Concentrating Solar Power

Summer School on Global Sustainability
July 20, 2009

Chuck Kutscher
National Renewable Energy Laboratory
Photovoltaics (PV)
CSP: The Other Solar Energy

- Parabolic trough
- Linear Fresnel
- Power tower
- Dish-Stirling
Parabolic Troughs
SEGS Historic Plant Capacity Value

On-Peak Performance
For 5 Parabolic Trough Plants

- Over 100% capacity with fossil backup
- Averaged 80% on-peak capacity factor from solar

SCE Summer On-Peak
Weekdays: Jun - Sep
12 noon - 6 pm

Source: KJC Operating Company
Why the Decline in Interest?

- Low natural gas prices
- Loss of financial incentives
- Utility deregulation
DOE CSP Budget
DOE CSP program 2003 - 2006
Why the resurgence?
More and More U.S. Gas Wells Producing Less and Less

Source: Baker Hughes, EIA/DOE (2004 and 2005 production volumes are EIA estimates)
World Renewable Resource Potential (TW)

- Hydroelectric: 2
- Wind: 4
- Ocean: 5
- Biomass: 7
- Geothermal: 12
- Solar: 600

Source: Marty Hoffert, Nate Lewis
Exclude:

- Used and sensitive land
- Solar < 6.75 kWh/m\(^2\) per day
- Ground slope > 1\%
Best Sites Only

6X U.S. electric capacity!
Solar and Wind Resources Are Often Complementary

Data from SE Iowa

Hours of sunshine/month

Average wind power/month

Hours of sunshine or average wind power (Watts/m²)

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
8 year extension of 30% ITC

No extension
<table>
<thead>
<tr>
<th>State</th>
<th>RPS Requirement</th>
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<tbody>
<tr>
<td>Arizona</td>
<td>15% by 2025</td>
</tr>
<tr>
<td>California</td>
<td>20% by 2010</td>
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<tr>
<td>Colorado</td>
<td>20% by 2020, 4% Solar</td>
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<tr>
<td>Nevada</td>
<td>20% by 2015, 5% Solar</td>
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<tr>
<td>New Mexico</td>
<td>20% by 2015</td>
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<tr>
<td>Texas</td>
<td>5,880MW (~4.2%) by 2015</td>
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2006 1-MW Saguaro Parabolic Trough Plant
New 64 MWe Acciona Solar Parabolic Trough Plant
but the BIG ATTRACTION: STORAGE!
Parabolic Trough Output Profile
Summer Day

Graph showing APS Load (MWe) and Net Solar Output (MWe) over time from 0:00 to 24:00, with curves for APS Load, Solar Output, and Solar with TES.
CSP Power Plant with Thermal Storage

[Diagram of CSP Power Plant with Thermal Storage]

- Solar Field
- Hot Tank
- Cold Tank
- 2-Tank Salt Storage
- HX
- Solar Preheater
- Solar Reheater
- Expansion Vessel
- Steam Generator
- Solar Superheater
- Steam Turbine
- Condenser
- Low Pressure Preheater
- Deaerator
CSP Power Plant with Thermal Storage
50 MW AndaSol-1 Parabolic Trough Plant w/ 7-hr Storage
Andalucia, Spain
Planned 280 MW Solana Plant with 6 hrs Storage

1500 construction jobs over two years

85 permanent jobs

Artist Rendition
Cost of CSP (¢/kWh)

- CSP w/10% ITC: 17
- CSP w/30% ITC: 14
- Comb. Cycle Gas: 12

The gap is closing!
Parabolic Trough
Potential Cost Reductions

![Graph showing potential cost reductions for different annual capacity factors.](chart.png)

- **Baseline 100 MWe 2-Tank Indirect**
- **Baseline Plus Advanced Solar Tech**
- **Molten-salt Thermocline @ 500C**
- **Scale-up to 200 MWe**
- **Power Park 4x200**
- **Power Park w/ 3X Learning**
Linear Fresnel
Planned 177 MW Air-Cooled Plant for PG&E

Artist Rendition
Power Tower or Central Receiver with Thermal Storage
BrightSource Distributed Power Tower
Dish/Stirling System

- Dish system
- Stirling engine
- Linear Alternator
- Cooling Water
- Flexure Bearings
- Heat In
- Electricity Out
- Flexure Bearings
- Cooling Water
Six Dish Prototypes at Sandia-Albuquerque
the future of csp
Contracts for over 4,500 MW of U.S. Projects

1,365 MW
1,750 MW
1,211 MW
177 MW
Solar Applications for BLM-Managed Land

- Over 50 different companies have filed 97,000 MW of applications
- 40% trough; 20% tower; 20% PV; 20% other

<table>
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<th>State</th>
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<th>MWs</th>
<th>CSP</th>
<th>PV</th>
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<td>Totals</td>
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<td>1,773,891</td>
<td>97,597</td>
<td>113</td>
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Over 7,500 MW Planned Worldwide
Long Distance Transmission: Europe

"Concentrating Solar Power for the Mediterranean Region," German Aerospace Center (DLR), 2005
Long Distance Transmission: U.S.
Challenges for CSP
Water Usage

- Hybrid air/water cooling systems can reduce water use 80% with modest performance and cost penalties
Land Use/Habitat
NREL CSP
R&D Highlights
Optical Collector Characterization

Indoor test

Field test
Optical Efficiency Test Loop

SkyTrough undergoing test

Control room showing tracker and loop controls
Distant Observer Field Assessment Tool
Receiver heat loss: laboratory measurements

Comparison of UVAC3 and UVAC2 Heat Loss
NREL Thermal Test Bed - March and October 2007
Information regarding testing available at:
http://www.nrel.gov/csp/conhnet/testing_standards_reports.html#receivers

Receiver test rig
Receiver heat loss: field surveys

Camera and GPS for exact positioning

Infrared image of hot and cold tubes
Advanced Materials Development

ReflecTech® film

Low-ε receiver coating
Modeling and Analysis Tools

Solar Advisor Model (SAM)

Regional Electricity Deployment System Model (REEDS)
Facilities Under Development/Construction

Energy Systems Integration Facility

Solar Technology Acceleration Center
By CHUCK KUTCHER

What comes to mind when you think of solar technology? If you’re like most people, you think of photovoltaic (PV) modules. But another type of solar technology generates electricity in a way that is much like conventional power plants. It’s concentrating solar power, or CSP. An ongoing solar advocate from the past period (as a tax credit on the industry), CSP is “the other white meat.”

CSP is simple enough. Mirrors concentrate solar energy, producing the high temperatures needed to efficiently run a thermal-dynamics engine. Because the power is focused, CSP plants can be built where space is at a premium, like the vast deserts of the United States. A study done for the Western Governors’ Association tied the Southwest and found out that it was already ideal for this type of technology. It has concluded that the remaining land could provide more than the current 34,000 GW of electricity.

CSP isn’t new. In the 1980s, the Italian company Enel constructed the first plant for a total of 34 megawatts (MW) of CSP at the Mojave Desert, and these plants are still operating successfully. They employ tracking parabolic troughs to focus sunlight on molten salt absorbers. The molten salt transfers heat to a boiler, and the steam drives a turbogenerator.

After the last Enel plant was built in 1988, Enel went out of business. The low oil prices of the period also caused the utilities and industrial consumers to divert investment dollars from utility-scale projects. But in the last few years, CSP has experienced a renaissance. Higher natural gas prices and a 30 percent federal investment tax credit, recently extended for five years, have made CSP attractive again. Renewable portfolio standards (RPS) in some states have put pressure on utilities to produce or buy electricity from renewable energy, and utility-scale CSP plants are increasingly generating power plants.

In 2000, SolEaS, Inc. (now Acciona, a global leader in utilities) built America’s first large parabolic trough power plant in 15 years. Although only 1 MW in size, the Solana plant outside Yuma provided the first experience needed to build the 640-MW Nevada Solar One plant outside Las Vegas. As a result, the plant was built in 2006, the same year as the first Nevada Solar One plant.

The current CSP projects in the Northwest that could be built are the 1.1-GW Desert Sunlight Solar Farm, that includes two power blocks, and the 1-GW Mountaintop Solar One project, which includes one power block. The Desert Sunlight Solar Farm would be built in 2013, and Mountaintop Solar One would be built in 2014. These projects would be the largest CSP projects in the world. In the 2014 CSP projects, the Desert Sunlight Solar Farm would be built in 2013, and the Mountaintop Solar One project would be built in 2014. These projects would be the largest CSP projects in the world.

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Climate Change: Here Today, Gone Tomorrow (2050)
A pathway to U.S. carbon emission reductions
Timothy Stovall, Kathleen Stynes, Philip Taylor

Climate Change Happening: Caused by People

- Rapid commercial, industrial, and agricultural expansion have released huge amounts of greenhouse gases into the atmosphere, causing global warming.
- Figure 1 shows that CO2 concentrations are higher than anytime during the last 450,000 years and that temperature changes are tightly coupled to the concentrations of greenhouse gases.
- Figure 2 shows that observations of recent global temperature rise are attributable to anthropogenic sources of emission.

Carbon Emission Displacement Wedges

- Figure 3: Long and short-term global CO2 concentration and temperature (Kt).
- Figure 4: Stabilization wedges accounting for emission reductions by end sector.

Stabilization at 450 ppm CO2

1) Limit warming to 2°C to avoid most “tipping points”
- Figure 5: Climate scenarios that exhibit threshold-type behavior with warming. Areas far to the left and downward to the right have a relatively cool 2°C.

2) Political Feasibility: 450 target fits emission reduction pathway in 10/11 Congressional cap-and-trade proposals

Transportation Efficiency

- Corporate Average Fuel Economy (CAFE) Standards
  - Increase fuel average 1 mpg/year
  - Historic precedent: 8 mpg (1978) to 28.5 mpg (1988)

- Reduce vehicle miles traveled (VMT)
  - Increased gas tax and improved public transportation
  - Historic precedent: 3% reduction from 2007 to 2008

Building Efficiency

- Design to the neutral cost point (50% energy savings) in all new and renovated buildings
- By 2050 75% of building stock will be either new or renovated

Funding Deployment of Renewables

- Currently, solar photovoltaics and concentrating solar power are more expensive than traditional electricity

- Figure 6: Annual costs to substitute renewable energy technologies

Carbon Cap-and-Trade Policy

- Regulate emitters over 10,000 Gt to 83% of U.S. emissions
- Establish an emissions target each year for those emitters
- Auction carbon allowances equal to that emissions target
- Reroute revenues to subsidize renewable energy technologies
- Allow regulated emitters to buy and sell allowances from each other

Conclusions

- Climate change is a real and pressing issue
- Stabilization at 450 ppm CO2 will avoid the most devastating consequences
- The U.S. can achieve the necessary carbon emission reductions through energy efficiency and low-carbon electricity
- Renewable energy deployment will be subsidized with revenue from a cap-and-trade policy
- Marketing and regulation will be used to promote energy efficiency improvements
the **POWER** of csp