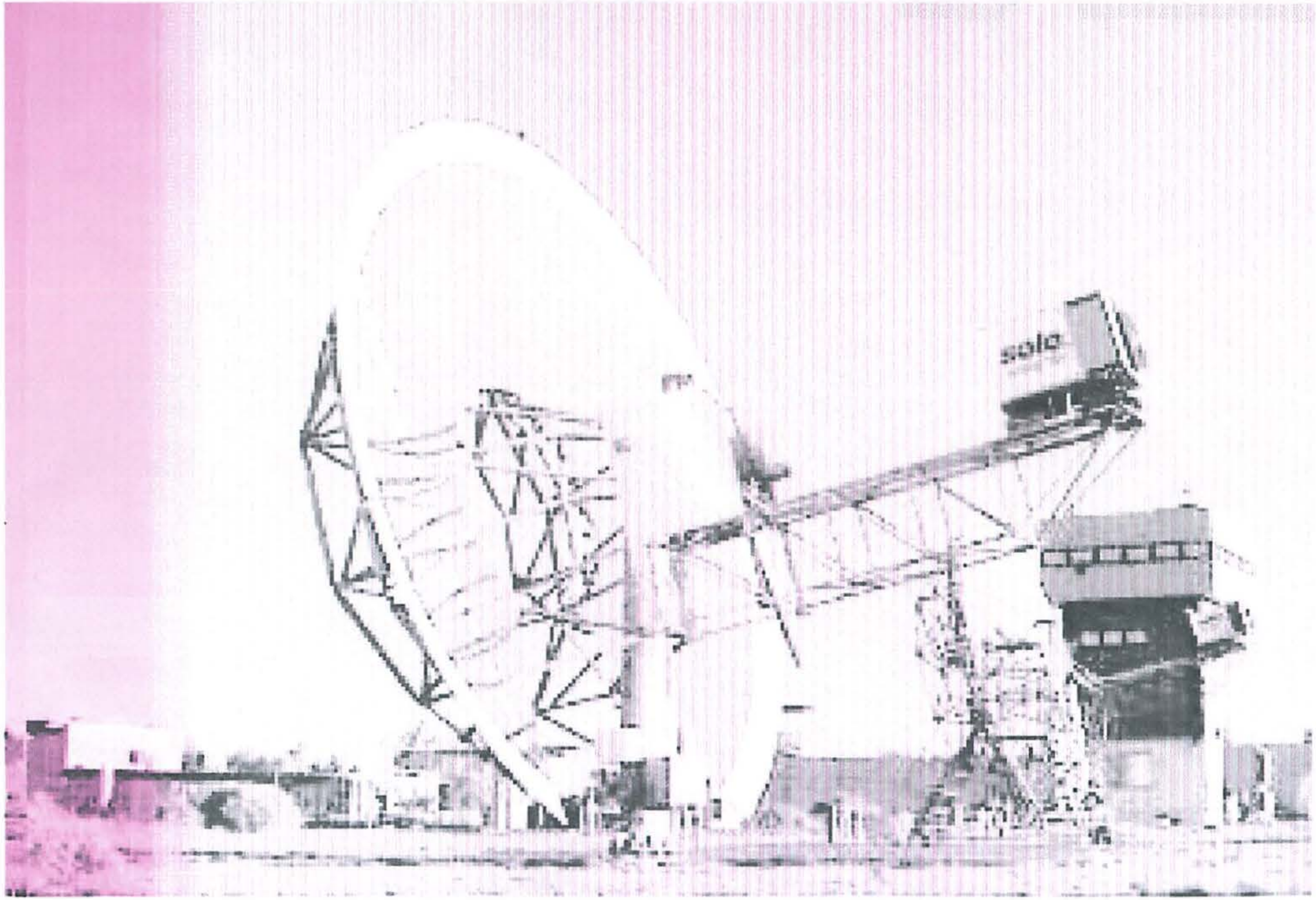
Tracking Concentrators

Receiver, engine, PV generator at focal point

Capable of hybrid operation

Primarily Stirling engines but evaluating concentrating PV

SES 10 kW Systems



Dish Systems are .....

- Modular (10 to 25 kW) deployable in fields of few kW to MWs
- Low-cost deployment due to modularity compared with trough and power tower systems
- High performance achieving 23 – 25% annual conversion
- Currently at prototype stages of development

What is current status?

- Operating 6 systems in U.S.
- Accumulated > 40,000 hours on sun
- generated > 300 MWhrs
- Demonstrated hybrid operation solar or gas on natural gas, hydrogen, and landfill gas
- Demonstrated remote (non-gridtie) operation
- Reliability needs improvement
- Manufacturing improvements needed

What are barriers?

Technical Barriers (performance)

- Installed Cost (tech. and production levels)
- Operating Costs (tech. and reliability)

Reliability database under development. Data will guide future R&D needs. The problem is that 10s or 100s of systems are needed to develop the data.

Solution – leverage prototype deployment opportunities.

What are costs?

Installed Cost

- Current Prototype Costs ~ $10,000/kW
- Intermediate targets -- $2500 – 3500/kW
- Long-term goals < $1200/kW

O & M Costs

- Current O & M at prototype costs
- Intermediate targets – 1 – 2 ¢/kWhr
- Long-term goals < 1 ¢/kWhr

Potential cost reductions?

Solar Concentrators

- Advanced, lower-cost designs to reduce construction and installation costs
- Optical surface development
- Concentrator azimuth drives
- Cleaning and maintenance issues

Status: conventional glass and metal construction; mass production could reduce installed costs by factors of 4 to 6; O&M centers on cleaning reflectors.

Potential cost reductions?

Engines/converters

- Engine focus on solar-specific issues
- Engine seals and controls need work
- Tubular receivers potentially replaced by lower maintenance heat pipes
- Evaluate advanced converters (cpv and microturbines)

Status: Engine cost reductions by factors of 10 – 20 possible with mass production for other applications.

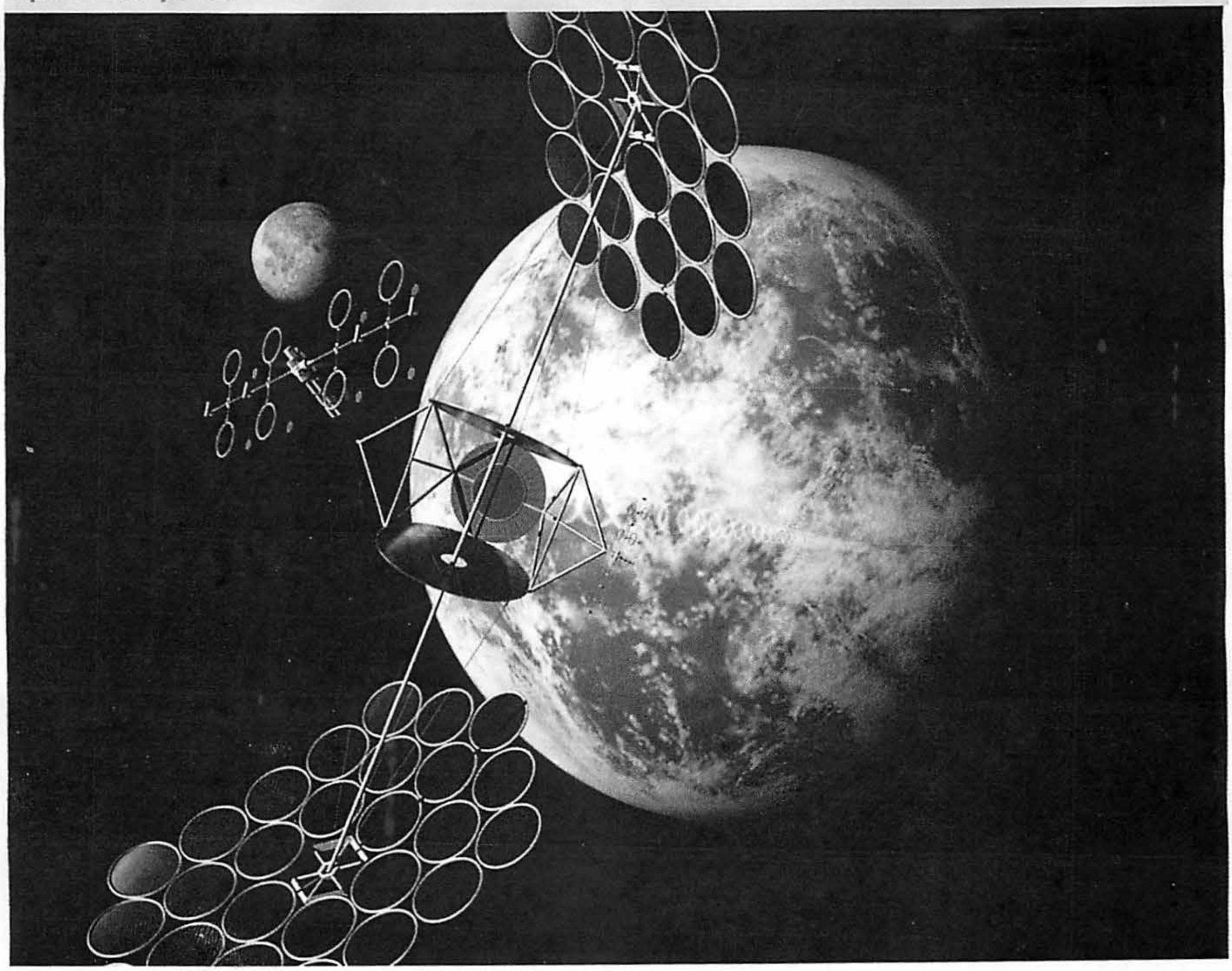
Potential cost reductions?

Balance of System

- Prototype, diagnostic controls need to be turned into field-level commercial controls
- Design for shipping, installation, and repair
- Controls for deployment of multiple systems at a single location
- Operational strategies for single and multiple systems
- O&M strategies and procedures

Bottom Line on Dish Systems

- Over the past 5 years, DOE, labs, and industry have made significant progress
- Still much to be done on reliability and manufacturing cost reductions
- Advanced components will improve reliability and simplify systems
- Potential applications in niche market situations including remote, small village, and high-value applications.



Let the sun shine in

Energy: Satellites that beam solar power to earth have often appeared in science fiction. Will they ever become reality?

"REASON", a short story written by Isaac Asimov that was published in 1941, is set on a space station which collects solar energy from the sun and sends it, via microwave beams, to earth and other planets. The robots that control the beams are under the command of a more advanced model called Cutie, which turns out to have developed its own religion, and ignores the wishes of two astronauts who visit the station. As a solar storm approaches, the humans worry that Cutie will be unable to control the beam sending power to earth, causing it to fall on cities and incinerate them. But in the event, the robot's religious yearning to keep the power flowing means that no harm is done. The moral: actions matter more than beliefs.

Today it is not just robots in science-fiction tales who are believers in the wonders of space solar power (SSP); the idea also has a small but growing number of human adherents. The basic idea is simple. Light from the sun is the most abundant and cleanest source of energy available in the solar system. Around the clock, 1.3 gigawatts of energy pour through every square kilometre of space around the earth. This energy could be captured by vast arrays of photovoltaic cells mounted on a satellite in orbit around the planet. These solar cells would be illuminated at all times of day, whatever the weather or the season, overcoming one of the main drawbacks of solar power on the earth's surface. And with no atmosphere in the way to absorb or scatter the incoming sunlight, solar panels in space would produce over five times as much energy as those on the ground. (Some proposals for SSP involve large arrays of mirrors or lenses to concentrate the light onto a smaller array of panels.)

The logical place to put the satellite would be in a geostationary orbit, 35,800 kilometres above the earth's equator, so that it completes one circuit of the planet per day, and thus appears (from the ground) to hover in a fixed place in the sky, like the communications satellites used to broadcast television signals. The solar-power satellite would send the collected energy down to earth in the form of a microwave beam, which would be picked up on the ground by a huge array of antennae, spread over several square kilometres in open country. The power density of the beam at the receiver would be little greater than what leaks out from a domestic microwave oven, so there would be no dan- ▸▸

Space solar power is an idea far ahead of its time, but the necessary technology already exists.

ger of incinerating entire cities. Microwave communications links are already used in the telecoms industry without doing any harm to wildlife.

The concept of beaming gigawatts of solar power down from space was first put on a sound scientific footing by Peter Glaser of Arthur D. Little, a consultancy, in 1968. He built on the research of William Brown of Raytheon, an American defence firm, who pioneered the transmission of electric power by microwave beams. Since the oil shocks of the early 1970s, the idea has been dusted off and re-evaluated every ten years or so by America's Department of Energy, its space agency, NASA, and big aerospace companies such as Lockheed Martin and Boeing.

These studies usually conclude that there is no technical barrier to implementing SSP. For example, a study published in 1981 by the Department of Energy, NASA, the Environmental Protection Agency and the Department of Commerce found "no show-stoppers" or "insurmountable obstacles" to the idea. But further development work has always fallen between the cracks of different agencies. "The trouble is that the Department of Energy doesn't do space, and NASA does space, not energy," says Colonel M.V. ("Coyote") Smith of the National Security Space Office (NSSO), a Pentagon think-tank, who recently conducted another study of SSP.

Although there may not be any technical difficulty with the idea, the economics are another matter. The main obstacle to SSP is the huge cost of launching the satellites into space. Conventional electricity in America costs between four cents per kilowatt hour (kWh) for hydro-electric power (the cheapest kind) and ten cents for coal-fired generation. Even under the most optimistic scenario, SSP would produce electricity at a cost of around 50 cents per kWh with existing technology. It sounds hopeless. Yet recent developments mean that advocates of SSP are more optimistic than ever before.

Bridging the gap

These developments were not so much technological as geopolitical. The NSSO's recent evaluation of SSP, published in 2007, took a more favourable view of the idea than any previous assessment. Colonel Smith admits that he was sceptical about the idea at first. But he concluded that the Department of Defence was "a potential anchor-tenant customer of space-based solar power", because SSP could provide a much cheaper alternative to existing energy supplies.

The armed forces are America's single greatest consumer of oil. The Department of Defence delivers 1.6m gallons (7.3m litres) of fuel a day—accounting for 70% by weight of all supplies delivered—to its forces in Iraq alone, at a delivered cost per gallon of $5-20. It also spends over $1 per kWh on electric power (ten times the domestic civilian price) in battle zones, because electricity must often be provided using generators that run on fossil fuels.

If some of this fuel could be replaced by power beamed down from space, it could cut costs and reduce the need for complex and vulnerable supply lines, the NSSO report argues. It could be used to power electric vehicles, along with radar stations and other pieces of equipment that currently rely on electrical power from generators. (The study dismisses the notion that the Pentagon might be interested in SSP as a means of beaming death rays down on enemies: it points out that the beam is nowhere near powerful enough to present a plausible alternative to conventional missiles and other weapons.)

Getting SSP off the ground will require the involvement of the private sector, the study observes, but private firms are unlikely to act without a demonstration project to confirm the viability of the scheme. The NSSO estimates that this would cost $8 billion-10 billion, and suggests that it could be funded by a consortium involving America and its allies—such as Canada, Japan, the European Union or Australia, all of which have shown interest in SSP in the past. In the meantime, NASA is evaluating the possibility of an experiment involving the International Space Station.

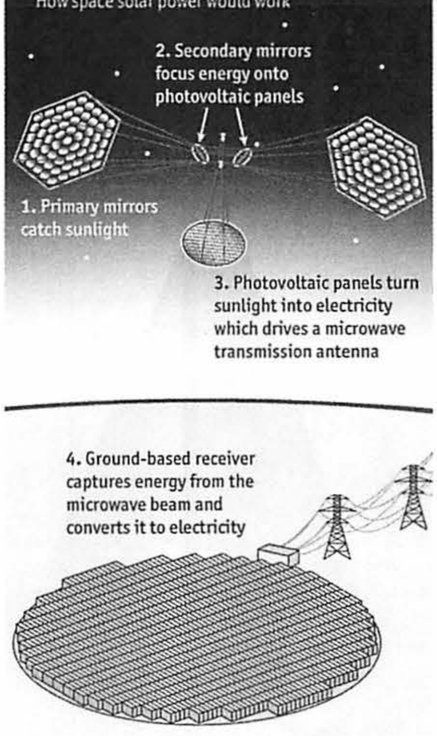
SSP was one of the original projects in Japan's "New Sunshine Plan" for renewable-energy development after the first oil shock of the 1970s. India is interested because it has a huge problem building a grid that serves the more remote parts of the subcontinent and suffers chronic blackouts. Canada thinks solar power could be used to process the filthy tar-sands deposits of Alberta. Shell, an oil company, has developed a process for refining the dirty tar underground, so that all that comes out is relatively clean oil. But the process needs lots of energy, and the government has ruled out the use of nuclear power.

The optimistic NSSO report was followed in May 2008 by a milestone for SSP, with the transmission of a microwave beam, of the kind that would be used to transmit energy to Earth, between two Hawaiian islands 148 kilometres apart. The distance was chosen because it is equivalent to the thickness of the atmosphere that a microwave beam from space must penetrate. The experiment was carried out by American and Japanese researchers in only four months, and for less than $1m, under the direction of John Mankins of Managed Energy Technologies, a firm he founded after a long career developing space systems at NASA. The experiment was sponsored by Discovery Communications, a TV company, for a documentary.

Announcing his results, Mr Mankins said that what was needed next was a two-year engineering study of a full SSP system, covering everything from the launch vehicles to the ground receivers. Such a study has not been carried out since the 1980s, and technology has since changed radically. With that done, at a cost of about $100m, the next step would be to develop the necessary architecture to make SSP economically viable, and to test it in low-Earth orbit. Mr Mankins thinks this could be done by 2015, at a cost of less than $1 billion. After that, a full pilot system could be deployed in geostationary orbit, at a cost of $10 billion, and commercial operation could begin by 2025.

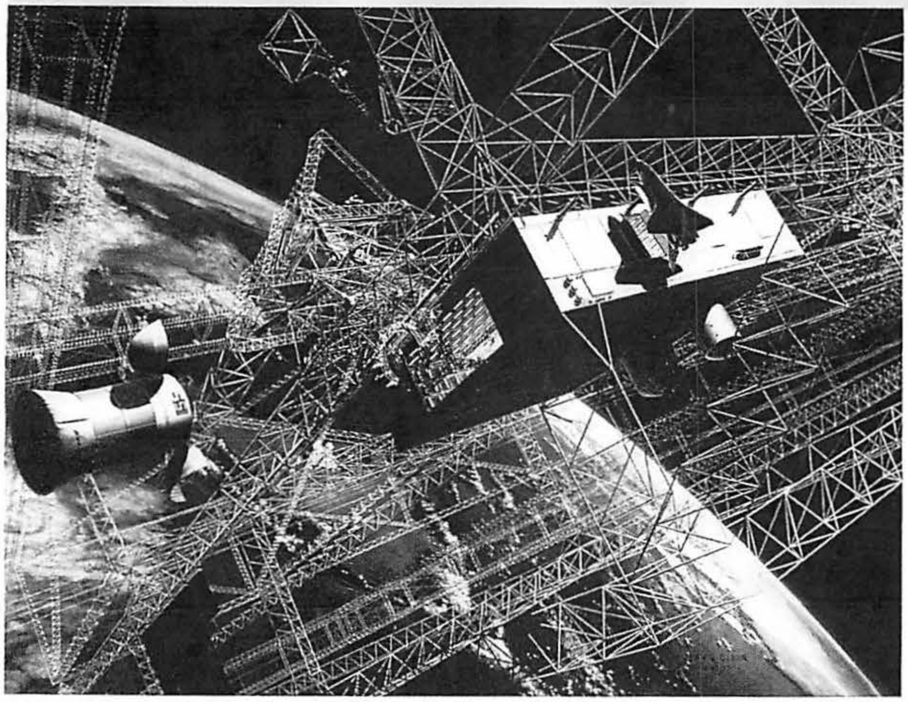
Beam me down, Scotty

How space solar power would work



Sources: Mafic Studios; *The Economist*

There is no doubt that SSP has become



A high-flying construction project

far more practical since engineers began evaluating it in any detail. Since 1977 the efficiency of solar cells has increased from around 10% to over 40%, and that of solid-state amplifiers from 20% to over 80%. New lightweight composite materials have been developed. Most striking of all have been the advances in computing and robotics, as demonstrated by the presence of several semi-autonomous rovers on the surface of Mars. An SSP system need not be constructed by astronauts working in an orbiting factory, as was originally assumed, but could be a self-assembling system made up of lots of small parts.

Enter the space entrepreneurs

But there is one area where there has been much less progress, and it remains SSP's Achilles heel: the cost of access to space. For its first half-century, since the launch of *Sputnik* in 1957, space has been largely the province of governments, for which prestige and strategic clout (military rockets) often matter more than cost. But the growth of communications and other services delivered by satellite has spawned a commercial space industry around the world.

George Nield of the Office of Commercial Space Transportation at the Federal Aviation Administration (FAA) points out that the commercial space business, including its suppliers, accounted for over $139 billion in economic activity in 2006—up from $61 billion in 1999. (This covers everything from making launch vehicles and spacecraft to satellite-navigation systems for cars and boats.)

As the industry develops, interest is growing in making cheaper launch vehicles, not least for space tourism, starting with sub-orbital projects. According to the FAA there are about 18 companies involved in developing low-cost launchers. Most (such as Blue Origin, a company founded by Jeff Bezos, an internet tycoon, who is building a spacecraft at a ranch in Texas) are keeping a low profile for the moment. The notable exceptions are Virgin Galactic, founded by Sir Richard Branson, a British entrepreneur intent on taking his aged parents for a holiday in space before too long, and SpaceX, founded by Elon Musk, another internet millionaire.

SpaceX's *Falcon 1* rocket successfully reached orbit at the fourth attempt in September 2008, becoming the first privately funded, liquid-fuelled rocket to do so. The company is developing a much larger rocket, *Falcon 9*, which will be able to carry payloads of up to 12 tonnes into orbit (compared with a few hundred kilograms for *Falcon 1*). SpaceX is one of two companies chosen by NASA to develop crew and cargo resupply systems for the space station. It has also been contracted to launch satellites for a number of government and commercial clients.

Mr Musk thinks his non-bureaucratic, low-cost approach could reduce the cost of launching payloads into low-earth orbit from around $6,000-10,000 per kilogram today to around $3,000 with *Falcon 9*, and eventually (by reusing more of each launcher) to around $1,000. Mr Musk has his eye on manned missions to Mars, among other things, but much lower launch costs would also have the side-effect of making SSP more viable. The NSSO estimates that a launch cost of $440 per kilogram, for example, would reduce the cost per kWh to between eight and ten cents.

One company with a specific plan for SSP is Space Island Group, based in California. Its novel scheme involves using the technology that has already been developed by NASA for the space shuttle to build orbiting space-stations out of the empty fuel tanks that are usually discarded when the shuttle reaches orbit. Space Island's plan is to launch several of these tanks, convert them into living quarters and rent them out. Gene Meyers, the boss of Space Island, says it has identified 200 companies and 300 university research groups which would be interested in renting facilities at its proposed rates; there would also be opportunities for space tourism. The resulting revenues, the company says, would cover the cost of launching the components for a large SSP system, piggy-backed onto each fuel tank. It sounds rather far-fetched—but the same was true of Mr Musk's plans just five years ago, before he had launched a single rocket. That is an indication of how quickly things can change in the commercial space industry.

When Mitsubishi Electric started looking at solar power in Japan it, too, was thinking along the lines of launching giant structures and assembling them in space. After a while it balked at the difficulty and cost of that route, and in recent years it has been concentrating on the idea of launching squadrons of small satellites orbiting in formation. Mitsubishi Electric has continued to invest in SSP research, and Japan's space agency, JAXA, is also taking the idea seriously, with talk of a working system in orbit by 2030.

If today's gloomy economic conditions make SSP seem even more outlandish, it is worth remembering that America's commercial-aviation industry was born in the midst of the Depression. The 1930s witnessed the formation of aerospace companies such as Grumman and Hughes, the launch of airlines such as American and United and the birth of the Douglas DC-3—the workhorse of the pre-jet age, which is still going in some corners of the world.

Space solar power is still an idea far ahead of its time. But the necessary technology already exists and is gradually falling in cost. The commercialisation of space—and, in particular, the enthusiasm building around space tourism—could be the trend that brings down launch costs and brings SSP within reach. It will take entrepreneurs as well as engineers to kick-start the public-private process needed to tap the energy of the great fusion reactor in the sky. Lots of people believe it can be done. But as Cutie the robot demonstrated, what you believe matters less than what you actually do. ■

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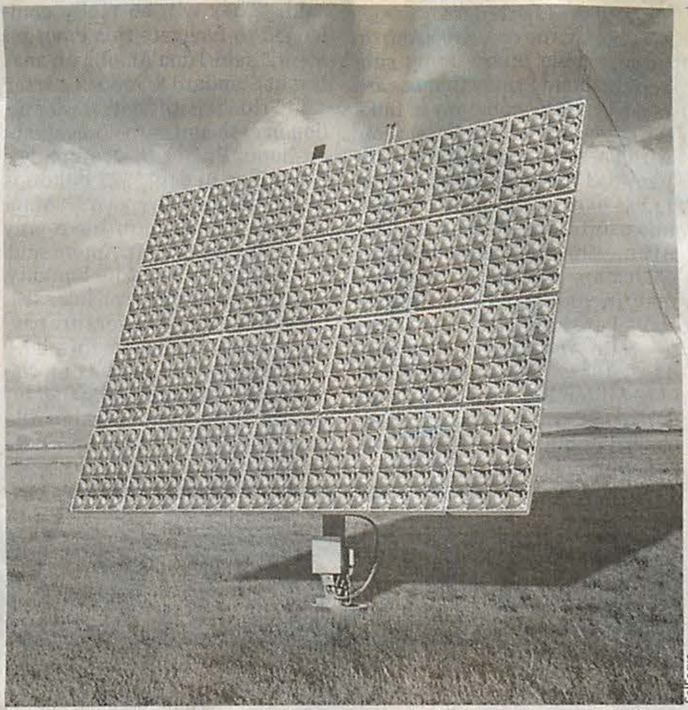
SolFocus panels can be made from glass and aluminum, instead of silicon.

Greek Power Plant to Use New Solar Technology

By Jim Carlton

WSJ p B4 15 Dec 08

A technology that uses special mirrors and lenses to help generate electricity from sunlight may be a new bright spot for the solar industry.

Often called "concentrated photovoltaics," the technology was the focus of a $103 million deal in November to install 10 megawatts of generating capacity in southern Spain, enough to power a city of 40,000. **SolFocus** Inc., the Silicon Valley company that supplied technology in that transaction, on Monday is also announcing a deal to help build a 1.6-megawatt power plant in Greece that is based on the same approach.

Concentrated photovoltaics use mirrors and lenses to direct an increased amount of energy on smaller solar panels, which can be made from low-cost materials such as glass and aluminum, thus avoiding the use of silicon, a commodity that can be subject to shortages that keep panel prices high.

The technology is on a trajectory to grow from less than 10 megawatts of generating capacity world-wide this year to as many as six gigawatts by 2020, according to a report issued earlier this year by Greentech Media and the Prometheus Institute for Sustainable Development, research groups both in the Boston area. That would pale in comparison to the projected 300 gigawatts in overall solar production by then, but would still double the current overall capacity of nearly three gigawatts—most of which is supplied by silicon-based solar panels.

SolFocus is expected to announce a transaction Monday with Samaras Group, a renewable-energy developer in Greece. Including the latest deal, SolFocus officials say they will have contracts to install up to 20 megawatts of capacity.

The start-up, based in Mountain View, Calif., has raised $96 million in venture capital since its inception in 2006, and expects to close another $60 million to $80 million in venture financing by the end of January, said Chief Executive Mark Crowley. He said that money is being used to help increase the company's manufacturing capacity.

In all, investors have poured almost $400 million in venture capital into the concentrated photovoltaic sector over the past three years, Greentech Media estimates.

One big limitation for the technology, analysts say, is that it is best suited for locations with ample direct sunlight, like southern Europe and the American Southwest.

Conventional solar panels, by contrast, are being deployed almost everywhere. The concentrated technology isn't seen as practical for many homes and businesses, because it requires more room to set up.

The technology is best suited for locations with ample direct sunlight.

The technology also has a few bugs to work out, some industry officials say. **Sharp** Corp., for instance, is testing concentrated photovoltaics on three continents. But the Japanese company hasn't marketed anything yet because of issues including a tendency of the machinery to be impacted by dust and getting the concentrating equipment to point directly at the sun for best results.

"It's still a few years out, but there is a spot for this," said Ron Kenedi, vice president of Sharp Solar Energy Solutions Group, a Huntington Beach, Calif., unit of Sharp's U.S. subsidiary.

The technology is seen having the highest potential in supplanting conventional power sources in midsize applications, such as supplying power for a water treatment plant. "It will occupy the middle ground of 10 to 50 megawatts over time," said Eric Wesoff, a Greentech Media analyst based in Woodside, Calif.

Economic, Energy, and Environmental Benefits of Concentrating Solar Power in California

Subcontract Report
NREL/SR-550-39291
April 2006

May 2005 – April 2006

L. Stoddard, J. Abiecunas, and R. O'Connell
Black & Veatch
Overland Park, Kansas

NREL Technical Monitor: M. Mehos

Prepared under Subcontract No. AEK-5-55036-01

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ASSESSMENT OF CONCENTRATING SOLAR POWER TECHNOLOGY COST AND PERFORMANCE FORECASTS

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INTRODUCTION

In 2002 and 2003, Sargent & Lundy undertook a review of the cost of electricity generation using concentrating solar power (CSP) technology. The study was done for the United States Department of Energy (USDOE) and National Renewable Energy Laboratory (NREL) [Ref. 1]. This paper updates that work to include information from a feasibility study Sargent & Lundy performed for the World Bank regarding an Integrated Solar Combined Cycle System (ISCCS) project proposed for Baja California. This discussion also introduces cost comparisons between CSP-generated electricity and other generating technologies, which were not a part of the original USDOE/NREL project.

Increased production of electricity from renewables is widely regarded as desirable for reducing consumption of non-renewable resources and as a means of reducing greenhouse gas emissions. Renewable electricity generating technologies include hydro, geothermal, solar, wind, and biomass.

Electric power from renewables faces cost challenges compared with conventional approaches to generating electricity. In most cases, the problem for renewables is primarily high capital cost, which is partially, but not entirely, offset by lower operation and maintenance costs. Dispatchability is another important issue. Measures aimed at achieving competitiveness for renewable technologies include tax incentives, green power incentives, and renewable portfolio standards. Such incentives have been helpful in increasing the amount of renewable generating capacity attached to the U.S. generating grids, particularly for wind power, over the last few years.

Besides being more costly than conventional generating sources, CSP electricity generation also is more costly than certain other renewable power generating technologies (notably wind) due primarily to CSP's higher capital cost. CSP cost-competitiveness relative to other renewables is important because CSP will be compared with other renewable technologies in states that have adopted renewable portfolio standards.

MHC GREEN ENERGY INC

Utility Scale Solar Power & Integrated Infrastructure

Electrical - Thermal - Co-Generation

Clean Green Energy

<u>Fuel-Free</u> <u>Carbon-Free</u>
<u>Emission-Free</u>

SOLAR CONCENTRATOR PLATFORM

Cost-Competitive Utility Scale Solar Energy

he Power-Spar System

Power-Spar Provides Flexibility in Energy Output:

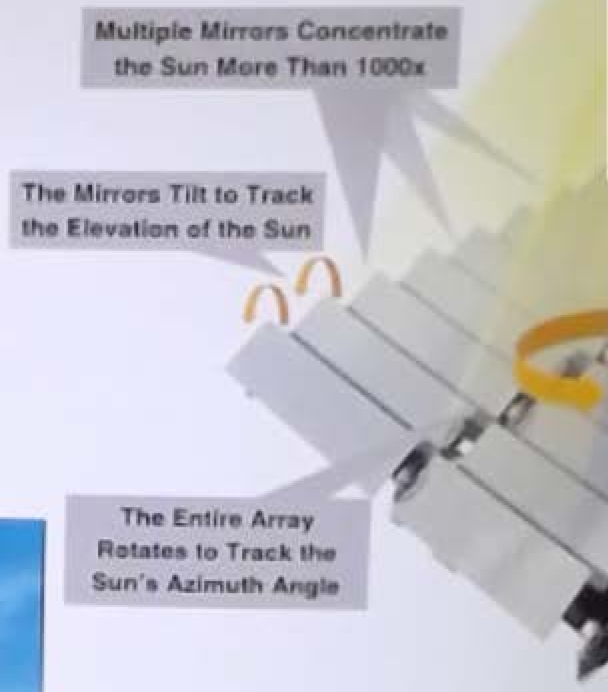
- Electricity
- Heat
- Process Steam
- Co-generated Electricity
- Fiber Optic Light

Versatile Installation:

- Ground, Rooftop or Parking Lot Mounts
- Unique Modular Design, Scalable in Size
- Quick Timeline: Start to Completion
- No Water Requirements

Affordable:

- Low Cost of Surface Area
- Efficient Scalability
- Cost-Competitive Solar Energy:
  - Residential and Commercial Buildings
  - Large Multi-Megawatt Solar Farms



Reduced Environmental Impact

- No Cement Foundation or Platform to Install
- Functions Well on Uneven Terrain

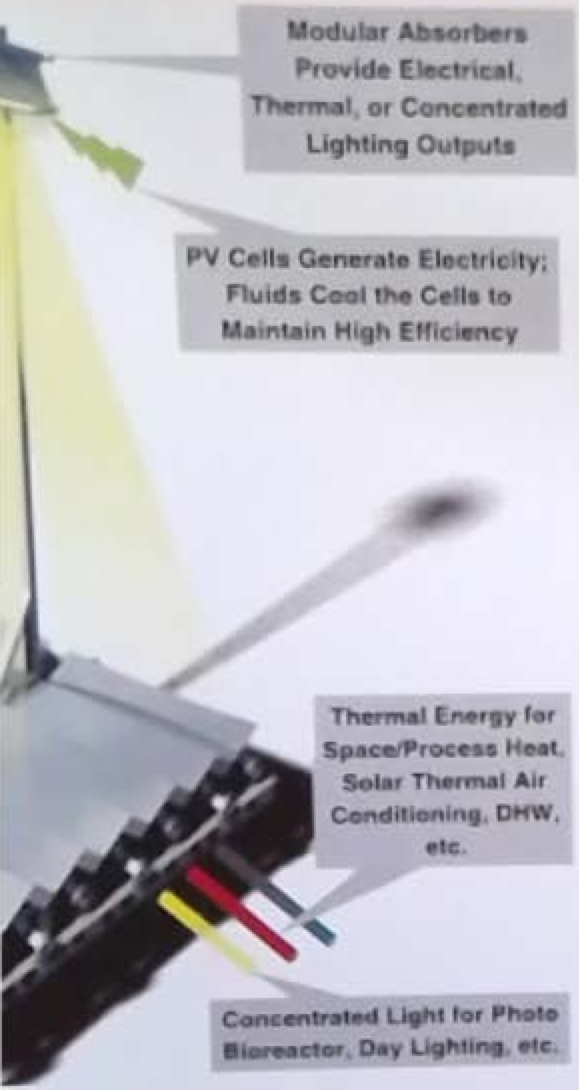
HIGHEST POW
ANY SOLAR TECH

- Highest System Efficiencie
- Highest Thermal Efficiency
- Very High Sunlight Capture
- Integrated Twin Axis Solar T Elevation and Azimuth Angl
  ⇒ 35% More Energy Pro

High Cost Efficiency in Solar Co-Generation

- Ultra High Efficiency Multi-Sun III-V Solar PV Cells (40% and Increasing Rapidly)
  - High Solar Concentration Ratio of 1400x
  - Captures a Greater Fraction of the Sun's Energy
- Patented High Efficiency Superior Optical Design
- Greater Electrical Production Due to Lower PV Operating Temperatures
- Enhanced Efficiency from Active Cooling in the Concentrated PV + Thermal (CPVT)

Generation	Conversion
Electricity	III-V PV Cells
Heating & Air Conditioning	Thermal Absorber
Process Steam	Optical Receiver, Transmitter, & Diffu



ER DENSITY OF
OLOGY AVAILABLE

Optical, Concentration, PV)
: Wide Range of Temperatures
Aperture-to-Land Area Ratio
racking System to Adjust to the
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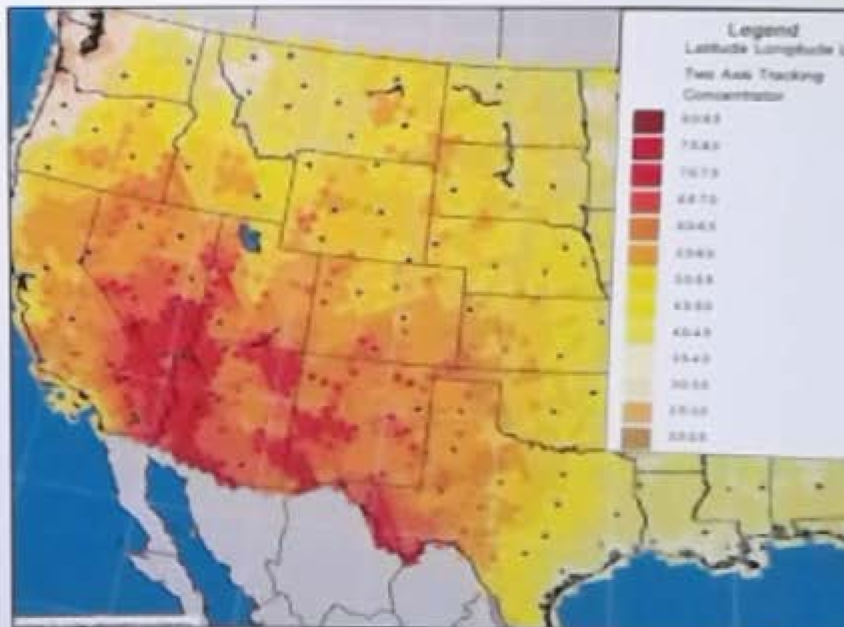
uced than with Flat-Plate PV!

	Installation	Concentration
	Ground Mount	Fresnel Parabolic Mirrors with Twin Axis Tracking
	Parking Lots	
r	Roof Mount	

Applications for Power-Spar Energy

- High-Density Commercial Thermal:
  - Hot Water, Building Heat, and Solar Thermal Air Conditioning (STAC)
- Co-Generation of Heat and Electricity
- Utility Scale Electricity Generation
  - Net Zero Energy Buildings
- Solutions for Desalination and Waste Water Treatment: Heat For Drying Anaerobic Digester Sludge
- Energy for Thermal-Based Refrigeration (Chilling and Pre-Cooling) and Dehumidification
- Waste-to-Energy Facilities and Photo Bioreactors



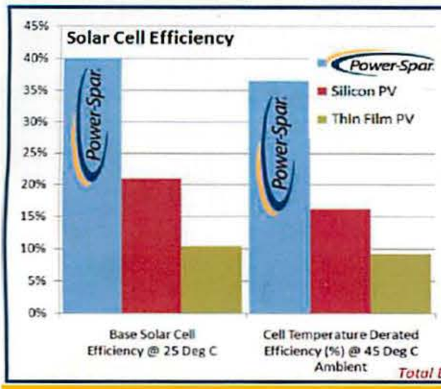
Increased Returns

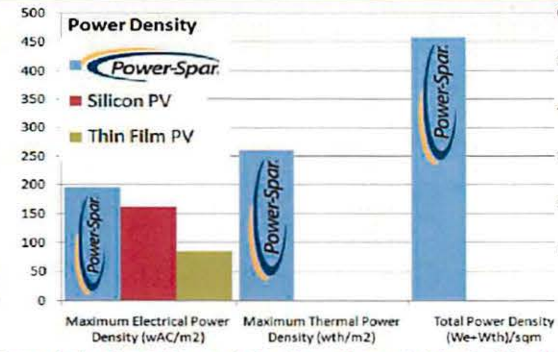
- Projects Financed and Completed Quicker
- Incremental Start-up Generates Rapid Revenue
- Reduces Financial Risk, Generates Increased Returns
- Real Time Energy Monitor, Data Logging, and Weather Monitor to Track Energy Production

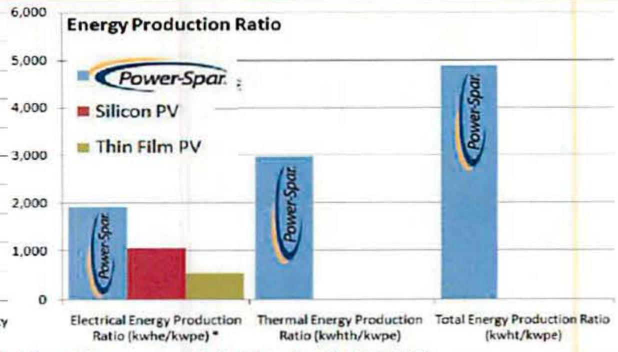
Low Operations and Maintenance Costs

- Low Wind and Shading Profile
- Self-Cleaning with Fewer Moving Parts
- Comprehensive Online Remote Monitoring
- Performance Based Alert System

Power-Spar



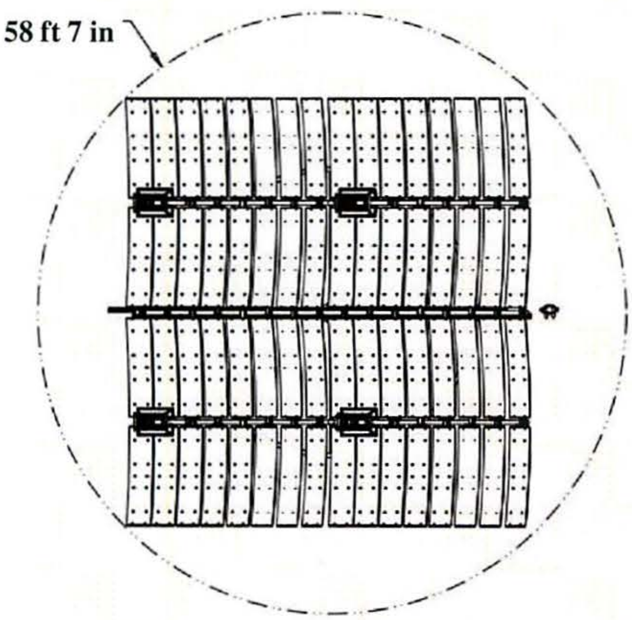


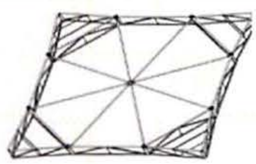


*Total Energy - kwht Electrical Energy - kwhe Thermal Energy - kwhth Peak Electrical Power - kwpe * - Data based on Abu Dhabi, UAE*

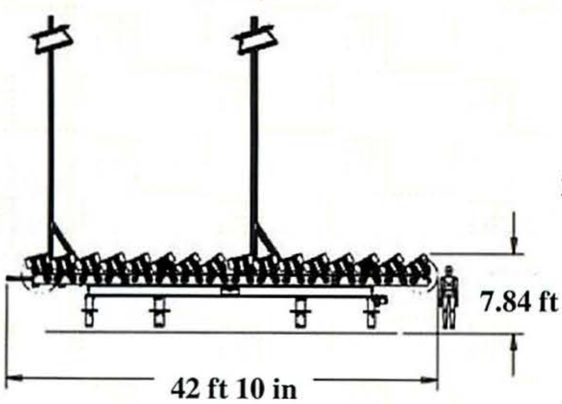
Power-Spar 140 Solar Concentrator Specifications

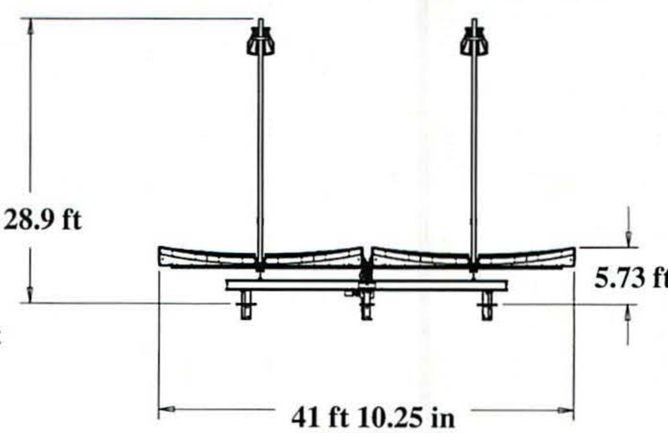
Size: 28 ft 10 7/8 in High x 58 ft 8 3/4 in Swing Diameter Weight: 12,125 lbs





Optional Frame Base for Roof Mount Load Spreading Installations





FSC

Contact Jim Meehan
MHC Green Energy, Inc.

Discover the Performance of Power-Spar at Your Location

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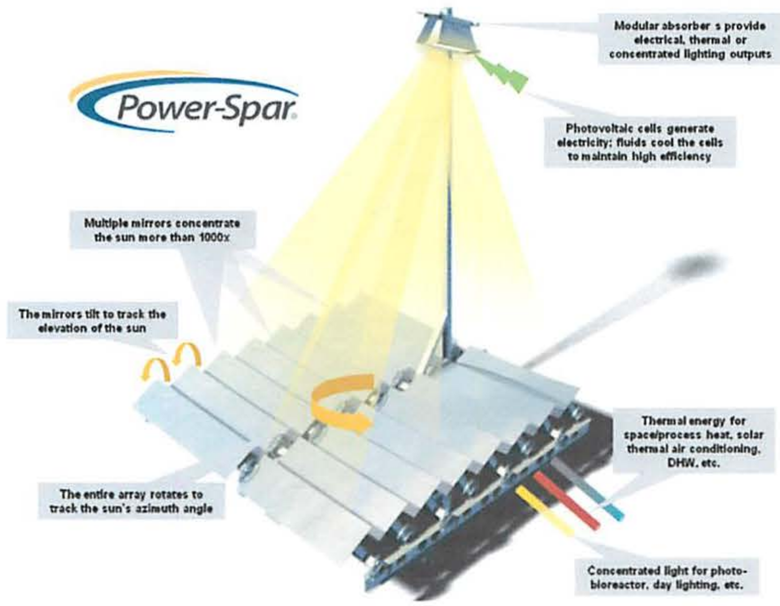
970-376-5120 Fax: 970-845-9569
www.power-spar.com

MHC GREEN ENERGY INC

Standards: CSA F379.1, CSA F378, CSA F383, UL 62108, UL 8703, UL 1703

Technical Specifications may change.

How it works



The Power-Spar is a two-axis tracking solar concentrator - one motor adjusts the tilt of the mirrors according to the elevation angle of the sun; the second motor rotates the entire array according to the azimuth angle.

The individual mirrors are parabolic so they focus the sun onto the absorbers which are suspended above the mirror surfaces - the light is concentrated to more than **1000** suns inside the absorber.

Did you know that all PV cells lose efficiency as their temperatures rise?

Conventional flat plate PV cells suffer a reduction of 0.09% (absolute efficiency) for every degree about 25°C whereas the Power-Spar's III-V (triple junction) cells have losses of only 0.06%.
So, when the cell temperatures rise to 45°C, the flat plate system efficiency will decrease by 1.8% while the III-V cells reduce by only 1.2%. However, from a production perspective this is a 10% loss for a conventional PV system (i.e., 1.8% of an 18% cell) but a very much smaller fraction for the Power-Spar because the initial III-V cell efficiency is more than 35%.

The Power-Spar is avaiable in two sizes - the PS-35 and the PS-140 (the PS-35 has approximately 35 m^2 of reflective surfaces; the PS-140 has 140 m^2). Each size is currently available in three different configurations - Combined PV & Thermal (CPVT); PV-only and Thermal-only. Another variant which simply transports the concentrated light is also under development and will be available commercially in the near future.

A heat transfer fluid (HTF) is run over the backsides of the PV cells to keep them cool (and the maintain their high efficiency). In the CPVT system, the heated fluid is then used for space, process or domestic water heating. With the inclusion of a Solar Thermal Air-Conditioning (STAC) unit, the thermal energy can also be used to provide cooling. In a PV-only system, the thermal energy in the HTF is dissipated through highly efficient coils. In both the CPVT and PV-only configuations, the temperature of the HTF is kept as low a possible to maximize the electrical output of the system.

The fluid temperatures in the Thermal-only configuration can be tailored to suit the requirements of the installation - ranging up to several hundred °C. An appropriate heat transfer fluid will be selected to match the desired outlet temperatures.

Visit the product info page for specification sheets or contact our sales staff for additional information.

MENOVA ENERGY IS HIRING!

CONTACT SALES
Get additional information for your project

TECHNICAL DRAWINGS
Updated technical drawings can now be found on the products page.

CURRENT SPAR-NET READINGS
Outside Temperature: **15.2° C** (59.4° F)
Collector Outlet: **19.8° C** (67.6° F)
Total Energy: **224,149 kWh** (764,828 mBTU)
CO_2 displaced: **88,999 lbs** (40,369 kg)
(as of 2009-05-04 20:20:00)

CBC NEWS STORY

This is a segment that ran on the CBC (Canadian Broadcast Corporation) following our Wal-Mart project announcement

Power-Spar

North America +1 (613) 599-6232 power-spar.com
Europe +34 617 86 87 67 power-spar.eu

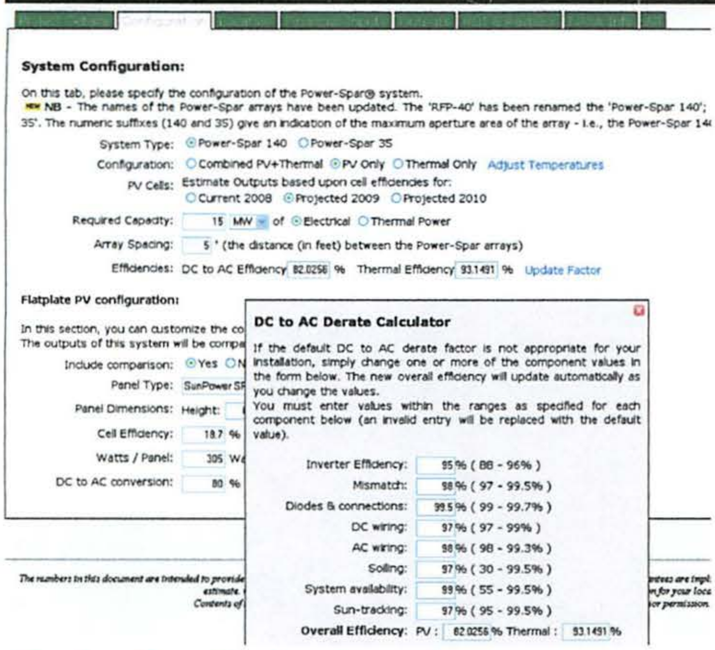
go to power-spar.com\sales for local sales

Power-Calc

System Configuration:

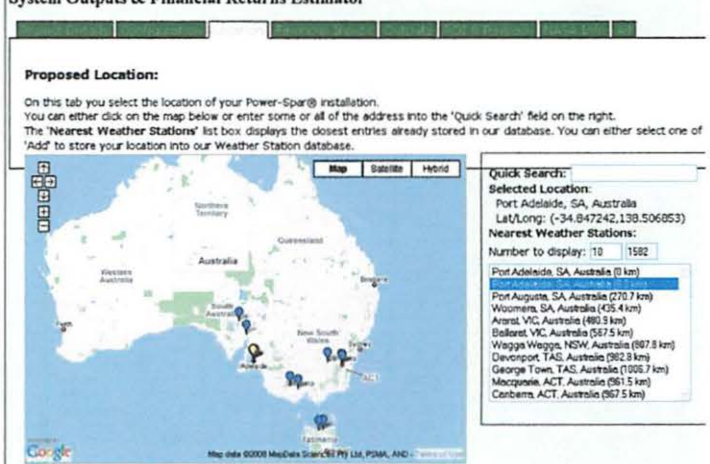
Web based
Return on Investment Analysis Tool
Performance Estimator
Google Maps Enabled
Automatic Solar Database look-up
Estimates monetary returns
Estimates Thermal and Electrical Energy

Password Protected Estimates
Data Base Driven
Multiple Language Enabled
Compares outputs to Flat Plate PV
Configurable Integrated Tax Calculator
Production Based Incentive Calculator
User Configurable for Energy Costs
Graphical & Tabular Output



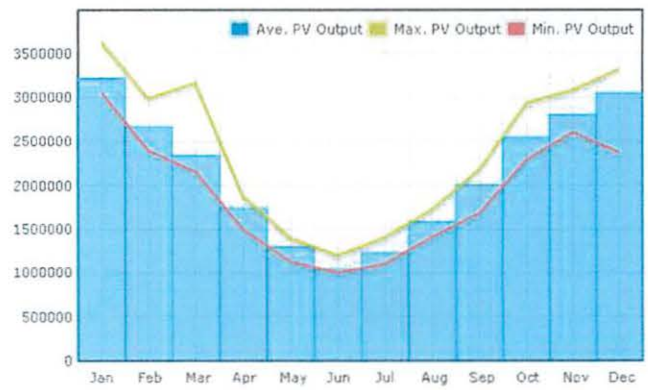
Project Specific Configuration

System Outputs & Financial Returns Estimator



Google Maps Enabled

Expected PV Outputs (in kWh/month)



Time-Based Energy Output Estimator

FSC

Applications:

Utility Scale Electricity Generation (PV)
High Density Commercial Thermal
Photo Bioreactor
Solar Thermal Air Conditioning
Net Zero Energy Buildings
Combined Solar Heat and Power

Mounting Options:
Parking lot, ground and roof top

Power-Spar

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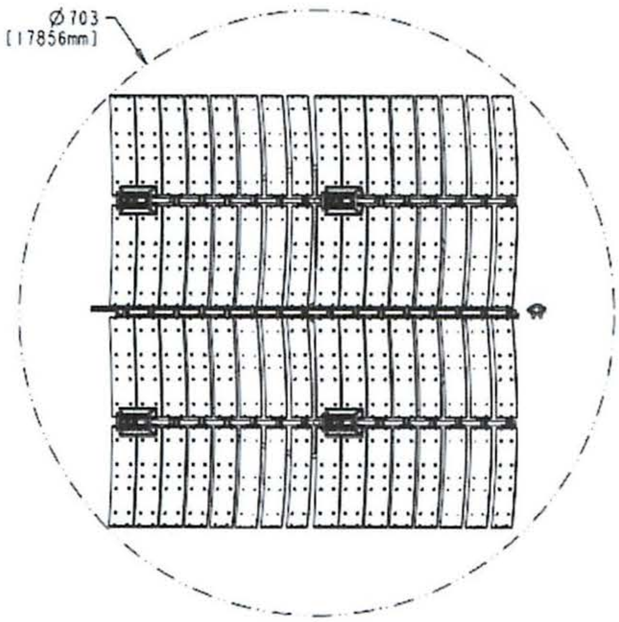
PS-140 Solar Concentrator

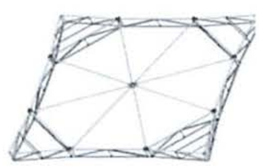
Size: 8810 mm h x 17900 mm swing diameter mass: 5500 kg

System Peak Performance:

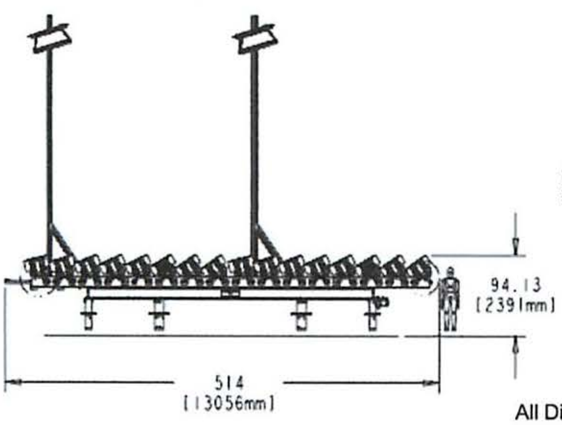
Combined Thermal & Electrical:	28 kW_e AC *Electrical* and 42 kW_{th} *Thermal* (143,000 BTU/h_{th})*
Electrical Only:	26 kW_e AC *Electrical*
Thermal Only:	85 kW_{th} *Thermal* (kW_{th}) (290,000 BTU/h_{th})*
Optical Only:	4,460,000 Lumens @ 30'

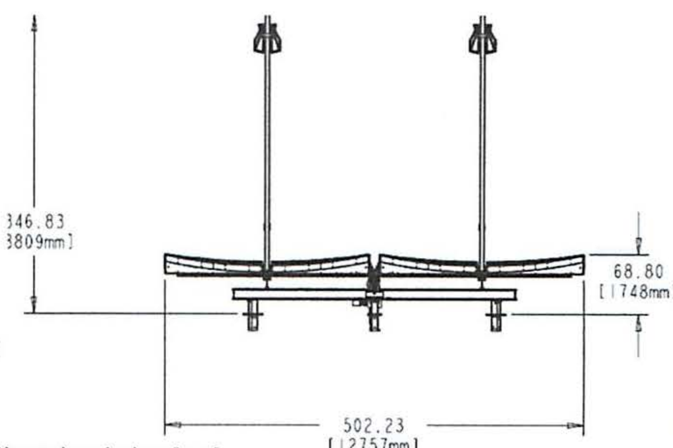
* Peak watts @ 890 watts/sqm solar radiation - 25°C, measured at module output. Consult Menova for a solar simulation with our "EnerCalc" software.





Optional Frame base for roof mount load spreading installations





All Dimensions inches [mm]

FSC

Applications:

Utility Scale Electricity Generation (PV)
High Density Commercial Thermal
Photo Bioreactor
Solar Thermal Air Conditioning
Net Zero Energy Buildings
Combined Solar Heat and Power

Mounting Options:

Parking lot, ground and roof top

Solar Plant to Generate Power After Sundown

LOSS 31Dec10 B1

BY REBECCA SMITH

Something new is headed for the Southwest desert: solar power plants that can make electricity whether or not the sun is shining.

Abengoa Solar Inc. expects to start construction in mid-2011 on a plant in Arizona that will store sun-generated heat to provide six extra hours a day of electric-generating capacity. The heat creates steam that is used to turn power turbines.

Abengoa's $2 billion Solana plant is expected to be the first major stored-heat plant in the U.S. when it enters service in 2013. Some already exist in Spain and a few more are on the drawing board for Nevada and California.

On Dec. 21, Abengoa, a unit of Spanish utility company **Abengoa** SA, cleared a major hurdle when it announced it received a $1.45 billion U.S. loan guarantee for the 250-megawatt Arizona project, planned for a site 70 miles southwest of Phoenix near Gila Bend.

The Solana plant will be able to meet winter heating and lighting needs by putting electricity on the grid early in the morning—before the sun is shining—and help satisfy summer cooling demand by producing power after sundown. The plant, which can power up to 70,000 houses, has signed a 30-year agreement to sell electricity to utility company Arizona Public Service.

Such utility-scale solar plants use mirrors to focus the sun's rays on a liquid, contained in tubes, which can be heated to very hot temperatures. The liquid is used to boil water and create steam. By using a conventional steam-turbine generator, electricity is produced.

Bloomberg News

Abengoa Solar's solar-generated plant for Arizona will provide extra electric-generating capacity. Above, an Abengoa facility in Seville, Spain.

But the twist is that the Arizona facility will have two giant salt tanks, each 122 feet in diameter and 34 feet deep, that together can hold and store 40% of the heat created by the plant.

Such storage technologies are expected to become more commonplace in the U.S. at solar plants as officials try to limit the release of carbon dioxide from fossil-fuel power plants and make renewable power production more dependable.

Mark Mehos, a solar program manager for the National Renewable Energy Lab in Golden, Colo., said such molten salt storage systems add about 20% to the construction cost of solar plants but more than make up for it by boosting a plant's flexibility and productivity.

Electricity from solar plants is expensive, especially at a time when natural-gas prices have plunged, making gas-generated electricity cheap by comparison. Utilities, which are under state mandates to buy more clean power, say solar power may look more economical in the future if fossil fuel prices rise or if a tax is imposed on carbon emissions by power plants.

When it comes to renewable energy, solar competes most heavily against wind power. A study by the Lawrence Berkeley National Laboratory in Berkeley, Calif., in February 2010 found that utility-scale solar plants with storage capacity were three times as costly to build as wind farms without energy storage.

The study found that solar electricity was more valuable, though, because its output was more correlated to peak electricity demand. Still, experts say that unless costs come down, the number of solar projects that get built will be limited.

SolarReserve LLC, a power development company in Santa Monica, Calif., is working on two solar projects in Nevada and California that will have even more heat-storage capacity, relative to their size, than Abengoa's project. These plants will put out 110 megawatts and 150 megawatts in electricity, respectively, and will be able to store enough heat to run eight to 12 hours without additional sunlight.

SolarReserve has power sales agreements with **NV Energy** Inc. and **PG&E** Corp., and expects to have the two plants in service by 2014. Each will cost $650 million to $750 million.

Don Brandt, chairman and chief executive of **Pinnacle West Capital** Corp., parent of Arizona Public Service, said heat storage at the Solana makes it "an extremely attractive project for us." By 2015, Arizona Public Service wants to get 10% of its electricity from renewable sources, and Abengoa's plant is expected to contribute a third of that.

Mr. Brandt said peak electricity demand for his utility typically hits about 4 p.m. in the summer but "we remain at elevated levels until around 10 o'clock at night" so getting renewable power later in the evening is valuable.

The U.S. National Renewable Energy Laboratory, part of the Department of Energy, says molten salt storage is "proven technology."

"When you put heat into one of these tanks, you get 95% or 96% of the heat back out again," said Mr. Mehos, at the energy lab. "It's a nice big Thermos."

Another plus of all three plants is they will produce power that can be tailored to a utility's specific needs, said Santiago Seage, president of Abengoa Solar. That's an asset to electrical grid operators that like to know they can rely on certain amounts of power flowing onto lines.