2008 Solar Annual Review Meeting

Session: CSP Advanced Systems – Advanced Heliostats
Company or Organization: Sandia National Laboratories
Funding Opportunity: DOE Program Funding

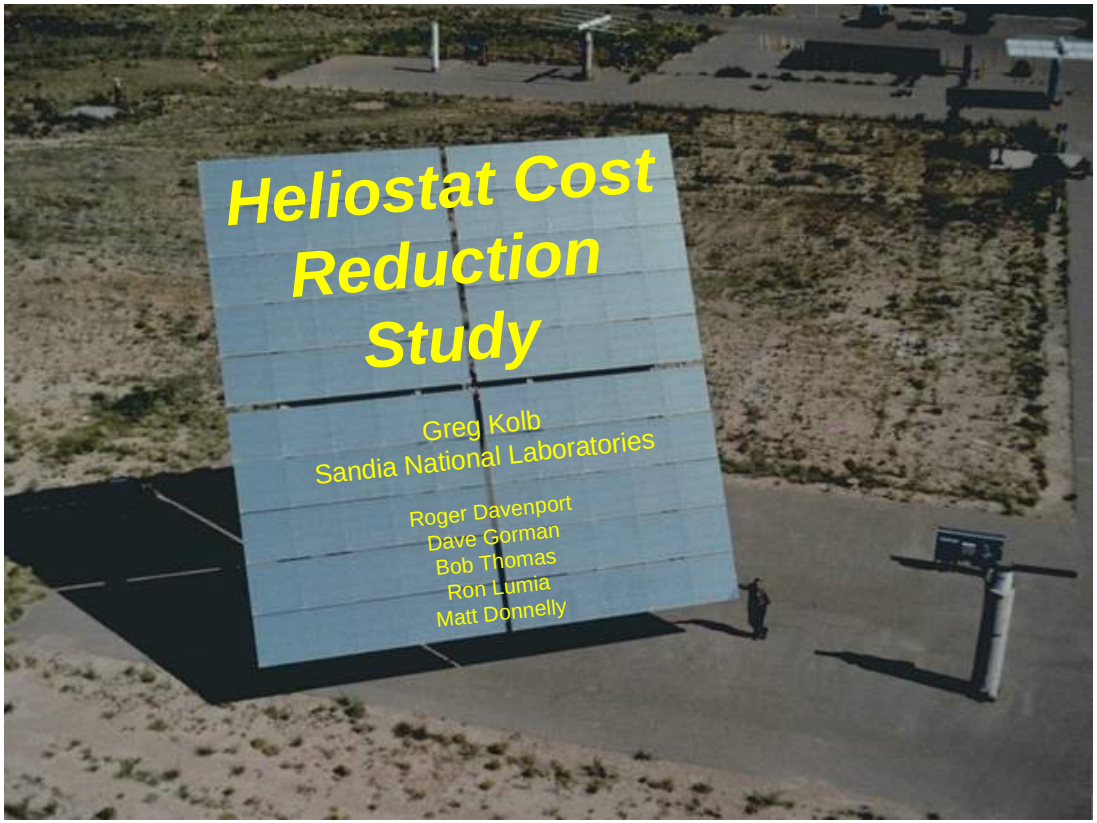
Greg Kolb
Sandia National Laboratories
MS 1127
Albuquerque, NM, 87185
gjkolb@sandia.gov

Sandia National Laboratories

Relationship to Solar Program Goals

- General CSP program goal
  - "…to make CSP cost competitive in the intermediate power markets by 2015 (~7¢/kWh with 6 hours of storage) and in baseload power markets (~5¢/kWh with 16 hours of storage) by 2020."
- Specific solar power tower goal
  - This is the first DOE R&D budget allocated for power towers in several years
  - Power tower goals do not currently exist in current version of the MYPP (2007 – 2011)

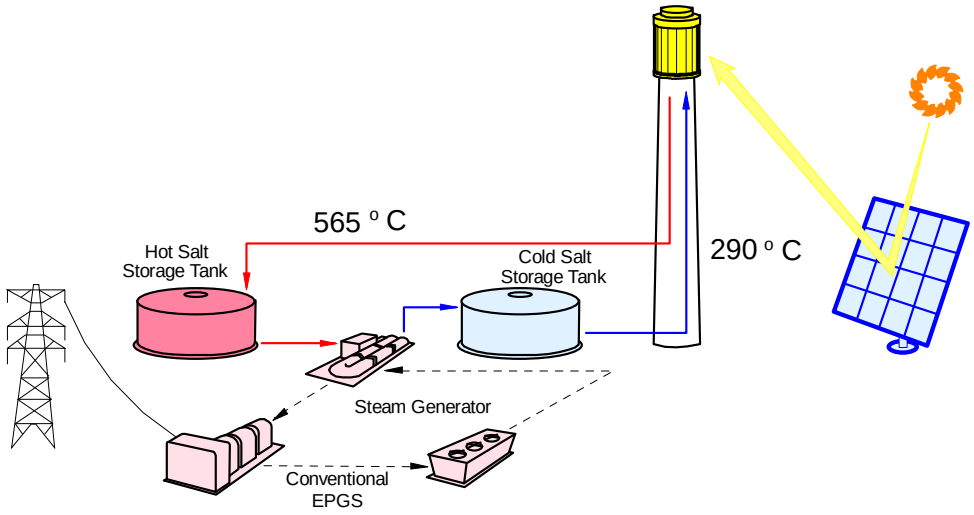
FY07 accomplishments



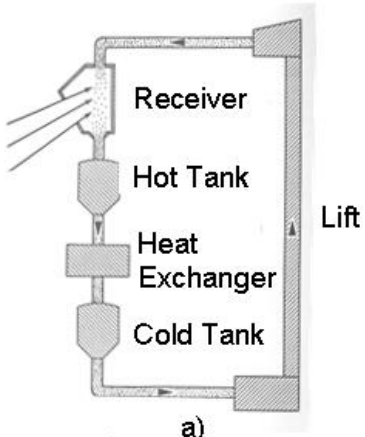
SAND2007-3293 issued in June 2007

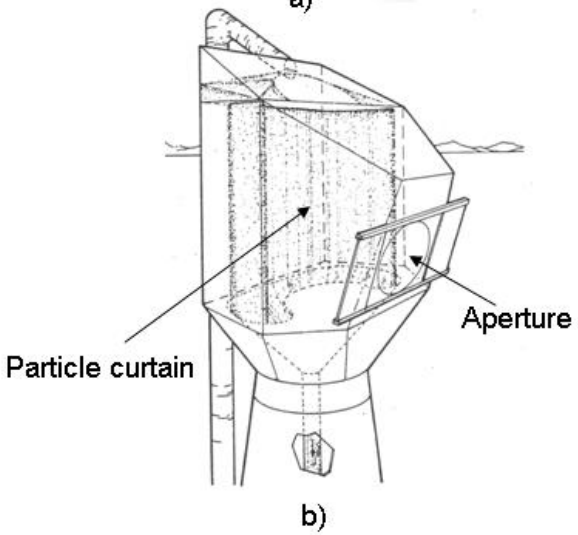
Power Tower Systems

Solar electric power plant
- 565 ºC molten salt receiver
- 13 hrs molten salt storage



Solar hydrogen plant
- 950 ºC solid particle receiver
- 13 hrs solid particle storage





Since heliostats contribute ~50% to plant capital cost, they have a large impact on power tower economics

Heliostat Cost	Molten Salt Power Tower (S&L economics)	Hybrid Sulfur Hydrogen Plant (H2A economics)
$80/m^2	5.4 cents/kWh	$2.6/kg
$100/m^2	5.9 cents/kWh	$2.9/kg
$150/m^2	7.3 cents/kWh	$3.5/kg
$200/m^2	8.7 cents/kWh	$4.1/kg
$300/m^2	12 cents/kWh	$5.4/kg

← Tentative Goal

- Large optimum plants with mirror areas of 1.4 km^2 and 13 hrs of storage
- 100 MWe electric power tower and 100,000 kg/day hydrogen plant

Cost reduction potential was estimated relative to ATS base case

- ATS 148 m^2 is base case
  - Also base case in Sargent & Lundy study (DOE “Bible”)
  - 20 years of successful operation

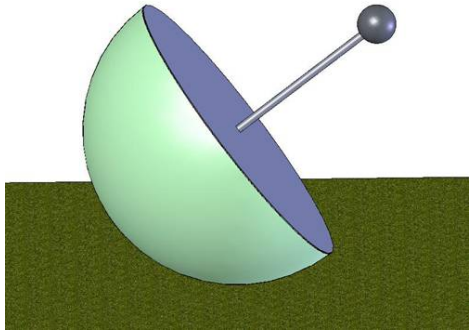
Baseline Heliostat Price in 2006 ($/m^2)

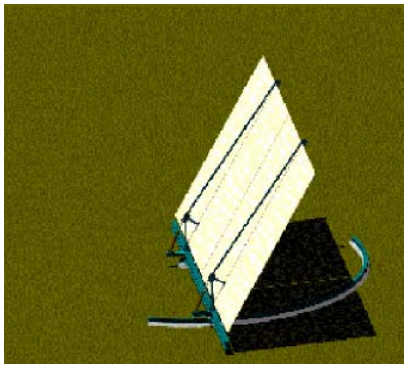
	5000 per year (60 MW)	50,000 per year (600 MW)
Mirror Module	26.5	23.1
Support Structure	23.3	21.2
Azimuth Drive	38.5	20.3
Elevation Drive	10.1	6.8
Electrical/Controls	4.8	3.7
Pedestal	18.7	17
Total Direct Cost:	122	92.1
Overhead/Profit (20%)	24.4	18.4
Total Fabricated Price:	146.4	110.5
Field wiring	8.1	7.4
Foundation	2.6	2.3
Field align/checkout	7.0	6.3
Total Installed Price:	$164/m^2	$126.5/m^2

The Azimuth Drive is the Only Solar-Unique Component

- ***If 60 are ordered, the price is $100/m^2***
- ***If 5000/yr are ordered, ~$3 M manufacturing plant is built and price is $38.5/m^2***

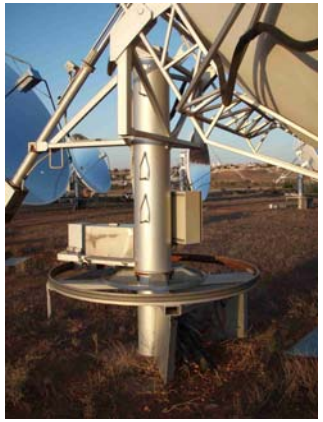
30 international experts brainstormed several heliostat types

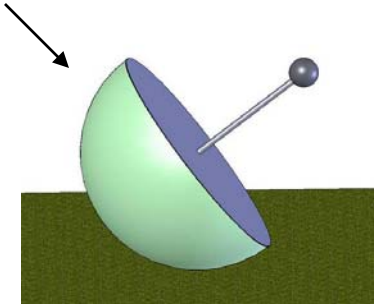




Evaluation of TIO's suggested the following R&D projects

- Less-conservative azimuth gear drive
- "Pipe-in-pipe" azimuth drive
- Large carousel stretched-membrane heliostat
- Large fabric-based stretched-membrane facet
- Mega heliostat (>300 m^2) with hydraulic drives
- Water-ballasted heliostat





Incremental Improvements vs. Totally New Heliostat

Crystal Ball Prioritized R&D

R&D Budget	Mean Price Reduction	Less Conserv Az Drive	Pipe in Pipe Az Drive	Carousel SM Helio	Large Fabric SM Facet	Mega Helio
$1 M	$7.8/m2					X
$2 M	$10.2/m2	X				X
$3 M	$10.6/m2			X		
$4 M	$13.8/m2			X		X
$5 M	$15.8/m2			X	X	X
$6 M	$16.4/m2	X		X	X	X
$7 M	$16.4/m2	X		X	X	X
$8 M	$16.6/m2	X	X	X	X	X

Most Bang For Buck

Study Conclusions

- Heliostat price is strongly dependent on production rate
  - $164/m^2 given 5,000/yr and $126/m^2 given 50,000/yr
    - Price reduction dominated by lower cost azimuth drive
  - Key to achieving high production is to obtain multiple power purchase agreements
- ATS heliostat is the current low-cost baseline in the USA
  - Except for the azimuth drive, it uses common parts that are already mass produced
  - A prototype has successfully operated for 20 years
  - The current PS-10 and PS-20 tower projects in Spain use a heliostat similar to ATS

Study Conclusions (continued)

- Large heliostats are more cost effective than smaller ones
  - Detailed analysis suggests that optimum is 150 m^2 or larger, and no smaller than 50 m^2
  - *However …. Micro developers LUZ2 and eSolar may disagree*
- Moderate investments in R&D should reduce heliostat price by $17/$m^2$
  - Lower cost az drive will benefit initial tower plants
  - Mega-helio or Carousel heliostat are longer term options
- Learning curve effects should result in an additional cost reduction
- $100/$m^2$ cost goal appears to be achievable

FY 08 Progress Report

- Sandia received $221 K from DOE in Jan 08 for heliostats and tower systems R&D
- Assume ~50% or $110 K for heliostat R&D
- This is not enough money to implement any of the R&D plan described in the FY07 study
- What can we do for $110 K??
  - With industry, develop R&D plan to reduce cost of Micro (1 to 10 m^2) heliostats
    - Micro heliostats are being pursued by a few companies
      - Bright Source and eSolar
    - Micro should cost more, but may be a market entry strategy
    - In early March 08, Sandia contacted Micro suppliers and suggested that we work together
      - No response from Bright Source
      - eSolar is thinking about it … concerned about release of their intellectual property

FY 08 Progress Report (cont.)

- What can we do for $110 K?
  - Perform additional testing of existing large-area heliostats to resolve perceived-risk issues
  - For example …… SolarReserve's commercial-project investors need assurance that heliostats within very large fields will meet performance specs at distances of up to 1 mile away from tower
    - Furthest heliostats at Solar Two and PS10 -- 0.25 and 0.5 mile
    - For a portion of the $110 K, the "1-mile" test can be done at Sandia
    - With industry, we will define other low-budget tests that resolve perceived risk issues

DOE has suggested that $1M to $2M may soon be available for heliostat R&D

- With this budget the R&D plan identified in the FY07 study can begin
  - R&D Path A will require 1.5 yrs
    - Contractor study of az-drive to achieve 33% cost reduction ($500 K)
    - If cost target met, contractor builds new az prototype ($500 K)
    - If cost target met, test new drive at Sandia ($200 K)
    - Total cost of new low-cost az drive = 500 + 500 + 200 = $1.2 M
  - R&D Path B will require 2 yrs
    - Az-drive study completed and cost target not met ($500 K)
    - Contractor study of Mega-helio to achieve $15/$m^2$ cost reduction ($500 K)
    - If cost target met, Mega-helio built and tested at Sandia ($500 K)
    - Total cost leading to new Mega-helio = 500 + 500 + 500 = $1.5 M
- Alternatively, we can development an optimized micro heliostat

Heliostat R&D Vision -- FY07 through FY10

- FY07 ($100 K to $600 K)
  - Min budget – Micro heliostat R&D plan and/or risk reduction tests
  - Max budget – Design of low-cost azimuth drive
- FY08 ($1M to $2M)
  - Min budget – Build and test low-cost azimuth drive
  - Max budget – Design, build, and test Mega helio or Micro helio
- FY09 ($1M to $2M)
  - Min budget – Design of Carousel heliostat
  - Max budget – Build and test Carousel heliostat
- FY10 ($1M to $2M)
  - Min budget – Design of fabric facet for Carousel heliostat
  - Max budget – Build and test fabric facet