Energy Services BULLETIN

Vol. 26, No. 6, June 2007

This column features helpful information, innovative equipment, systems and applications utilities around the nation can use to save energy and improve service.

Solar thermal energy an option in large facilities

Solar thermal energy may be used to provide energy for a variety of uses including building space heating, refrigeration and air conditioning, domestic hot water, hot water and steam for industrial processes, drying and electric power generation.

The technology

In a typical solar thermal system, water or other heat-transfer fluid is heated by solar collectors and then circulated through equipment where the energy is used. Solar collector types include flat-plate collectors, evacuated-tube collectors and concentrating collectors such as parabolic troughs. The Canadian Renewable Energy Network describes the technologies.

Solar collectors can attain high temperatures—more than 500° F in commercially-available parabolic solar troughs and more than 300° F in evacuated-tube collectors. However, systems are generally not designed to deliver such high temperatures. Most systems using evacuated-tube or parabolic-trough collectors will deliver hot water at 195° F or less. For power generation or some industrial process heating, the system may be designed to achieve higher temperatures.

Cost-effectiveness

Because of economies of scale, solar thermal systems can be cost-effective for commercial, industrial and institutional facilities that require large volumes of mid- to high-temperature hot water, even if conventional fuel costs are relatively low. Solar thermal energy is most cost-effective in facilities that have a relatively constant energy requirement over the course of the day, week and year, or that have higher needs during the summer and during the day. Hotels, laundries, kitchens, prisons and military bases, for example, have relatively constant water heating needs.

Facilities with large, relatively constant *cooling* requirements that may be met by solar absorption cooling include computer data centers and cold storage facilities. CanREN provides background on solar cooling.

Generally, the bigger the project, the more cost effective it is. If the system is large enough, parabolic-trough collectors can be much less expensive than flat-plate collectors or evacuated-tube collectors. Parabolic troughs may be appropriate for projects with hot water requirements greater than about 10,000 gallons per day or with peak energy requirements for heating or cooling of at least 2 million Btu/h.

While economies of scale can bring costs down, often cost-effectiveness depends on Federal, state and utility incentives. Incentives are becoming more available, and the Database of State Incentives for Renewables and Efficiency contains a comprehensive listing of incentives available throughout the United States. The Solar Energy Industries Association also has a guide to Federal tax incentives.

Other considerations

- Energy can be stored for use at night and during brief cloudy periods.
- Systems generally require a large area for the collector field. A parabolic-trough project sized for a heating load of 3,000,000 Btu/h will require approximately 20,000 square feet of collectors. Including the necessary space between the collectors themselves, the total collector field will be three times this, or about an acre and a half. $78, 875 KWh
- Parabolic troughs require direct sunlight and so require a tracking system. This means the solar resource must be better than for flat plate collectors or evacuated tube collectors, which make better use of indirect light.
- Parabolic troughs are typically ground-mounted because of the large areas that are usually required to meet heating requirements. If trough collectors are roof-mounted, the stresses they transmit to the structure due to wind loading must be considered.
- Sizing affects cost-effectiveness. Often the most cost-effective system will be sized to just meet the full summer demand and 50 percent to 80 percent of the annual demand.
- Solar thermal energy is not restricted to southern latitudes. The number of clear, sunny days each year is more important than latitude. Eastern Oregon and Eastern Washington, for example, have good solar resources. Also, many solar thermal projects have been installed in New Jersey recently because of state incentives there.

Manufacturers

There are many suppliers of flat-plate and evacuated-tube collectors. There are at least three companies currently manufacturing modular solar parabolic troughs for commercial and industrial applications:

- Acciona (formerly Solargenix), North Carolina

- Solucar (formerly Industrial Solar Technology Corp.), Colorado
- Solitem, Germany

In 2005, the International Energy Agency published a list of various types of medium-temperature (up to 250°F) solar collectors commercially available or in pre-production at the time.

Case Studies

- Roof Mount Parabolic Troughs; Fort Sam Houston Army Medical Base, San Antonio, Texas. Industrial Solar Technology Corp., June 2003.
- *Heating Water with Solar Energy Costs Less at the Phoenix Federal Correctional Institution*; parabolic trough case study, Federal Energy Management Program, 1998.
- *Evacuated-Tube Heat-Pipe Solar Collectors Applied to the Recirculation Loop in a Federal Building*, June 2004. Social Security Administration, Philadelphia, Penn.

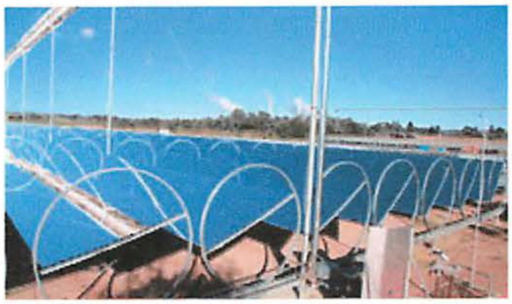
The Energy Blog

The Energy Revolution has begun and will change your lifestyle

« American Electric Power to Install Six MW of NAS® Battery Storage | Main

September 13, 2007

Compact Linear Fresnel Reflector Solar Power System Lower Cost Than Parabolic Trough Sytems, Ready Now



On Sept 10, Ausra Inc., the developer of utility-scale solar thermal power technology, announced that it has secured more than $40 million in funding from Silicon Valley venture capital firms Khosla Ventures and Kleiner, Perkins, Caufield & Byers (KPCB).

Ausra's power plants drive steam turbines with sunshine. Locally manufactured solar concentrators made of steel and glass focus sunlight to boil water, generating high-pressure steam that drives conventional turbine generators. New thermal energy storage systems using pressurized water and low cost materials will provide for on-demand generation day and night. Ausra's core technology, the Compact Linear Fresnel Reflector (CLFR) solar steam generation system, was originally conceived in the early 1990s by founder David Mills while at Sydney University. Mills later worked with Graham Morrison to develop the idea between 1995 and 2001.

Austra's innovation is that it uses commodity flat mirrors that sit low to the ground. The refectors concentrate sunlight on water-filled pipes that hang over the mirrors. As the water is heated up to 545 degrees fahrenheit (285 celsius) the resulting steam drives a standard turbine.

> *"We had been working on a wide range of alternatives and kept finding that simpler, cheaper approaches outperformed higher-temperature, more sophisticated designs,"* says Ausra Chairman David Mills.

The company claims that:

> CLFR technology has significant advantages in cost, scalability and emissions profile.
>
> Utility scale solar technology has traditionally been parabolic trough, but Ausra's less complex flat mirrors are much less

WELCOME TO THE ENERGY BLOG

Increasingly expensive oil and global warming are causing an energy revolution by requiring oil to be supplemented by alternative energy sources and by requiring changes in lifestyle. The Energy Blog is a place where all topics relating to The Energy Revolution are presented and form the basis for discussion. I hope that this site will be a useful reference for those who wish to find information about The Energy Revolution. Please contact me with your comments and questions. Further Information about me can be accessed by clicking HERE.

Jim

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Amazon.com: Harry Potter and the Deathly Hallows (Book 7) (Deluxe Edition): Books: J. K. Rowling,Mary GrandPré

THE ENERGY REVOLUTION

The following are the posts that define The Energy Revolution. They describe the causes and solutions as I envision them. I hope that you will find them useful in providing a background for your journeys in exploring The Energy Revolution.

The Energy Revolution Has Begun

Elements of the Energy Revolution

Further Elements of the Energy Revolution

Obstacles to The Energy Revolution

RECENT POSTS

Compact Linear Fresnel Reflector Solar Power System Lower Cost

GE BL

AP

Aft

Parabolic Trough System and Component Test

Here you'll find information about parabolic trough system and compon laboratories used for testing. Tests include those for:

- Concentrator thermal efficiency
- Receiver thermal performance
- Mirror contour and collector alignment
- Mirror reflectivity and durability

Some of the following documents are available as Adobe Acrobat PDFs.

Concentrator Thermal Efficiency Testing

Researchers and industry use the following facilities for testing paraboli

AZTRAK Rotating Platform

At Sandia National Laboratories' National Solar Thermal Test Facility (N platform has been used to test several parabolic trough modules and re tested a LS-2 collector. And they've recently conducted a number of ad

For more information, read Sandia's poster on *Testing Capabilities-NST* (PDF 545 KB).

Plataforma Solar de Almería

CIEMAT and DLR (German Aerospace Center) have tested a number of Plataforma Solar de Almeria (PSA) in Spain on its collector thermal test a collector loop to test direct steam generation (DSG) in the solar field.

For more details, see Plataforma Solar de Almeria's information on its li facilities.

ENEA Solar Collector Test Facility

The Italian National Agency for New Technologies, Energy and the Envi has installed a collector thermal test loop to test the operation of parab molten-salt heat transfer fluid. This solar collector test facility-called PC up to 550°C.

For more information, read ENEA's presentation on *Trough Molten Salt Test Experience* (PDF 4.0 MB).

SEGS Plant Test Loops

A number of instrumented test loops have been installed in operating p collector or component performance.

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(G=German)

Parabolic Trough Power Plant

Concave mirrors and lenses have been used for ages to concentrate the sun's rays on a single point and therefore multiply its strength. Mirrors with a parabolic cross-section are especially suited to this purpose because they can also focus the outer rays towards the middle. If a mirror is designed in the form of a trough, the solar radiation, concentrated about forty times, can be focused on an absorber tube with a heat-conducting fluid inside.

The best use for these tube collector thermal solar power systems is for domestic water heating and heating support. A well-known high-tech system is the parabolic trough power plant in the Californian Mojave Desert. It has a total of 2.3 million square meters of mirror surface area and produces 354 megawatts of electricity. To improve their performance they can be rotated about their roll axis. The heat-conducting fluid is heated up to 400 °C and by means of a turbine and generator then produces electric current. Similar large plants are also planned at Crete, Egypt and India and should be able to deliver electricity at a price of about $ 0.07 (0.08 €) per kilowatt-hour.

The Center for Solar Energy and Hydrogen Research (Zentrum für Sonnenenergie- und Wasserstoff-Forschung (ZSF)) in Stuttgart, Germany operates an experimental plant in Almeria, Spain with oil as the heat-conductor and heat-storage fluid.

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Affordabe Der
photovoltaic s
design and ins
www.vibrantSolar

Previous Topic:
Parabolic Mirror

Next Topic:
Passive Building

Solar Lexicon Index

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Lexicon | Basic Knowledge | Educational Institutions | Imprint | Contact Us | Home
(G=German)
Last modified: 01/19/2008 12:42:28
A service of: Heindl Internet AG

1- 7 Oct 07
file - www1.eere.energy.gov/femp/pdfs/FTA-para-trough.pdf
44 pages.

Federal Technology Alert

A publication series designed to speed the adoption of energy-efficient and renewable technologies in the Federal sector

Prepared by the New Technology Demonstration Program

Parabolic-Trough Solar Water Heating

Renewable technology for reducing water-heating costs

Parabolic-trough solar water heating is a well-proven technology that directly substitutes renewable energy for conventional energy in water heating. Parabolic-trough collectors can also drive absorption cooling systems or other equipment that runs off a thermal load. There is considerable potential for using these technologies at Federal facilities in the Southwestern United States or other areas with high direct-beam solar radiation. Facilities such as jails, hospitals, and barracks that consistently use large volumes of hot water are particularly good candidates. Use of parabolic-trough systems helps Federal facilities comply with Executive Order 12902's directive to reduce energy use by 30% by 2005 and advance other efforts to get the Federal government to set a good example in energy use reduction, such as the 1997 Million Solar Roofs Initiative.

This *Federal Technology Alert* (FTA) from the Federal Energy Management Program (FEMP) is one of a series on new energy-efficiency and renewable energy technologies. It describes the technology of parabolic-trough solar water-heating and absorption-cooling systems, the situations in which parabolic-trough systems are likely to be cost effective, and considerations in selecting and designing a system. This FTA also explains energy savings performance contracting (ESPC), a method for financing Federal facility energy conservation and renewable energy projects. ESPC is available for parabolic-trough systems and offers many important advantages.

Parabolic-trough collectors use mirrored surfaces curved in a linearly extended parabolic shape to focus sunlight on a dark-surfaced absorber tube running the length of the trough. A mixture of water and antifreeze or other heat transfer fluid is pumped through the absorber tube to pick up the solar heat, and then through heat exchangers to heat potable water or a thermal storage tank. Because the trough mirrors will reflect only direct-beam sunlight, parabolic-trough systems use single-axis tracking systems to keep them facing the sun.

Application

Use of parabolic-trough systems is more limited by geography and system size than are other types of solar water heating, but where parabolic troughs are usable they often have very attractive economics. As concentrating systems, parabolic troughs use only direct radiation, so are less effective

Warren Gretz, NREL/PIX01019

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Contents

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. Downloa

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 (PDI
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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Content Last Updated: April 04, 2007

U.S. Parabolic Trough Power Plant Data

Here you'll find data on parabolic trough power plants in operation and under development in the United States. The data include plant type, technology, net output, project type, and funding.

Plant Name	Location	First Year of Operation	Net Output (MW_e)	Solar Field Outlet (°C)	Solar Field Area (m^2)	Solar Turbine Effic. (%)	Power Cycle	Dispatchability Provided By
Nevada Solar One	Boulder City, NV	2007*	64	390	357,200	37.6	100 bar, reheat	None
APS Saguaro	Tucson, AZ	2006	1	300	10,340	20.7	ORC	None
SEGS IX	Harper Lake, CA	1991	80	390	483,960	37.6	100 bar, reheat	HTF heater
SEGS VIII	Harper Lake, CA	1990	80	390	464,340	37.6	100 bar, reheat	HTF heater
SEGS VI	Kramer Junction, CA	1989	30	390	188,000	37.5	100 bar, reheat	Gas boiler
SEGS VII	Kramer Junction, CA	1989	30	390	194,280	37.5	100 bar, reheat	Gas boiler
SEGS V	Kramer Junction, CA	1988	30	349	250,500	30.6	40 bar, steam	Gas boiler
SEGS III	Kramer Junction, CA	1987	30	349	230,300	30.6	40 bar, steam	Gas boiler
SEGS IV	Kramer	1987	30	349	230,300	30.6	40 bar,	Gas boiler

	Junction, CA						steam	
SEGS II	Daggett, CA	1986	30	316	190,338	29.4	40 bar, steam	Gas boiler
SEGS I	Daggett, CA	1985	13.8	307	82,960	31.5	40 bar, steam	3-hrs TES

Notes: *Planned date of operation

For information and data on international parabolic trough power plants, visit the SolarPaces Web site.

Nevada Solar One

Location: Eldorado Valley, Boulder City, Nevada
First Year of Operation: 2007 (planned)
Type: Reheat steam Rankine cycle power plant
Fossil fuel: None
Net Output: 64 MW
Principals: Acciona/Solargenix Energy (Developer/Solar Technology/Operator), Nevada Power (Utility PPA), Siemens (power cycle)
Solar Technology: Solargenix SGX-1 parabolic trough collector; Schott PTR70 & Solel UVAC receivers; Flabeg mirror.
Project Type: Independent power project for meeting Nevada renewable portfolio standard (RPS), special power purchase agreement
Operational Dispatch: Solar-only operation
Special Incentives: Project supports Nevada solar RPS set aside; federal 30% investment tax credit
Status: Start-up in Spring 2007

Back to Top

Arizona Public Services Saguaro Project

Location: Saguaro, Arizona, near Tucson
First Year of Operation: 2006
Type: Recuperated organic Rankine cycle power plant, using pentane working fluid heated to 300°C.
Fossil fuel: None
Net Output: 1 MW
Principals: Arizona Public Service (owner/operator), Solargenix Energy (developer/solar provider), Ormat (power cycle)
Solar Technology: Solargenix DS-1 parabolic trough collector; Schott PTR70 receivers; Flabeg mirrors
Project Type: Utility ownership; supports Arizona renewable portfolio standard (RPS) requirements.

Parabolic Trough Thermal Energy Storage Pub

This section features publications about parabolic trough thermal energ

- General
- Indirect two-tank
- Molten-salt heat transfer fluid and thermocline
- Advanced heat transfer fluid development
- Other

Some of the following documents are available as Adobe Acrobat PDFs.

Parabolic Trough Thermal Energy Storage — General

Presentations on Thermal Energy Storage for Parabolic Trough I
Event: 2003 Thermal Energy Storage for Trough Power Systems Works

Survey of Thermal Energy Storage for Parabolic Trough Power P
Article Available from: Journal of Solar Energy Engineering
Authors: Herrmann, U.; Kearney, D.
Publication Date: May 2002

Survey of Thermal Storage for Parabolic Trough Power Plants
NREL Subcontract Report: (PDF 1.6 MB)
Author: Pilkington Solar International GmbH
Publication Date: September 2000

Presentations on Parabolic Trough Thermal Energy Storage
Event: 2006 Parabolic Trough Technology Workshop, Incline Village, Ne

Parabolic Trough Thermal Energy Storage Indirect Two-

Thermal Storage Commercial Plant Design Study for a 2-Tank In
NREL Subcontract Report: (PDF 891 KB)
Authors: Kearney, D; Kelly, B.; Price, H.
Publication Date: July 2006

Parabolic Trough Molten-Salt Heat Transfer Fluid and Tl

Testing Thermocline Filler Materials and Molten-Salt Heat Trans Storage Systems Used in Parabolic Trough Solar Power Plants
Posted with Permission from Sandia National Laboratories: (PDF 8.2 MB
Authors: Brosseau, D.A.; Hlava, P.F.; Kelly, M.J.

Publication Date: July 2004

Evaluation of a Molten Salt Heat Transfer Fluid in a Parabolic Tr
Conference Paper Available from: American Society of Mechanical Engir
Event: ASME 2002 International Solar Energy Conference, June 2002, I
Authors: Kearney, D; Kelly, B.; Herrmann, U.; Cable, R.; Pacheco, J.; N
Nava, P.; Potrovitza, N.

Development of a High Temperature, Long-Shafted, Molten-Salt Applications
Article Available from: Journal of Solar Energy Engineering
Authors: Barth, D.; Pacheco, J.; Kolb, W.; Rush, E.
Publication Date: May 2002

Development of a Molten-Salt Thermocline Thermal Storage Sys Plants
Article Available from: Journal of Solar Energy Engineering
Authors: Pacheco, J.; Showalter, S.; Kolb, W.
Publication Date: May 2002

Development of a Molten-Salt Thermocline Thermal Storage Sys Plants
Conference Proceedings Available from: American Society of Mechanica
Event: ASME International Solar Energy Conference: The Power to Cho
D.C.
Authors: Pacheco, J.E.; Showalter, S.K.; Kolb, W.J.

Parabolic Trough Advanced Heat Transfer Fluid (HTF) D

Lifetime of Imidazolium Salts at Elevated Temperatures
Article Available from: Journal of Solar Engineering
Authors: Blake, D.M.; Moens, L.; Rudnicki, D.; Pilath, H.
Publication Date: March 2005

Thermal Stability and Corrosivity Evaluations of Ionic Liquids as Media
Article Available from: British Library Direct
Authors: Reddy, R.G.; Zhang, Z.; Arenas, M.F.; Blake, D.M.
Publication Date: 2003

Advanced Thermal Storage Fluids for Solar Parabolic Trough Sys
Available from: American Society of Mechanical Engineers
Event: ASME 2002 International Solar Energy Conference, June 2002, I
Authors: Moens L.; Blake, D.M.; Rudnicki, D.L.; Hale, M.J.

Other

Phase-Change Thermal Energy Storage
NREL Subcontract Report: (PDF 4.8 MB)
Author: LUZ International
Publication Date: 1989

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Content Last Updated: April 04, 2007

Solar Power Plant

Solar Power Plant

We are going to use the solar power plant as our first study case for the analysis of a complete thermal system. Throughout this class, and the second class as well, we are going to revisit this system over and over again. The main purpose is to provide you an integrated view of the entire system and to show the connectivity between different disciplines in thermal science.

What is a solar power plant? Go visit **SunLab** and other Internet links to learn more about it.

Technology
Solar Trough System

Solar Power Towers

Solar Dish/Engine Systems

Relevant Subjects
Heat Transfer

- General Description- A short definition
- Radiation
- Convection
- Conduction-links to lecture notes
- Heat Exchanger- **CyclePad** models thermal cycles by analyzing each component. This links to **CyclePad**'s definition of a Heat Exchanger.

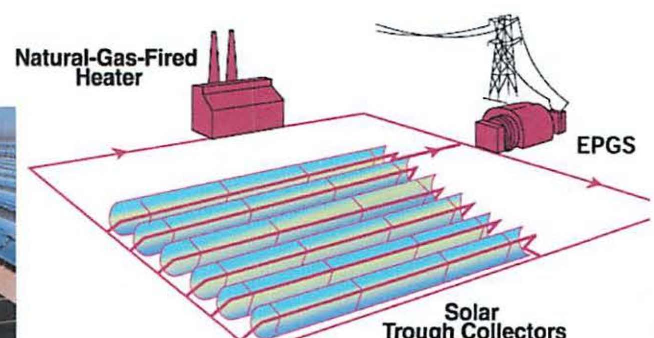
Fluid Mechanics

Sandia's National Solar Thermal Test Facility is an important resource for users and manufacturers of solar thermal power systems. Manufacturers can use the NSTTF to test new designs, ideas, and products in an outdoor environment much like the environment the equipment will be in when it is used in the field.

Solar Trough System

Trough systems predominate among today's commercial solar power pl: Trough systems convert the heat from the sun into electricity. Because o parabolic shape, troughs can focus the sun at 30 to 60 times its normal intensity on a receiver pipe located along the focal line of the trough. Sy oil captures this heat as the oil circulates through the pipe, reaching temperatures as high as 390°C (735°F). The hot oil is pumped to a gener station and routed through a heat exchanger to produce steam. Finally, electricity is produced in a conventional steam turbine.

Solar Trough Systems



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Advanced Optical Materials
Concentrating Photovoltaics
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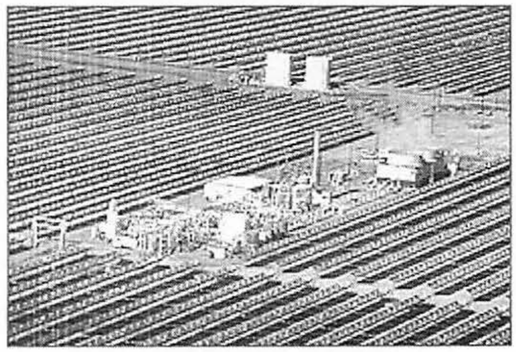
Publications
Data & Resources
Related Links

TroughNet

Parabolic-Trough Solar Power Plant Technology



A concentrating solar power plant at Kramer Junction in Boron, California. *Credit: Sandia National Laboratories Photo Database*

NREL continues to evaluate and develop opportunities for improving the cost effectiveness of parabolic-trough concentrating solar power plants.

Primarily, we're working to integrate parabolic-trough technology into Rankine cycle power plants—the power plants of choice because of their efficiency. We're also working to reduce power plant and solar-field operation and maintenance (O&M) costs by:

- Scaling up plant size
- Increasing capacity factor
- Improving receiver and mirror reliability, and mirror-washing techniques
- Developing improved automation and control systems
- Developing O&M data integration and tracking systems.

Specific project activities include participating in the design review of the first small modular, parabolic-trough plant to utilize an organic Rankine cycle power plant. We'll also help develop an O&M database to track the plant's component failures and maintenance, and evaluate its thermal energy storage options.

Printable Version

Parabolic Trough Thermal Energy Storage Tec

One advantage of parabolic trough power plants is their potential for st during non-solar periods and to dispatch when it's needed most. As a r (TES) allows parabolic trough power plants to achieve higher annual ca without thermal storage up to 70% or more with it.

Parabolic trough thermal energy storage technology includes:

- Storage systems
  - Two-tank direct
  - Two-tank indirect
  - Single-tank thermocline
- Molten-salt heat transfer fluid
-

Thermal Energy Storage Systems

Two-Tank Direct

The first Luz trough plant, SEGS I, included a direct two-tank thermal e hours of full-load storage capacity. This system simply used the minera (HTF) to store energy for later use. It operated between 1985 and 199 power to meet the Southern California Edison winter evening peak dem 5-10 p.m.).

Because power plants later moved to higher operating temperatures fo efficiency, they also switched to a new higher temperature heat transfe biphenyl-diphenyl oxide (Therminol VP-1 or Dowtherm A). Unfortunatel pressure. Therefore, it cannot be used in the same type of large unpres similar to the one used for SEGS I.

Pressurized storage tanks are very expensive. They cannot be manufac for parabolic trough plants.

Two-Tank Indirect

In recent years, a new indirect thermal energy storage (TES) approach has been developed. This approach takes advantage of the experience with the storage system used in the Solar Two— a molten-salt power tower demonstration project—and integrates it into a parabolic trough plant with the conventional heat transfer fluid through a series of heat exchangers.

Figure storag

The thermal energy storage system is charged by taking hot, heat transfer fluid (HTF) from the solar field and running it through the heat exchangers. Cold molten-salt is taken from the cold storage tank and run counter currently through the heat exchangers. It's heated and stored in the hot storage tank for later use. Later, when the energy in storage is needed, the system simply operates in reverse to reheat the solar heat transfer fluid, which generates steam to run the power plant system because it uses a fluid for the storage medium that's different f field.

Flagso

Several parabolic trough power plants under development in Spain plar storage concept. For future parabolic trough power plants, a number of being considered for reducing the cost of the thermal energy systems.

A two-tank indirect thermal energy storage system is relatively expensi The expense is due to the heat exchangers and the relatively small terr cold and hot fluid in the storage system.

For more information, see our publications on two-tank indirect therma

Single-Tank Thermocline
A single tank for storing both the hot and cold fluid provides one possib of a direct two-tank storage system. This thermocline storage system f the cold fluid on the bottom. The zone between the hot and cold fluids i

A thermocline storage system has an additional advantage—most of th with a low-cost filler material. Sandia National Laboratories has demon thermocline storage system with binary molten-salt fluid, and quartzite material.

Depending on the cost of the storage fluid, the thermocline can result i storage system. However, the thermocline storage system must mainta tank, so that it does not expand to occupy the entire tank.

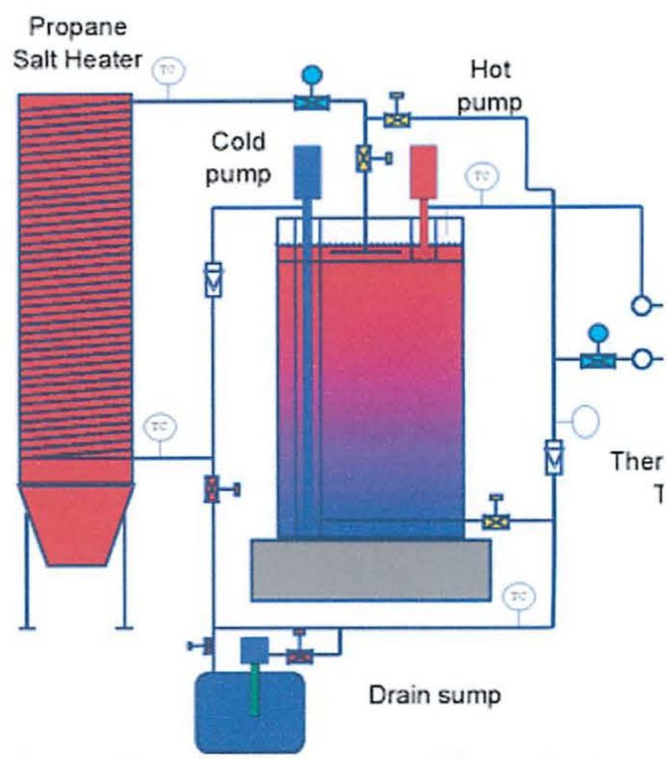


Figure 2. Thermocline test at Sandia National Laboratories.
Sandia National Laboratories

For more information, see our publications on thermocline systems.

Direct Molten-Salt Heat Transfer Fluid

Using molten-salt in both the solar field and thermal energy storage sy: expensive heat exchangers. It allows the solar field to be operated at h heat transfer fluids allow. This combination also allows for a substantial thermal energy storage (TES) system.

Unfortunately, molten-salts freeze at relatively high temperatures 120 means that special care must be taken to ensure that the salt does not during the night.

The Italian research laboratory, ENEA, has proven the technical feasibil parabolic trough solar field with a salt mixture that freezes at 220°C (4 Laboratories are developing new salt mixtures with the potential for fre At 100°C the freeze problem is expected to be much more manageable

For more information, see our publications about molten-salt heat trans

Thermal Energy Storage Media

Concrete

The German Aerospace Center (DLR) is examining the performance, durability and cost of using solid, thermal energy storage media (high-temperature concrete or castable ceramic materials) in parabolic trough power plants.

The Ge facility testin systen

This system uses the standard heat transfer fluid (HTF) in the solar field. The heat transfer fluid passes through an array of pipes imbedded in the solid medium to transfer the thermal energy to and from the media during plant operation.

The primary advantage of this approach is the low cost of the solid media. Primary issues include maintaining good contact between the concrete and piping, and the heat transfer rates into and out of the solid medium.

At the Plataforma Solar de Almeria in Southern Spain, Ciemat and DLR performed initial testing that found both the castable ceramic and high-temperature concrete suitable for solid media, sensib However, the high-temperature concrete is favored because of lower cc and easier handling. There is no sign of degradation between the heat material.

DLR has also developed a design tool that helps optimize the storage la dimensions and piping and module arrangement to minimize pressure l manufacturing aspects and costs.

Because of the modular nature of concrete storage, DLR has identified storage system to better integrate with the solar field and power cycle. utilization of the concrete storage system. DLR is also testing a new, m module at the University of Stuttgart.

Phase-Change Materials
Phase-change materials (PCMs) allow large amounts of energy to be st
resulting in some of the lowest storage media costs of any storage con

Initially phase-change materials were considered for use in conjunction
used Therminol VP-1 in the solar field. Luz, and later ZSW, proposed ar
set of phase-change materials to transfer heat from the heat transfer fl
thermal energy transfers to a series of heat exchangers containing pha
slightly different temperatures. To discharge the storage, the heat tran
results in reheating of the heat transfer fluid.

Although testing proved the technical feasibility of this system, further
hindered because of the:

- Complexity of the system
- Thermodynamic penalty of going from sensible heat to latent hea
- Uncertainty over the lifetime of phase-change materials.

More recently DLR is evaluating phase-change thermal energy storage
generation in the parabolic trough solar field. This allows for a better th
the phase-change material and the phase-change of steam used in the
single phase-change material can be used to preheat, boil, and superhe
the cost of the system is driven not only by the cost of phase-change s
rate at which energy will be charged or discharged from the material.

Also, DLR has developed a graphite foil that it uses to sandwich the pha
increasing heat transfer rates. Lab scale tests of this approach have de
future tests will be integrated into the DISS facility at the Plataforma S

For more information, see our publications about phase-change materia

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Content Last Updated: April 04, 2007

Selected Concentrated Solar Power Pr

1. Parabolic trough

Contract Reference: ENK5-CT-2001-00540
Title: Integration of DSG Technology for Electricity Productio
ACRONYM: INDITEP
Objectives
Direct steam generation in the absorber pipes of parabolic trough s collectors (the so-called DSG process) is a promising option for cost reduction and could achieve a 26% cost cut in the electricity produc INDITEP is based on the experience and knowledge gathered by the partners of the DISS project and it is the logical continuation of DIS Once the technical feasibility of the DSG technology has been valida experimentally in DISS-phase II, INDITEP will undertake four main packages aimed at integrating DSG technology into the energy mar

- The engineering design of a first 5MWe pre-commercial DSG power plant.
- The development of advanced components to enhance the a of DSG technology to compete, e.g. cheap water/steam separators, and advanced components to increase the stean temperature from 400ºC to 500ºC etc.
- The qualification of key components and operation procedur DSG power plants.
- Socio-economic research on DSG technology.

Expected Impact
The main expected result will be the design of a modular paraboli trough system adaptable to both electricity and steam generation project is also expected to improve the cost reduction potential of DSG technology so that installation costs could fall below 2000€/k
Co-ordinating institution
Iberdrola Generation S.A.
Hermosilla 3
ES-28001 Madrid
Spain
Start Date: 1 July 2002
End Date: 30 June 2005
Duration: 36 months
Total cost: €5,397,570
EC funding: €2,698,784
Link to the European Commission's project database on CORDIS f further details

Contract Reference: ERK6-CT-1999-00018
Title: EuroTrough II, test and qualification of a full scale loo eurotrough collectors
ACRONYM: EuroTrough - II
Objectives
The objective is to extend the total collector length from today's 10 state-of-the-art to 150m and to reduce the number of tracking syst controllers and flexible joints in a solar field by 33%. The goals and

TROUGHNET
PARABOLIC TROUGH SOLAR POWER NETWORK

Projects

NREL's R&D projects in concentrating solar power focus on parabolic-trough solar technology and advanced concentrating solar power technologies. We also support the U.S. Department of Energy in its concentrating solar power deployment efforts.

Parabolic-Trough Solar Technology

Parabolic-trough solar technology is a proven, robust, and reliable power source for large, utility-scale power plants. In addition to proven performance, the main advantages of parabolic troughs include:

- Manufacturing simplicity
- Use of standard equipment and improvements
- Improvement in cost effectiveness
- Low technical and financial risk to the investor.

Despite its advantages, parabolic-trough solar technology is not yet cost competitive in today's energy market. However, the technology has great potential for cost reduction. NREL works not only to improve parabolic-trough technology but also to increase its cost effectiveness through the following R&D projects:

Parabolic-trough solar field technology
Parabolic-trough thermal energy storage technology
Parabolic-trough solar power plant technology
Parabolic-trough systems integration

Advanced Concentrating Solar Power Technologies

NREL's research and development in advanced concentrating solar power technologies includes the following crosscutting projects that aren't tied to a single concentrating solar power technology:

Advanced optical materials for concentrating solar power
Concentrating photovoltaic technology

Concentrating Solar Power System Deployment

NREL currently supports the following U.S. Department of Energy concentrating solar power system deployment efforts:

Southwest Concentrating Solar Power 1000-MW Initiative
USA Trough Initiative

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Concentrating Solar Power Research Home
Technology Basics
Capabilities
Projects
1000 MW Initiative
USA Trough Initiative
Trough Solar Field Technology
Thermal Energy Storage
Trough Power Plant Technology
Trough Systems Integration
Advanced Optical Materials
Concentrating Photovoltaics
Research Staff
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Parabolic Trough Thermal Energy Storage Technology

NREL works to develop efficient and lower cost thermal energy storage technologies for parabolic trough concentrating solar power systems. Improved thermal energy storage is needed to:

- Increase solar plant capacity factors above 25%
- Increase dispatchability of solar power
- Help reduce the cost of solar electricity.

Parabolic trough technology currently has one thermal energy storage option—a two-tank, indirect, molten-salt system. The system uses different heat transfer fluids for the solar field and for storage. Therefore, it requires a heat exchanger. It has a unit cost of $30-$40/kWht.

To reduce the unit cost to below $10/kWht, we're working to develop single-tank, thermocline storage systems and heat transfer fluids that can be used in both the solar field and in the storage system.

See information on NREL's Advanced Thermal Storage Materials Laboratory to learn more about our capabilities concerning the research and development of heat transfer fluids.

Visit TroughNet for an overview of parabolic trough thermal energy storage technology.

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Parabolic-Trough Solar Collectors

Description: Parabolic-trough solar collectors use mirrored surfaces curved in a parabolic shape that linearly extend into a trough shape. The collector focuses sunlight on a tube running the length of the trough. A heat transfer fluid is pumped around a loop through this tube, picking up heat. The fluid then goes to a heat exchanger where it either directly heats potable water or heats a thermal storage tank. As with all concentrating solar collectors, parabolic-trough collectors use tracking systems that keep them facing the sun throughout the day, maximizing solar heat gain.

In fiscal year 1995, the federal government spent $3.6 billion on energy for their buildings and facilities. Water heating accounts for a substantial portion of energy use at many federal facilities. Parabolic-trough solar water heating is a well-proven renewable energy technology with considerable potential for application at federal facilities.

Applications: Parabolic-trough collectors are likely to be most effective in areas such as the southwestern United States that have good solar resources. As with any renewable energy technology that requires significant initial capital investment, the primary condition that will make a parabolic-trough system economically viable is replacement of expensive conventional water heating. In combination with absorption cooling systems, parabolic-trough collectors can also be used for air-conditioning.

To make effective use of tracking systems and of the much higher temperatures that can be generated by a concentrating system, it is most cost effective to build a large system that will be used continuously. Typically, 3600 square feet of collectors (able to produce about 7500 gallons of hot water per day) would be the minimum size for a viable project. A parabolic collector array of this size would require land area of approximately 1130 square feet, an area of about 35'x35'.

Parabolic-trough collectors can be much less expensive than flat-plate collectors if the system is large enough. Parabolic-trough solar water heating is therefore an effective technology for serving large facilities that operate 7-days-a-week and have a steady need for hot-water. This technology can be used at federal facilities such as:

- Hospitals
- Military and civilian detention facilities
- Food preparation and service facilities
- Dormitories, barracks, bachelor officer quarters, and guest residential facilities
- Laundries
- Central plants for district heating or water-heating systems
- Operation and maintenance (O&M) facilities, such as for transportation vehicles and equipment requiring large volumes of hot water
- Production or assembly facilities requiring large amounts of hot water (e.g., munitions facilities)

Gymnasiums and recreation facilities with large heated, indoor swimming pools

The table below gives the number of federal facilities that are located within southwestern or other states where there are probably adequate solar resources for parabolic-trough collectors and that are large enough that they would likely benefit from a parabolic-trough system. This is not a guarantee that every such facility in these states is a good application or that other types of facilities in other states are clearly not good applications, but provides some guidance for successful application. Given the expected performance listed below, parabolic-trough solar water-heating is worth investigating for economic viability if the available conventional water heating is using electricity or fossil fuel energy costing more than about $6 per million Btu.

Numbers of Federal Facilities That Are Likely Candidates for Parabolic-Trough Systems

State	Prisons of more than 25,000 sq. ft.	Hospitals of more than 25,000 sq. ft.	Housing complexes of more than 100,000 sq. ft. or more than 10,000 sq. ft. and 5,000 sq. ft. per building
Arizona	2	14	16
California	5	24	67
Colorado	2	6	9
Hawaii	0	1	5
New Mexico	0	11	12
Nevada	1	3	4
Puerto Rico	0	1	0
Texas	6	23	26
Utah	0	1	5
Wyoming	0	3	3
Total	16	87	147

Source: FEMP Tracks database

Performance/Costs: In the southwestern United States, there is sufficient sunlight for parabolic-trough collector systems to operate about 30% to 35% of the time. The systems will generally be most cost effective if sized so that on the best summer days they are just able to meet the demand—that is, there is no excess capacity. Such a system can provide about 50% to 80% of annual water-heating needs.

Parabolic-trough collector systems can provide hot water at a levelized cost of $6 to $12 per million Btu for most southwestern areas.

Availability: Industrial Solar Technology (IST) of Golden, Colorado, is currently the sole manufacturer of parabolic-trough solar water heating systems. IST has an Indefinite Delivery/Indefinite Quantity (IDIQ) contract with FEMP to finance and install parabolic-trough solar water heating on an Energy Savings Performance Contract (ESPC) basis for any federal facility that requests it and for which it proves viable. Many facilities have used ESPCs and found them highly advantageous. For an ESPC project, the facility does not pay for any of the up-front costs, including design, capital equipment, installation or maintenance directly. Instead, they pay a share of the realized energy savings.

For Additional Information:

Parabolic-Trough Solar Water Heating

A FEMP site that details all aspects of this technology.

http://www.eren.doe.gov/femp/prodtech/parafta.html

Concentrating Solar Power

A U.S. Department of Energy site that covers their Concentrating Solar Power (CSP) Program. Fact sheets, publications, photographs, and other resources can be found under "Resources".

http://www.eren.doe.gov/csp/

Solar Parabolic Trough

From the Energy Efficiency and Renewable Energy Network, this is a 21-page PDF publication with information and excellent illustrations on this technology.

http://www.eren.doe.gov/power/pdfs/solar_trough.pdf

ESPCs and Super ESPCs

This FEMP site details the process of energy saving and performance contracting agreements to help finance a solar project.

http://www.eren.doe.gov/femp/financing/espc.html

Analytical Software Tools

FEMP site for software that evaluates the cost-effectiveness of solar water heating.

http://www.eren.doe.gov/femp/techassist/softwaretools/softwaretools.html

Credits: Photo courtesy of FEMP Technology Alert, Parabolic Trough Solar Water Heating

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NREL

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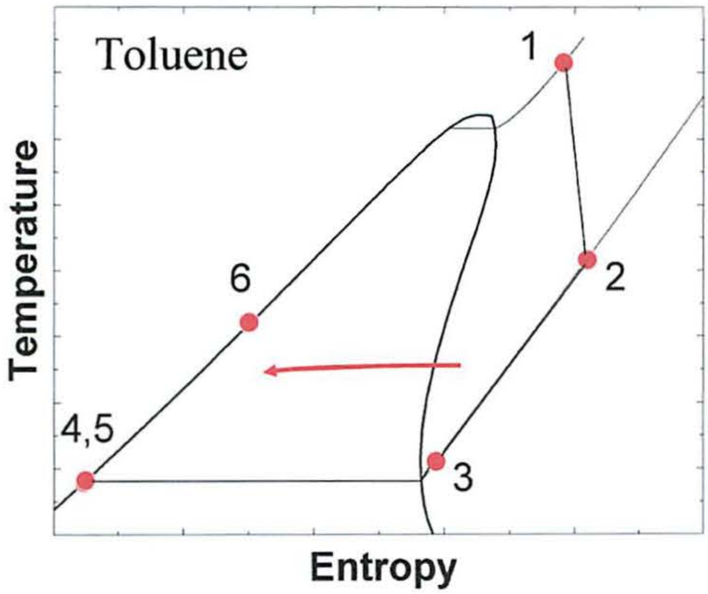
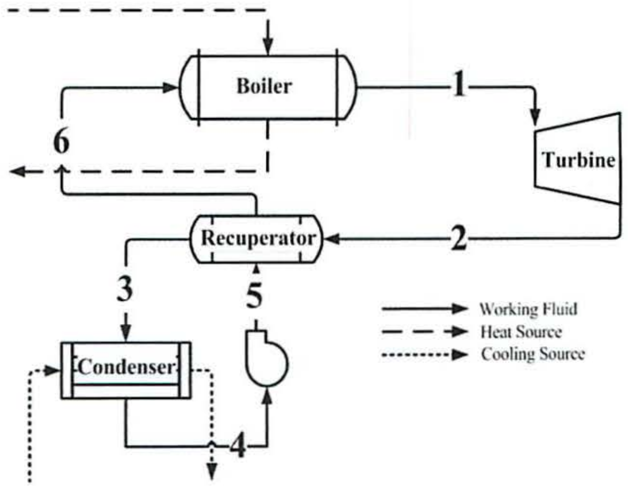
DESIGN AND OPTIMIZATION OF PARABOLIC TROUGH ORGANIC RANKINE CYCLE POWERPLANTS

Andrew C. McMahan
Sanford A. Klein
Douglas T. Reindl
University of Wisconsin - Madison
Solar Energy Laboratory

July 12, 2006

Typical Organic Rankine Cycle





Background

- Organic Rankine Cycles
  - Organic working fluids (toluene, n-pentane)
  - Well suited for lower resource temperatures
  - Used extensively in geothermal applications
  - Compact, economical design relative to steam Rankine cycles

Österreichische 400 kW ORC

Industrial Solar Technology Corp.

IST-PT Parabolic Trough Solar Collectors

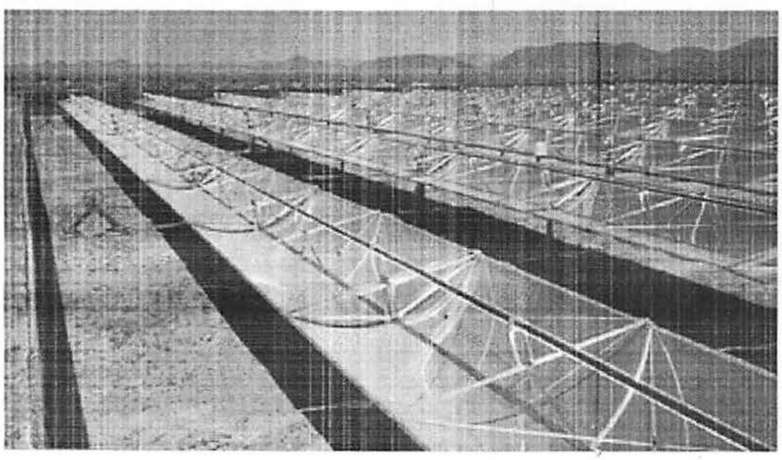
The patented IST-PT collector design has been continuously improved since it was first deployed commercially in 1985. The latest IST systems have benefited from 50+ years of operational experience and the development of a new tracking and field control system. In addition, the newest systems will offer thin-silvered glass as a reflector option.

IST trough systems operate automatically at high efficiency with minimal maintenance. Commercial trough systems can be competitive with natural gas and will deliver energy at a cost not influenced by outside events for more than 20 years.

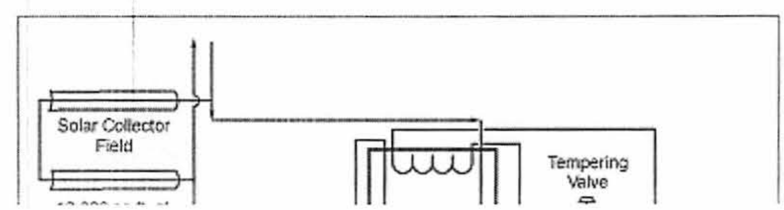
Below is a detailed description of an operating IST-PT system followed by specifications and performance data.

Prisoners in Hot Water: Details of an IST Parabolic Trough Installation at the Federal Correctional Institution, Phoenix, Arizona

The parabolic trough solar system at the Federal Correctional Institution (FCI), Phoenix comprises 18,000 square feet of solar collectors. It provides over 70 percent of the facility's annual need for hot water. Because of the solar system, according to Frank Foster prison facilities foreman, "We save a bunch of money on (electric water heater) elements, maintenance calls and repairs. The calls we've gotten from the inmates about cold water have basically gone away." [1] O&M savings are in addition to the savings due to reduced utility charges.



The FCI solar system serves the hot water heating needs of approximately 1100 inmates and staff. IST designed, fabricated and installed the system under an Energy Service Performance Contract (ESPC) with the Federal Bureau of Prisons. This was the first renewable energy ESPC to be contracted with the federal government. The contract term is 20 years, after which time ownership of the solar system reverts to the federal government. IST maintains the plant with the help of a local solar company, North Canyon Solar.



The solar field consists of 120 parabolic trough concentrator modules with a total gross collectorarea of 18,000 square feet (17,000 square feet net area). The

modules are arranged in 10 parallel
rows. Total system flow is about 100 gpm. Flow is divided into five U-loops in parallel. Using a multi-row drive system, the entire solar field tracks the sun using only four drive/control units.

The solar system operates unattended. Collectors track the sun continually during the day to heat circulating propylene glycol antifreeze solution. Heat from the solar collectors is transferred through immersed copper coils to two hot water storage tanks with a total volume of 23,000 gallons. In the summer, these tanks can heat to the high temperature limit of approximately 185° F (85°C).

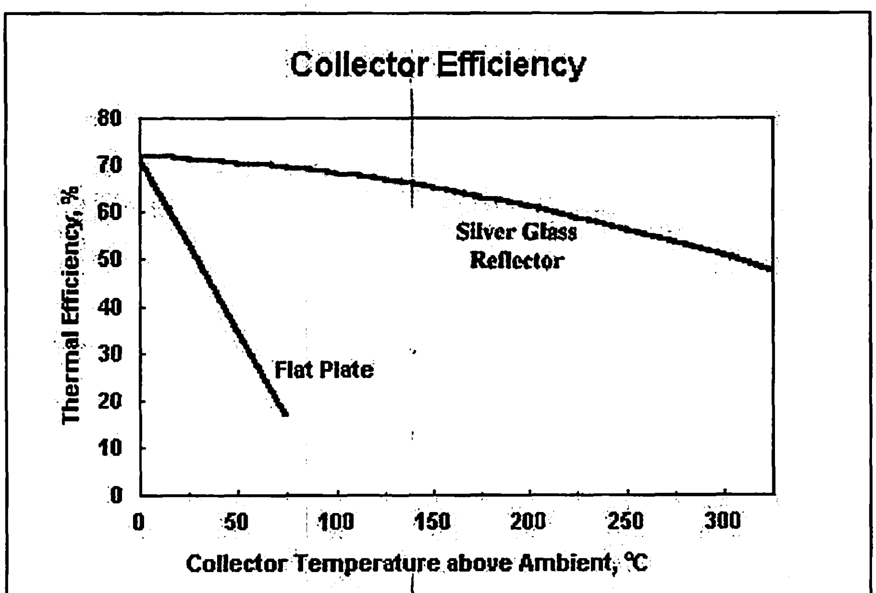
Incoming domestic water is heated as it flows through a second set of copper coils immersed at the top of the tanks. Hot water exiting the tank coils is tempered to 135°F for delivery to the jail through an extensive underground piping system. This piping system serves the needs of five housing units and the central kitchen and laundry. Energy stored in the tanks allows solar-heated hot water to be delivered around the clock. Over the course of a year, over 70% of the hot water needs of the institution is supplied by solar energy. Prior to the installation of the solar system, all water was heated by electricity.

Under solar peak conditions and when the modules are clean, the solar system delivers about 3.0 million Btu/h (850 kW) of heat to the energy storage tank at an efficiency of about 60% of the solar energy incident on the solar collectors. On a sunny day, the solar system delivers 45,000 gallons of hot water to the institution displacing approximately 4,000 kWh of electricity.

The solar system has been running routinely since the beginning of 1999. Each year the solar system delivers about 1.1 million kWh of hot water net of electric power consumption. Peak electric demand at FCI has been reduced by over 200 kW compared to before the solar system was installed.

[1 | Mike McCloy, Arizona Republic, June 19, 1999.

Technical Description of IST-PT



IST systems are efficient over a wide temperature range

Thermal Performance

Sandia National Laboratories independently measured the thermal performance of the IST parabolic trough system.* The efficiency based on the net aperture area for different reflective materials, is:

$$\eta = K[72.6 - 0.006836(\Delta T)] - 14.68(\Delta T)/I - 0.1672(\Delta T^2)/I$$

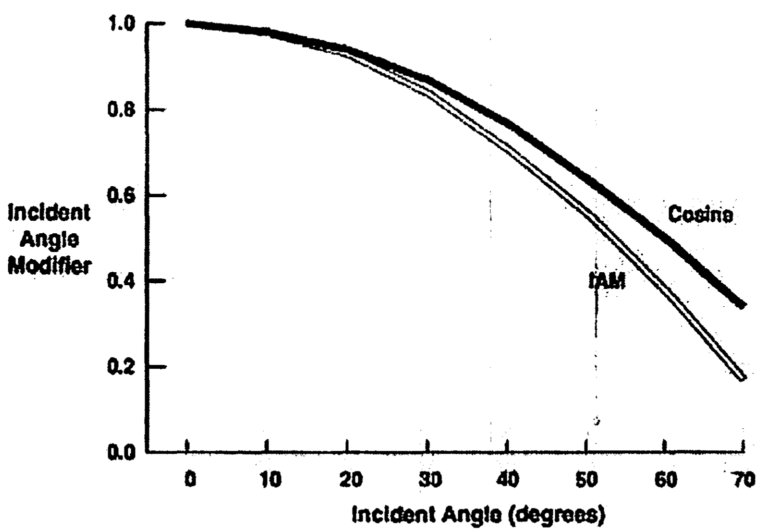
enhanced polished aluminum reflector

$$K = \cos(Ia) + 0.0003178(Ia) - 0.00003985(Ia)^2$$

where,

- η = Collector efficiency based on a net aperature area of 13.2 m^2 (%)
- ΔT = Average receiver fluid temperature above ambient air temperature (°C)
- K = Incident angle modifier
- I = Incident direct normal insolation (W/m^2)
- Ia = Solar beam incident angle (degrees)

*Dudley, V. E. and Evans, L. R. Test Results: Industrial Solar Technology Parabolic Trough Solar Collector. SAND94-1117, Sandia National Laboratories, Nov. 1995. The curve shown is for a silver reflective film.



Incident Angle Modifier Compared to the Angle Cosine

Concentrator

The IST concentrator is built according to a unique patented design making it very lightweight, yet exceedingly strong. All aluminum construction minimizes concentrator maintenance requirements. The physical characteristics of the concentrator modules are:

Lightweight, low maintenance concentrator

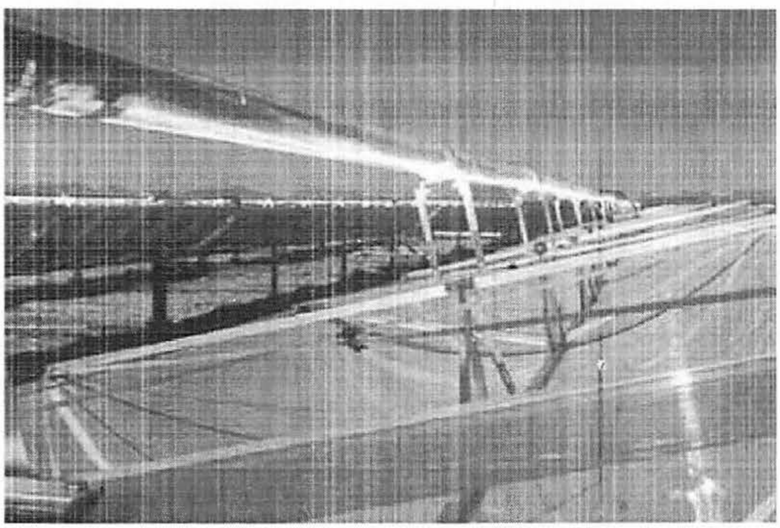
Overall Module Size	7 ft. 6 in. x 20 ft.(2.3m x 6.1 m)
Concentrator Weight	178 lb (81 kg)
Concentrator Rim Angle	72°
Materials of Construction	Aluminum
Reflective Surface	Aluminum acrylic
Options	Enhanced polished aluminum

Receiver

Reflected solar energy is focused by the parabolic concentrator onto the receiver at the focal point. The receiver comprises a steel absorber, that is coated with a selective blackened nickel surface, and a surrounding envelope of tough Pyrex, glass to reduce heat loss. An anti-reflective coating on the glass increases light transmission. The receiver specifications are:

Absorber Tube Outside Diameter	2.0 inch (5.08 cm)
Absorber Material	Steel
Selective Surface	Blackened nickel
Absorptance	0.96 - 0.98
Emittance (80°C)	0.15 - 0.25
Absorber Envelope Material	Borosilicate glass
Envelope Anti-Reflective Coating	Sol gel
Transmittance	0.95 - 0.965
Maximum Operating Temperature	550°F (288°C)

Efficient heat collection



Light is focused on the receiver tube of the parabolic trough at a concentration of 40 suns

Drive and Controls

Honeywell Controls

The collectors track the sun continuously using the Honeywell Fluxline Control System. A local controller at each drive regulates collector tracking, while a single field controller monitors operation of the overall system. The control system incorporates safety devices that monitor sun, wind, and system temperatures and pressures. A unique multi-row configuration drives up to six rows of troughs in unison (up to a total of 36 modules) so reducing the number of moving parts and increasing reliability. The drive power source is a standard three-phase electric motor.

Flexible Hoses

Long-life hoses

Fully insulated stainless steel hoses accommodate the motion of the receiver with respect to the fixed field piping.

Operating and Maintenance

IST concentrator systems have been operating for 15 years. Basic design concepts have remained unchanged, although the system has been continually improved to increase performance and reliability.

Minimal maintenance and running costs

Typically, IST systems run unattended. O&M requirements are minimal. Site inspections every one or two weeks are generally adequate to monitor system operations and to perform routine maintenance. Rain is very effective at washing the reflective surfaces to maintain performance. In dry climates, two months is a typical interval between manual washings of the collectors.

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file NREL Troughnet
date 26 Nov 08

lots of links

Find answers to frequently asked questions about parabolic trough solar technology. Question topics include:

Some of the following documents are available as Adobe Acrobat PDFs.

The cost of a parabolic trough power plant depends on many factors such as plant size, whether thermal energy storage is included, and whether the solar field has been enlarged to increase the annual plant capacity factor. Based on these considerations the current capital cost for large ~100-MWe-sized systems are on the order of $3-6/W for plants that produce 25-50% annual capacity factors.

For more information, see parabolic trough .

Electricity costs will vary from plant to plant, area to area. For a 100-MWe parabolic trough plant the nominal levelized cost of electricity is expected to be approximately 13/kWh assuming a 30% Investment Tax Credit (ITC) and a solar property tax exemption (CA). This equates to a real cost of electricity of 9/kWh.

For more information, see parabolic trough .

Recent siting studies for parabolic trough technology show that sites in the southwestern United States have a high direct normal solar resource potential and low slope (<1%). And exclusions for environmentally sensitive lands and urban areas sufficiently provide the total U.S. electric power generation several times over.

Realistically, the potential of concentrating solar power in the Southwest could reach hundreds of gigawatts or greater than 10% of U.S. electric supply. By 2015, the Western Governors' Association estimates that 4 GWe of new concentrating solar power plants could be built in the United States.

For more information about U.S. potential, read the *Western Governors' Association Clean and Diversified Energy Initiative: 2006 Solar Task Force Report* ( ).

Worldwide potential for concentrating solar power also could reach hundreds of gigawatts by 2040. For more information, read *Greenpeace's Concentrated Solar Thermal Power — Now!* ( ).

Also see our information on parabolic trough power plant .

See our information on parabolic trough .

Also read NREL's subcontract report, *Economic, Energy, and Environmental Benefits of Concentrating Solar Power in California* ( ).

See our information on .

In general a parabolic trough power plant uses about 5 to 10 acres land per megawatt of electric capacity depending on whether or not the solar field has been oversized to take advantage of thermal energy storage.

One concern often raised about large, central solar power plants is the amount of land required and the potential destruction of pristine desert lands. Solar plants need to be built on flat areas in the best solar regions (such as the Mojave Desert or the Imperial Valley in California). Therefore, they likely compete with agriculture for land availability. The following case study compares land and water use for agriculture and parabolic trough solar power plants in the Imperial Valley in California.

Imperial Valley Case Study
During 2001, 522,000 acres of land were used for growing crops in the Imperial Valley Irrigation District. An additional 278,000 acres of land was undeveloped. A 100-MW solar plant uses approximately 500 to 1000 acres depending on whether the solar field is oversized for use with [illegible]. Approximately 1% of the undeveloped land would be sufficient for approximately 2 GWe of solar capacity.

The primary crop in the Imperial Valley Irrigation District is alfalfa. On average, alfalfa uses 5.5 acre-feet per year per acre of cropland. A parabolic trough plant with [illegible] uses 1.3 acre-foot/year per acre of solar field land use. Water use from a solar plant is approximately one quarter that of alfalfa. In addition, the Imperial Valley water district charges industrial customers five times the agriculture rate. Therefore, a solar power plant would generate more revenues for the district.

One acre of alfalfa crop land generates 7.2 tons of alfalfa per acre per year. The gross revenue for alfalfa farming is approximately $600-900/year/acre. Gross income (before expenses) from a 100-MWe solar power plant (at 10¢/kWh) is approximately $42,000/year/acre. Operation and maintenance (O&M) expenses are approximately $9000/acre/year. Most of this O&M cost is for labor or local goods and services.

Solar plants use less water than most agriculture in the imperial valley. They also can generate more revenue for the local community, and offer more and higher-paying jobs.

More Information
See [illegible].

[illegible]

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For more information, see parabolic trough power plant [illegible].

[illegible]

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- Reduce electricity costs for large-scale solar power plants
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For a large-scale system, the increased cost for transmission—including losses in the transmission and distribution system— is small compared to the cost savings of building a large plant and the performance improvement of siting a plant in the best resources locations.

While large-scale solar power plants serve many customers, distributed solar power provides small, modular systems for on-site delivery of electricity. Because it's on the customer side of the meter, a modular solar system in many cases offers a higher value and reduces demand charges The system also can take advantage of net metering.

In desert climates like the southwestern United States, parabolic trough technology offers the lowest cost solar electric option for large-scale power plants.

Electricity from large-scale parabolic trough power plants is 50% to 75% cheaper than electricity from photovoltaic systems. However, photovoltaics can be more cost effective for small, modular solar electric applications.

A number of factors contributed to the lack of any new parabolic trough power plants construction during this period. Because of declining federal and state incentives combined with declining energy prices, parabolic trough power plants were no longer economically competitive with conventional power plants.

These factors combined with a general move to deregulation of the power industry, which focused on least-cost power options, precluded any new large solar plant developments.

Some companies in the solar energy industry work on parabolic trough technology efforts. See information about our .

PHOTOVOLTAIC TROUGH CONCENTRATION SYSTEM

The photovoltaic trough concentration system reduces the cost of photovoltaic solar electricity by using a parabolic reflective trough that tracks the sun and concentrates light onto a much smaller number of high-efficiency solar cells.

Currently the cost of generating electricity using photovoltaic solar systems compares unfavourably with most other generating technologies. This is mainly caused by the cost of producing efficient solar cells, which are high-precision electronic components. One way of reducing this cost is to deploy concentrating photovoltaic solar systems that do not use many solar cells.

The photovoltaic trough (PV/T) concentration system was designed at the Australian National University (ANU) and installed by Solahart and ANU with the assistance of a $300,000 grant under the Renewable Energy Industry Program. The program has facilitated technology transfer from ANU to Solahart, which is the exclusive licensee.

Concentration systems can reduce the cost of photovoltaic electricity by using a large-area optical system to focus sunlight onto a much smaller area of cells. In principle, most of the expensive cell area is replaced by a cheap focusing system. The basis for the PV/T concentration system is a parabolic reflective trough which tracks the sun, concentrating light onto a line of cells. The few solar cells in the system (at the focal line of the trough) are a relatively small part of the total system cost. Thus the relatively expensive but highly efficient cells are used without undue economic penalty.

The 150m2 PV/T concentration system is situated at Rockingham, 40 kilometres south of Perth, Western Australia, and was commissioned in August 2000. The system comprises 80 suntracking glass mirrors, which reflect sunlight upwards onto a line of highly efficient solar cells mounted on the solar receivers. Each mirror delivers a concentration ratio of about 20 to 1. The solar receiver has an integrated passive heat sink to maintain the solar cells at a moderate temperature. The mirrors are supported by metal frames, which in turn are mounted on a 2-axis tracking mechanical structure. An open loop controller provides sun tracking and emergency stow provisions. The peak DC electrical power of the system under nameplate operating conditions (1kW/m2 direct beam, 25°C) is estimated to be 17kW. The DC electrical output is converted to AC, and fed into the grid.

The PV/T concentration system is operated by Western Power, which will benefit from operating a novel photovoltaic generation technology that will help diversify its portfolio of renewable energy sources for its 'green energy' customers.

The PV/T concentration system may be inspected at any time by visiting the Murdoch University Rockingham Campus, Dixon Road, Rockingham, Western Australia. The system is situated just south of the library. More information and pictures are available at http://solar.anu.edu.au

PHOTOVOLTAIC TROUGH CONCENTRATION SYSTEM-OPERATING PARAMETERS AT STANDARD OPERATING CONDITIONS

DESCRIPTION	DATA
Overall length	79m
Mirror aperture	1600mm x 1170mm
Number of mirrors	80
Total reflector area	150m2
Concentration factor (geometric) (actual)	 30:1 22:1
Nominal cell efficiency	22 per cent under concentration
Power output per trough module	215 $W_{(peak)}$ (standard operating conditions)

Nominal power output of system	$17kW_pDC$
Tracking mechanism	2-axis (accurate to within 0.5^0)
Tracking limits	
- Tilt	38^0S79^0N
- Roll	$\pm 63^0$
Net system efficiency	11.5 per cent

For more information please contact

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Project details are also available for downloading as PDF files. (PDF Help)

- Download Photovoltaic trough concentration system (pv1.pdf - 511 KB)

From:
Renewable Energy Commercialisation in Australia, Australian Greenhouse Office, 2003
The status of these projects will have changed since the time of publication, and project contacts may also have changed.

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Australian Greenhouse Office, Dept of the Environment and Water Resources, GPO Box 787 Canberra ACT 2601 Australia - Phone: +61 02 6274 1888

Australian Government
Department of the Environment and Water Resources
Australian Greenhouse Office

Last modified 27 February 2006

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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
Principle Investigator: E. Kenneth May
4420 McIntyre Street
Golden, Colorado 80403, USA
(303) 279-8108
Fax: (303) 279-8107
E-mail: industrialsolar@qwest.net

Reference to NREL's Solar Advisor Model (SAM) for cost analysis p. 16

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4 pages
date 1 Dec 08

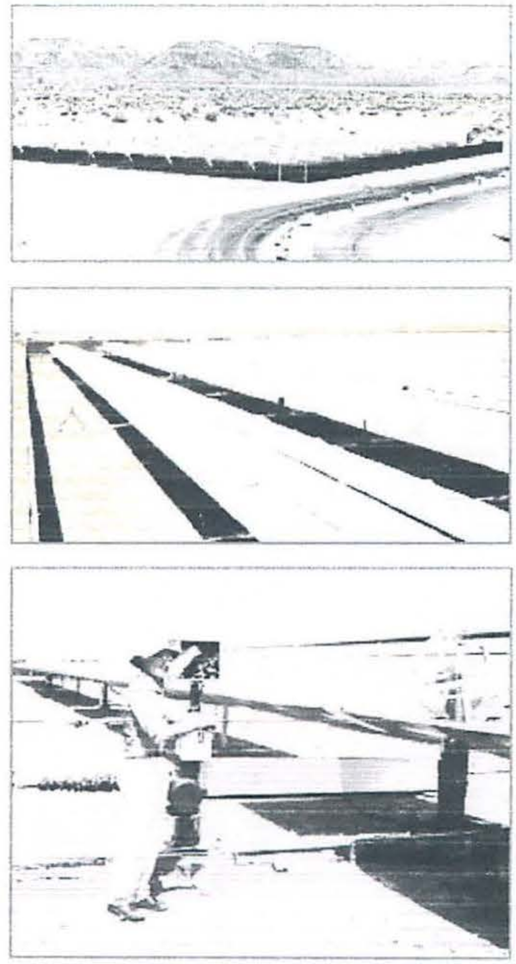
Achieving Results with Renewable Energy in the Federal Government

Heating Water with Solar Energy Costs Less at the Phoenix Federal Correctional Institution

A large solar thermal system installed at the Phoenix Federal Correctional Institution (FCI) in 1998 heats water for the prison and costs less than buying electricity to heat that water. This renewable energy system provides 70% of the facility's annual hot water needs. The Federal Bureau of Prisons did not incur the up-front cost of this system because it was financed through an Energy Savings Performance Contract (ESPC). The ESPC payments are 10% less than the energy savings so that the prison saves an average of $6,700 per year, providing an immediate payback. Boiler maintenance and hot water service call costs for the facility have also been reduced.

The solar hot water system produces up to 50,000 gallons of hot water daily, enough to meet the needs of 1,250 inmates and staff who use the kitchen, shower, and laundry facilities. Because solar energy is cleaner than conventional electric power, the environment benefits as well. Solar water-heating systems add no carbon dioxide or other emissions to the air around them. This renewable energy system offsets an average annual consumption of 1,000 megawatt-hours (MWh) of electricity and the release of nearly 600 tons of CO_2. For comparison, conventional electricity produced in Arizona emits 1,109 pounds of CO_2 per MWh.

The Federal Bureau of Prisons worked with the Department of Energy (DOE) Federal Energy Management Program (FEMP) and the ESPC contractor, Industrial Solar Technology Corporation (IST), to design and install the system. Under the terms of the 20-year ESPC contract, the prison receives 10% of the total energy savings annually (an average of $6,700 per year), and the other 90% goes to amortize the first costs of the system. At the end of the 20-year period, the prison will take over ownership, operation, and maintenance of the solar system and benefit from 100% of the energy savings for the remaining 10 years of the expected service life.



Parabolic trough concentrator modules at the Phoenix Federal Correctional Institution produce up to 50,000 gallons of hot water daily—enough hot water for kitchen, shower, laundry, and sanitation needs for 1,250 inmates and staff.

The solar system includes 17,040 ft^2 of parabolic trough concentrating collectors and a 23,000-gallon storage tank located adjacent to the collectors. Parabolic troughs, like other solar water-heating systems, are most cost effective for facilities with relatively constant hot water needs—places such as prisons, hospitals, and barracks. They heat water onsite using the sun's energy, so the facility can reduce the amount of energy purchased from the local utility for water heating.

Project Partners and Funding Sources

IST designed, fabricated, and installed the system under an ESPC with the Federal Bureau of Prisons. The ESPC was developed under a Cooperative Research and Development Agreement with the National Renewable Energy Laboratory. Expertise funded by DOE FEMP facilitated the project from feasibility through to performance measurement and verification. The contract term is 20 years, after which ownership of the solar system will revert to the federal government. ABB Energy Capital provided construction and long-term financing to build the system. IST will operate the solar plant over the life of the contract and currently employs the maintenance services of North Canyon Solar.

IST has invested the capital to install and operate the solar thermal system, charging Phoenix FCI a discounted rate for the energy delivered through an ESPC. The project also benefited from a 10% business energy tax credit for purchase of solar equipment and accelerated depreciation of solar energy property investment. DOE FEMP provided cost sharing in the form of technical assistance for this Site-Specific ESPC project, which was the first time a federal agency used an ESPC for a renewable energy technology.

Federal Renewable Energy Goal

This project is helping the federal government achieve the goal of obtaining 2.5% of electricity from renewable energy by 2005. The Phoenix FCI has one of the largest federal solar thermal systems and one of the earliest renewable energy systems in the U.S. Department of Justice.

O&M and Emissions Benefits

Operational benefits include maintaining temperatures for domestic hot water (in the past the prison frequently ran out of hot water), reducing electricity peak demand for water heating by more than 200 kW, and reducing maintenance and replacement parts for the offset electric boilers. "We save a lot of money on electric water heater elements, maintenance calls, and repairs," says the facilities manager. "[Plus,] the calls we've gotten from the inmates about cold water have basically gone away." Operation and maintenance savings on the existing boilers are in addition to the reduced utility costs. Furthermore, avoided emissions based on Environmental Protection Agency eGRID 2000 factors for Arizona, amount to 589 tons/yr of CO_2, 2,655 lbs/yr of SO_2, and 2,358 lbs/yr of NO_x.

Applications at Other Government Sites

- U.S. Army Fort Sam Houston, San Antonio, Texas: Roof-mounted parabolic troughs provide heat to a pressurized water district-heating loop. Installed June 2003.
- U.S. Army Yuma Proving Ground, Yuma, Arizona: 8,970 million Btu/yr of heat provided for absorption cooling, space heating, and domestic hot water. Installed in 1979 and refurbished in 1986.
- Jefferson County Detention Facility, Golden, Colorado: 1,200 million Btu/yr of heat for domestic hot water. Installed in 1996.
- California Correctional Institution, Tehachapi, California: District heating application. Installed in 1990.

A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a diverse portfolio of energy technologies.

Public Outreach and Awards

- "Million Solar Roofs Initiative Award for 2000," *Save with Solar*, Vol. 3, No. 2., Fall 2000, DOE/ GO-102000-1096.
- "Prisoners in Hot Water," *Arizona Republic*, June 19, 1999.
- "Solar Flares: Technology Hones the Efficiency of Sun-powered Energy Systems," *Mechanical Engineering Power*, July 1999.
- "Performance Contracting of a Large Parabolic Trough System at the Federal Correctional Institution–Phoenix," *Intersociety Energy Conversion Engineering Conference Proceedings; July 24-28, 2000, Las Vegas.* Collection of Technical Papers, 2000; Vol 1.
- "Performance of a Large Parabolic Trough Solar Water Heating System at Phoenix Federal Correctional Institution," *ASME Journal of Solar Energy Engineering*, Vol. 122, No. 4, November 2000.
- "Solar America: A Solar Energy Tour of the United States," CD-ROM, 2001, DOE/GO-102001-1492.

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Internet: www.eere.energy.gov/femp

Leading by example, saving energy and taxpayer dollars in federal facilities

Produced for the U.S. Department of Energy by the National Renewable Energy Laboratory, a DOE National Laboratory

DOE/GO-102004-1914
September 2004

Highlights

System Capacity	3.4 million Btu/hr (1,000 kW) of heat at 60% peak system efficiency
Power Production	300 million Btu/month of average delivered heat, offsetting 88,500 kWh/month of electricity consumption to meet 70% of annual need for hot water
Installation Date	1998
Motivation	Replace large domestic hot-water load heated by electricity with good solar resource
Size	120 parabolic trough concentrator modules
Annual savings	$67,000/yr average in electricity costs (90% goes to IST under a 20-year ESPC)

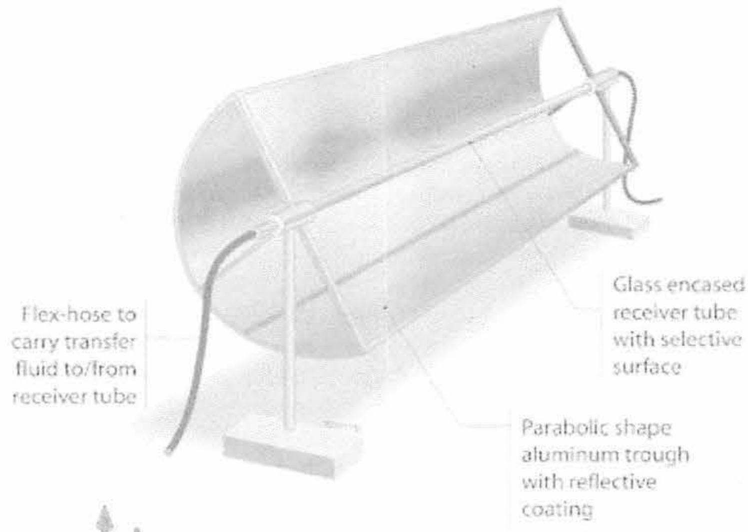


Figure 1: Parabolic trough collector

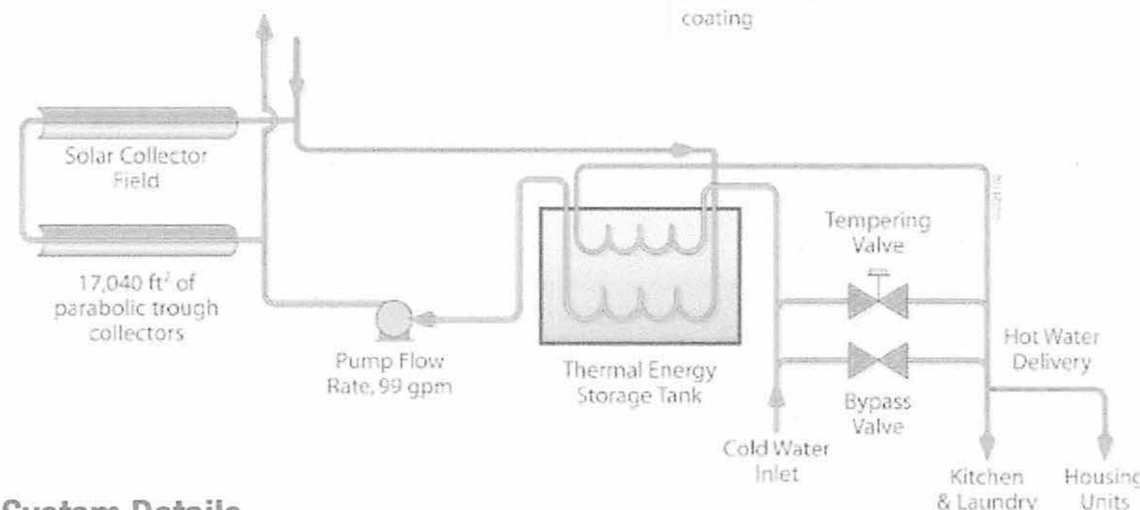


Figure 2: The solar collectors heat a circulating fluid that in turn supplies heat to domestic water storage tanks and end-uses.

System Details

Components	120 parabolic trough collectors totaling 17,040 ft² (1,584 m²) of collector aperture area; propylene glycol solution circulating fluid; a master field controller and four local sun-tracking controllers
Storage	Two steel water tanks with membrane liners, totaling 23,000 gallons (87,055 liters)
Loads	13 million Btu/day (4,000 kWh/day) average to heat 30,000-50,000 gallons of water for laundry, kitchen, and other domestic applications
Supplier/Installer	IST designed, fabricated, installed, and operates the system
Monitoring	Redundant Btu meters measure delivered hot water; plus a datalogger records solar radiation, wind, ambient temperature, flow rates, and fluid and water temperatures
Expected Life	30 years

How the Technology Works

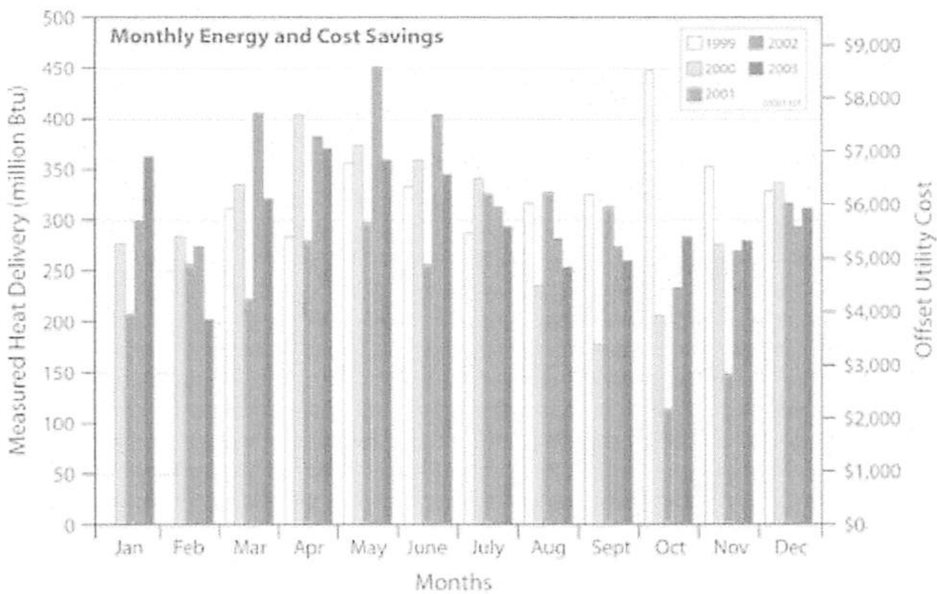
Parabolic trough solar systems convert solar energy to heat. Parabolic trough collectors use mirrored surfaces curved in a linearly extended parabolic shape to concentrate the sun's rays on a pipe running the length of the trough. A mixture of water and antifreeze is pumped through the pipe to pick up the solar energy and then through a heat exchanger to heat potable water. These systems also use single-axis tracking to stay aligned with the sun. Parabolic trough solar systems work well in locations with a high direct-beam solar resource, such as the Southwestern United States. Other solar water heating applications that work well in locations across the country include flat-plate or evacuated-tube collector technology.

Performance

The solar thermal system at Phoenix FCI has been running routinely since March 1999. Under peak solar conditions and when the modules are clean, the solar system delivers up to 3.4 million Btu/hr (1,000 kW) of heat to the energy storage tank at a peak efficiency of 60% of the solar energy incident on the solar collectors. On a sunny day, the solar system delivers up to 50,000 gallons of hot water to the institution, displacing approximately 4,000 kWh of electricity.

On a monthly basis, the system delivers an overall average of 300 million Btu/month, offsetting 89,000 kWh of electricity consumption and an estimated $5,600 of energy costs. The highest months of energy savings, May 2002 and October 1999, coincide with both the best solar resource (the greatest number of clear sunny days) and the highest hot water demand for prison operations. The lowest months of energy savings, such as October 2001, reflect unusually overcast weather, reduced hot water demand, or partial solar system shut down for maintenance or repairs. To optimize operational efficiency, collectors should be cleaned every 2 to 4 months, depending on weather conditions.

Because calculating the electricity rate is complex and variable, an average blended rate for electricity consumption and demand is used here to estimate the utility bill savings ($0.065/kWh). Total annual energy cost savings average $67,000, with 90% going to IST under the ESPC.



Costs

Cost Breakdown for Phoenix FCI Solar Thermal System	
System Cost (total includes: design, hardware, and installation)	$649,000
Per Unit Cost	$38 / ft²
Equivalent Energy Rate	$12/MBtu $0.04/kWh
Annual O&M Cost (rolled into ESPC)	N/A

Life Cycle Cost Analysis for the Phoenix FCI Solar Thermal System

Study Period: 20 years	Alternative (Electricity utility)	Solar System with Electric Heating Backup
Initial Investment	$ 0	$ 649,000
Recurring Costs (O&M, etc.)	$ 143,419	$ 226,891
Energy Costs	$ 1,528,397	$ 290,465
Total Present Value	$ 1,671,816	$ 1,166,356
Adjusted Internal Rate of Return		6.4 %
Simple Payback Period		8 years
Savings-to-Investment Ratio		1.78

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Parabolic Trough FAQs

Find answers to frequently asked questions about parabolic trough solar technology. Question topics include:

Some of the following documents are available as Adobe Acrobat PDFs. Download Adobe Reader.

How much does a parabolic trough power plant cost?

The cost of a parabolic trough power plant depends on many factors such as plant size, whether thermal energy storage is included, and whether the solar field has been enlarged to increase the annual plant capacity factor. Based on these considerations the current capital cost for large ~100-MWe-sized systems are on the order of $3-6/W for plants that produce 25-50% annual capacity factors.

For more information, see parabolic trough market and economic assessment.

Back to Top

What is the cost of electricity from a parabolic trough power plant?

Electricity costs will vary from plant to plant, area to area. For a 100-MWe parabolic trough plant the nominal levelized cost of electricity is expected to be approximately 13/kWh assuming a 30% Investment Tax Credit (ITC) and a solar property tax exemption (CA). This equates to a real cost of electricity of 9/kWh.

For more information, see parabolic trough market and economic assessment.

Back to Top

What is the potential for parabolic trough technology in the United States and the World?

Recent siting studies for parabolic trough technology show that sites in the southwestern United States have a high direct normal solar resource potential and low slope (<1%). And exclusions for environmentally sensitive lands and urban areas sufficiently provide the total U.S. electric power generation several times over.

Realistically, the potential of concentrating solar power in the Southwest could reach hundreds of gigawatts or greater than 10% of U.S. electric supply. By 2015, the Western Governors' Association estimates that 4 GWe of new concentrating solar power plants could be built in the United States.

For more information about U.S. potential, read the *Western Governors' Association Clean and Diversified Energy Initiative: 2006 Solar Task Force Report* (PDF 3.1 MB).

Worldwide potential for concentrating solar power also could reach hundreds of gigawatts by 2040. For more information, read *Greenpeace's Concentrated Solar Thermal Power — Now!* (PDF 1.3 MB).

Also see our information on parabolic trough power plant solar resource assessment.

Back to Top

What are the benefits of a parabolic trough power plant?

See our information on parabolic trough economic and environmental benefits.

Also read NREL's subcontract report, *Economic, Energy, and Environmental Benefits of Concentrating Solar Power in California* (PDF 1.5 MB).

Back to Top

Where can you build a parabolic trough power plant?

See our information on parabolic trough power plant siting.

Back to Top

How much land does a parabolic trough power plant use?

In general a parabolic trough power plant uses about 5 to 10 acres land per megawatt of electric capacity depending on whether or not the solar field has been oversized to take advantage of thermal energy storage.

One concern often raised about large, central solar power plants is the amount of land required and the potential destruction of pristine desert lands. Solar plants need to be built on flat areas in the best solar regions (such as the Mojave Desert or the Imperial Valley in California). Therefore, they likely compete with agriculture for land availability. The following case study compares land and water use for agriculture and parabolic trough solar power plants in the Imperial Valley in California.

Imperial Valley Case Study
During 2001, 522,000 acres of land were used for growing crops in the Imperial Valley Irrigation District. An additional 278,000 acres of land was undeveloped. A 100-MW solar plant uses approximately 500 to 1000 acres depending on whether the solar field is oversized for use with thermal energy storage. Approximately 1% of the undeveloped land would be sufficient for approximately 2 GWe of solar capacity.

The primary crop in the Imperial Valley Irrigation District is alfalfa. On average, alfalfa uses 5.5 acre-feet per year per acre of cropland. A parabolic trough plant with wet cooling uses 1.3 acre-foot/year per acre of solar field land use. Water use from a solar plant is approximately one quarter that of alfalfa. In addition, the Imperial Valley water district charges industrial customers five times the agriculture rate. Therefore, a solar power plant would generate more revenues for the district.

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Solar plants use less water than most agriculture in the imperial valley. They also can generate more revenue for the local community, and offer more and higher-paying jobs.

More Information
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Back to Top

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Back to Top

What are the benefits of central station solar?

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- Create thousands of jobs and generate millions of revenue dollars
- Provide a hedge against fuel price volatility

- Produce societal and environmental benefits.

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Back to Top

What's the difference between large-scale and distributed solar power?

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While large-scale solar power plants serve many customers, distributed solar power provides small, modular systems for on-site delivery of electricity. Because it's on the customer side of the meter, a modular solar system in many cases offers a higher value and reduces demand charges The system also can take advantage of net metering.

Back to Top

How does parabolic trough technology compare to other solar technologies?

In desert climates like the southwestern United States, parabolic trough technology offers the lowest cost solar electric option for large-scale power plants.

Electricity from large-scale parabolic trough power plants is 50% to 75% cheaper than electricity from photovoltaic systems. However, photovoltaics can be more cost effective for small, modular solar electric applications.

Back to Top

Why were no parabolic trough power plants built in the United States between 1990 and 2005?

A number of factors contributed to the lack of any new parabolic trough power plants construction during this period. Because of declining federal and state incentives combined with declining energy prices, parabolic trough power plants were no longer economically competitive with conventional power plants.

These factors combined with a general move to deregulation of the power industry, which focused on least-cost power options, precluded any new large solar plant developments.

Back to Top

How and where can I obtain what's needed to install and operate a parabolic trough power plant?

Some companies in the solar energy industry work on parabolic trough technology research and development efforts. See information about our industry partners.

Back to Top

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Content Last Updated: July 25, 2008

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Market & Economic Assessment
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Publications
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Parabolic Trough Power Plant Market, Economic Assessment and Deployment

Parabolic trough technology is the most commercially mature, large-scale solar power technology in the world. Here's an overview of how to assess the market and economic feasibility of a parabolic trough power plant.

Parabolic trough power plant market and economic assessment includes:

- Market overview
- Solar resource assessment and siting
- Cost reduction opportunities
- Financing, incentives and barriers
- Economic and environmental benefits
- Market development and deployment initiatives

For more detailed, technical information, see our publications on parabolic trough market and economic assessment.

Market Overview

The primary market for parabolic trough technology is large-scale bulk power. Because trough plants can be hybridized or can include thermal energy storage, they can provide firm capacity to utilities. Capacity factors for current parabolic trough systems under development range from 25% for solar only plants to greater than 40% for plants with thermal storage. Such plants provide firm peak to intermediate load capacity.

As the cost of thermal storage is reduced, future parabolic trough plants could yield capacity factors greater than 70%, competing directly with future baseload combined cycle plants or coal plants.

Back to Top

Solar Resource Assessment and Siting

The solar resource drives the cost of a parabolic trough power plant's solar field. Therefore, it is a significant factor in the economics of a parabolic trough power plant.

Parabolic trough power plants require direct normal solar radiation or beam radiation for cost-effective operation. Thus, sites with excellent solar radiation offer more attractive levelized electricity prices.

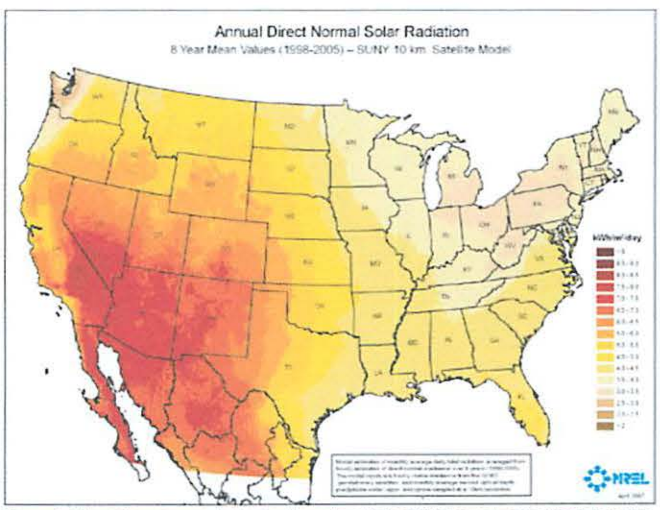

Figure 1. The solar resource in the southwestern United States ranks the highest in the world.

To be feasible and cost effective, parabolic trough power plants also require relatively large tracts of nearly level open land along with other siting characteristics. NREL performed a Geographic Information Systems (GIS) analysis of the southwestern United States to identify candidate areas for concentrating solar power. To find optimal sites with high economic potential, the GIS analysis excluded regions in urban or sensitive areas (national parks, etc.), regions with low solar resource, and regions where terrain would inhibit the cost-effective deployment of large-scale plants.

Parabolic trough power plant siting also involves other factors, including:

- Land ownership
- Road access
- Local transmission infrastructure capabilities and loadings
- State-level policies and regulations.

For the results of the GIS analysis, see NREL's concentrating solar power resource maps.

For related information, see our solar data resources for and publications on parabolic trough power plant siting.

Back to Top

Technology Cost Reduction Opportunities

There's great potential for reducing the costs of parabolic trough power plants. Factors driving cost reductions for parabolic trough power plant technology include:

- Research and development
- Volume production
- Scale-up in power plant or project size.

Figure 2 describes the projected current and anticipated future levelized cost of energy for parabolic trough systems. The current cost projection is based on an independent power producer (IPP) financed parabolic trough plant with 6 hours of thermal storage, assuming today's technology. Future cost projections assume implementation of advanced concentrator, receiver, and thermal storage designs. They also assume additional cost reductions due to plant scale-up and volume production.

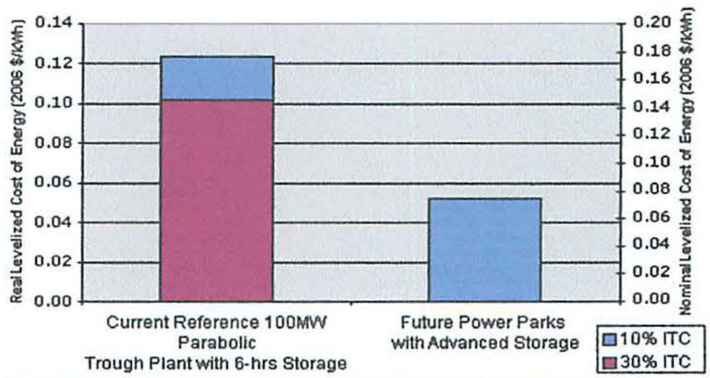

Figure 2. Projected current and anticipated future levelized costs for parabolic trough systems.

For a more detailed description of cost reduction opportunities, see our publications on parabolic trough feasibility studies and assessments.

Back to Top

Financing, Incentives and Barriers

The financing and incentives available for a parabolic trough power plant project will impact its feasibility. The fuel costs of a parabolic trough power plant need to be financed through capital investment at the beginning of a project. For most parabolic trough power plant projects, the solar field represents 50% of the total investment costs. However, once a parabolic trough power plant is constructed, the fuel—solar power—is free.

To be cost competitive, parabolic trough power plants require federal and state incentives. The Western Governors' Association Solar Task Force has recommended the following set of policies and incentives:

- Extend the 30% federal investment tax credit and expand its use to utilities
- Exempt them from sales and property taxes
- Allow longer-term power purchase agreements and set equitable central solar price references
- Encourage means for aggregating plant orders and project bids to accelerate scale-up cost reductions.

The availability of financing and/or incentives is often one of greatest barriers for parabolic trough power plant projects. Other barriers can include:

- The need for access to transmission
- The risk of using a relatively new technology
- Costly and time-consuming permitting and siting of power plants.

For more information, see our publications on parabolic trough financing, incentives, and barriers.

In addition, the Database of State Incentives for Renewables & Efficiency features a listing of state and federal incentives for renewable energy projects.

Back to Top

Economic and Environmental Benefits

A parabolic trough power plant can spur economic and environmental benefits.

A parabolic trough power plant project impacts the economy both directly and indirectly. The project directly spends dollar for materials, equipment, and wages. These dollars are then re-spent indirectly creating what's called the *multiplier effect*--the additional economic activity generated from an initial expenditure. For example, power plant employees spend their wages to purchase goods and services, and so on.

Ultimately, the economic benefits of a parabolic trough power plant project include:

- Creation of jobs for both construction and operation
- Increase in state and local tax revenues
- Increase in gross state output.

A parabolic trough power plant also lessens dependence on fossil fuels, which provides a hedge against fossil fuel price fluctuations.

Compared to fossil-fueled power plants, parabolic trough power plants generate significantly lower levels of greenhouse gases and other emissions. For example, an NREL study shows that 4,000 megawatts of concentrating solar power in California could offset the following emissions from natural gas power plants:

- 300 tons of nitrogen oxide
- 180 tons of carbon monoxide
- 7.6 million tons of carbon dioxide.

For more information, see our publications on parabolic trough economic and environmental benefits.

Back to Top

Market Development and Deployment Initiatives

Several initiatives are underway to expand the market and deployment of parabolic trough technology.

The Southwest Concentrating Solar Power 1000-MW Initiative has set a goal of achieving 1,000 megawatts of concentrating solar power systems in the southwestern United States by 2010. To achieve this goal, the U.S. Department of Energy is working closely with the Western Governors' Association Clean and Diversified Energy Initiative whose goal is to develop 30,000 megawatts of new clean and diversified generation by 2015.

SolarPaces is also promoting a Concentrating Solar Power Global Market Initiative (GMI). The initiative's overall goal is to deploy 5,000 megawatts of concentrating solar power to reach cost competitiveness by 2015.

For more information, see our publications on parabolic trough research and development.

Back to Top

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Content Last Updated: July 25, 2008

Modern Power System

August 2, 2007

SOLAR THERMAL; WILL FRESNEL BE THE MODEL T?

SECTION: Pg.22

LENGTH: 992 words

DATELINE: WORLD

A new **solar** thermal plant (pictured right) employing Fresneldiffraction mirrors was officially opened in Almeria (Andalusia) in Spainon 9 July. The new technology employed in the 1500 square metre 1 MWtdemonstration plant on the Plataforma **Solar** is expected to enable solarthermal power stations to be built much more **cost**-effectively than in thepast, says MAN Ferrostaal. MAN Ferrostaal, which has responsibilities forproject management, operation management and maintenance, built theAlmeria demonstration power station in collaboration with **Solar** PowerGroup (in which it has a 25% stake), the German Centre for Air and SpaceFlight (DLR), the Fraunhofer Institute (ISE) and PSE GmbH.

Currently, power from **solar** thermal power stations **costs** up to three timesthat of power from power stations in terms of p/kWh, while the generationcosts for photovoltaic power stations are about ten times as much.

Withthe Fresnel technology the **cost of solar**-generated electricity should becomparable with that for fossil-fuel power stations by about 2020, MANFerrostaal estimates.

In the new plant the moving Fresnel diffraction mirrors focus sunlightonto an absorber pipe, positioned eight metres above them (see diagramabove). Water in the pipe is heated to 450 degrees Celsius and the steamused to drive a turbine.

The plant is modular in design and in a full scale power station, severalmodules would be connected up in series.

The plant is made up of relatively cheap standardised components,manufacturable in many parts of the world, thus creating potential forestablishing a local supply chain with high value added. "Fresneltechnology is comparatively simple to construct, **cost**-effective to procureand reliable to operate," commented Michael Pohl, head of the **solar** powerbusiness unit at MAN Ferrostaal. "It has the potential to become the ModelT of **solar** thermal technology."

The Almeria pilot plant (which is 100m long, 21m wide and 8m high) isintended to demonstrate the commercial viability of the technology, with atest period running until 2008.

Around 1000 MW of **solar** thermal installed capacity is planned or alreadybuilt in Spain and the medium to long term prospects for this technologyare very good. The price of electricity has on average doubled throughoutEurope between 2003 and 2007 and a reversal of this trend is notanticipated any time soon.

The countries around the Mediterranean Sea, of course, stand to benefitfrom a "**solar** boom" because it is here that sunlight is at it mostintense, while energy-hungry Europe lies close by and as Mr Pohl observes,"**solar** thermal power stations would only have to be built on one percentof the Earth's desert regions to meet the total global electricitydemand." It has been estimated that "by 2050 up to 25% of Europe'selectricity demand could come from North Africa - if the political willexists," says Pohl.

MAN Ferrostaal announced in July that it was taking a 25% stake in Fresnelspecialist **Solar** Power Group, following approval of a joint venture withSolar Millennium AG.

Solar Power Group has already built two Fresnel pilot plants and has beenworking on the technology for several years. It was responsible for theengineering of the plant. DLR is responsible for the measurement programmeand will also have a technical supervisory and support role. TheFraunhofer Institute for **Solar** Energy Systems has made a significantcontribution to the development of the coating for the absorber and willplay a support role in the analysis and evaluation of the testresults.

The EUR2.6 million demonstration plant is financially supported by theGerman Federal Ministry for the Environment, but most of the investmentcosts are being borne by MAN Ferrostaal.

Among the tasks to be performed with the Almeria demo plant will be:

- determination of investment and operational and maintenance **costs** forextrapolation to full scale stations;

- estimation of the efficiency of the system and measurement of thecontamination and ageing of materials and the contour accuracy of thecollectors; and

- learning about the practicalities of operation and maintenance, withidentification of problems and implementation of solutions, includingdevelopment of cleaning systems which can be automated for full scaleplants.

The project partners say they are already planning power stations of up to50 MW and more.

SOLAR THERMAL TECHNOLOGIES COMPARED

According to MAN Ferrostaal Fresnel technology is the most **cost**-effectiveof the four main **solar** thermal technologies currently available (seediagram). Unlike a **parabolic** mirror, which requires multiple curvedmirrors, the Fresnel facility only needs flat mirrors, which substantiallyreduces **costs.**

A "power tower", in which a large array of two-axis tracking mirrorsdirect sunlight towards a tower fitted with absorbers, requires a vastnumber of separate components and is therefore a very expensive solarthermal power option.

Parabolic trough power stations are the most technologically advanced interms of engineering and have already proved themselves at large scale.All the components are already manufactured industrially and havetherefore reached an acceptable level in terms of production **costs.**

However Fresnel power stations are even more **cost**-effective than parabolictrough power stations, their key components being very simple. Themirrors, for example, are flat and readily available flat. The structureto which they are attached has one continuous axis and is required tocarry very little weight.

A Fresnel facility is relatively immune to problems arising from highwinds and thus does not need the very solid foundations and robust supportstructures needed for **parabolic trough** power stations. As only themirrors, and not the absorber tube, move in the Fresnel plant, there isalso no need for flexible high-pressure compensators, which are requiredto enable the **parabolic trough** mirrors to pivot towards the position ofthe sun.

GEOGRAPHIC: SPAIN (79%); MEDITERRANEAN (72%); EUROPE (70%); GERMANY (57%); WORLD

COUNTRY: SPAIN (79%); MEDITERRANEAN (72%); EUROPE (70%); GERMANY (57%); WORLD

SUBJECT: POWER PLANTS (94%); **SOLAR** ENERGY (92%); **SOLAR** POWER PLANTS (90%); FOSSIL FUEL POWER PLANTS (90%); ELECTRIC POWER PLANTS (90%); ENERGY & UTILITY CONSTRUCTION (78%); PLANT CONSTRUCTION (58%); DESERTS (50%);

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1 of 37 Back to Top

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Parabolic Trough Market and Economic Assessmen

This section features publications about parabolic trough power plant market a by the following topics:

- Feasibility studies and assessments
- Power plant siting studies
- Economic and environmental benefits
- Financing renewable power projects

Some of the following documents are available as Adobe Acrobat PDFs. Downl(

Parabolic Trough Power Plant Feasibility Studies and Assessn

Clean and Diversified Energy Initiative: Solar Task Force Report
Report Available from: Western Governors' Association (PDF 3.1 MB)
Publication Date: January 2006

Approved 2006 Market Price Referent (MPR) for California
Available from: California Public Utility Commission
Publication Date: December 2006

Potential for Renewable Energy in the San Diego Region
Appendix Available from: San Diego Regional Renewable Energy Study Group (
Publication Date: August 2005

Assessment of the World Bank/GEF Strategy for the Market Developm(Solar Thermal Power
Report Available from: Global Environment Facility (PDF 1.97 MB)
Author: Global Research Alliance for the World Bank
Publication Date: May 2005

CSP (Concentrating Solar Power) Global Market Initiative
Available from: SolarPaces

Assessment of Parabolic Trough and Power Tower Solar Technology Cc Forecasts
NREL Subcontract Report: (PDF 2.4 MB)
Author: Sargent & Lundy LLC Consulting Group
Publication Date: October 2003

Executive Summary: Assessment of Parabolic Trough and Power Towe Cost and Performance Forecasts
NREL Subcontract Report: (PDF 588 KB)
Author: Sargent & Lundy LLC Consulting Group
Publication Date: October 2003

Note: Includes additional reference lists

Fuel from the Sky: Solar Power's Potential for Western Energy Supply
NREL Subcontract Report: (PDF 3.0 MB)
Author: Leitner, A., RDI Consulting
Publication Date: July 2002

Report to Congress on: Feasibility of 1,000 Megawatts of Solar Power i 2006
Available from: U.S. Department of Energy SunLab (PDF 956 KB)
Publication Date: August 2002

The Commercial Path Forward for Concentrating Solar Power Technolo Existing Treatments of Current and Future Markets 2001
Report Available from: SolarPaces (PDF 953 KB)
Author: Morse, F.
Publication Date: December 2000

Cost Reduction Study for Solar Thermal Power Plants
Report Available from: SolarPaces (PDF 1.0 MB)
Author: Enermodal Engineering Limited with Marbek Resource Consultants Ltd.
Publication Date: May 1999

Parabolic Trough Solar Power for Competitive U.S. Markets
NREL Conference Paper: (PDF 68 KB)
Event: Renewable and Advanced Energy Systems for the 21st Century Confere
Authors: Price, H. W.; Kistner, R.
Publication Date: April 1999

Renewable Energy Technology Characterizations
Reports Available from: U.S. Department of Energy
Author: Electric Power Research Institute
Publication Date: December 1997

Parabolic Trough Power Plant Siting Studies

Mining for Solar Resources: U.S. Southwest Provides Vast Potential
Article Available from: Atmospheric Sciences Research Center (PDF 893 KB)
Authors: Mehos, M.; Perez, R.
Publication Date: 2005

Assessing the Potential for Renewable Energy on National Forest Servi
NREL Booklet: (PDF 5.1 MB)
Authors: USDA Forest Service and NREL
Publication Date: January 2005

Analysis of Siting Opportunities for Concentrating Solar Power Plants i United States
Conference Paper Available from: Ratepayers United of Colorado (PDF 1.09 ME
Event: World Renewable Energy Congress VIII, 29 August - 3 September 2004
Authors: Mehos, M. S.; Owens, B.

Assessing the Potential for Renewable Energy on Public Lands
U.S. Department of Energy Booklet: (PDF 4.5 MB)

Authors: U.S. Department of Energy and U.S. Department of the Interior Bure
Publication Date: February 2003

Parabolic Trough Power Plant Economic and Environmental B

Potential Carbon Emissions Reductions from Concentrating Solar Powe
Chapter Available from: American Solar Energy Society
Authors: Mehos, M.S.; Kearney, D.W.
Publication Date: 2007

Economic, Energy, and Environmental Benefits of Concentrating Solar I
NREL Subcontract Report: (PDF 1.5 MB)
Authors: Stoddard, L.; Abiencunas, J.; O'Connell, R.
Publication Date: April 2006

Schott Memorandum on Solar Thermal Power Plant Technology
Report Available from: Schott (PDF 1.3 MB)
Author: Schott, A.G.

Financing Renewable Power Projects

Economic Valuation of a Geothermal Production Tax Credit
NREL Technical Report: (PDF 591 KB)
Author: Owens, B.
Publication Date: April 2002

Financing Solar Thermal Power Plants
NREL Conference Paper: (PDF 96 KB)
Event: Advanced Energy Systems for the 21st Century Conference, April 11-14
Authors: Kistner, R.; Price, H.

Alternative Windpower Ownership Structures: Financing Terms and Pr
Report Available from: Lawrence Berkeley National Laboratory (PDF 225 KB)
Authors: Wiser, R., and Kahn, E.
Publication Date: May 1996

Tax Barriers to Solar Central Receiver Generation Technology
Conference Paper Available from: U.S. Department of Energy Information Brid
Event: ASME/JSME/JESE International Solar Energy Conference, March 1995, I
Authors: Jenkins, A.; Reilly, H.

A Manual for the Economic Evaluation of Energy Efficiency and Renewa Technologies
NREL Technical Report: (PDF 6.6 MB)
Authors: Short, W.; Packey, D.J.; Holt, T.
Publication Date: March 1995

Barriers to Commercialization of Large-Scale Solar Electricity: Lessons Experience
Posted with Permission from: Sandia National Laboratories (PDF 1.5 MB)
Author: Lotker, M.
Publication Date: 1991

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