Heliostat Cost Reduction

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ABSTRACT

Power towers are capable of producing solar-generated electricity and hydrogen on a large scale. Heliostats are the most important cost element of a solar power tower plant. Since they constitute ~50% to the capital cost of the plant it is important to reduce the cost of heliostats as much as possible to improve the economic viability of power towers. In this study we evaluate current heliostat technology and estimate a price of $126/m^2$ in 2006. This price yields electricity at 6.7 cents/kWh and hydrogen at $3.20/kg. We also propose R&D that should ultimately lead to a price as low as $90/m^2$, which equates to 5.6 cents/kWh and $2.75/kg. Thirty heliostat and manufacturing experts from the USA, Europe, and Australia contributed to the content of this study during two separate workshops conducted at Sandia.

1. Objectives

The objectives of this study were 1) review the history of heliostat development that has led to the current state of the art, 2) develop price estimates in 2006 dollars for state-of-the-art heliostats, 3) identify and evaluate technology improvement opportunities (TIOs) that lead to a significant price reduction, 4) determine whether it is feasible to achieve the strawman goal of $100/m^2$

2. Technical Approach

Given different prices for heliostats we used standard DOE methods [1,2] to calculate the levelized energy cost (LEC) for power tower plants. Power tower LECs are attractive given a heliostat price of $100/m^2$ and may be low enough to be competitive on the open market, especially if carbon-offset trading becomes the norm.

Table 1. Power Tower LECs

Heliostat Price	Molten Salt Power Tower	Hybrid Sulfur Hydrogen Plant
$80/m^2$	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

3. Results and Accomplishments

3.1 Current Heliostat Price in 2006

A detailed analysis of heliostat price has not been conducted by Sandia for more than 10 years. We first analyzed the weight of the current state-of-the-art heliostat in the USA (148 m^2 built by ATS) to obtain a lower bound cost estimate. The heliostat has a total weight of 6385 kg. When broken down by material type, 87% of the heliostat is found to be constructed of simple steel (4006 kg) components and mirrors (1518 kg). In 2006, carbon steel at the mill costs about $0.65 per kilogram and steel products that are relatively simple to fabricate cost about $2.17 per kilogram. The price of high-reflectance flat mirrors is $1.10 per kilogram. Using these costs yields a total of about $70/m^2$ as the minimum possible cost of the ATS.

We next estimated the installed price of the ATS, as well as 150 m^2 stretched membrane (SM) heliostats that are pedestal mounted. We performed a sanity check on our "bottom-up" cost analysis by extrapolating historical studies using appropriate price escalation indexes. Heliostat prices were estimated given production rates of 5000/yr and 50,000/yr; this corresponds to 60 MWe and 600 MWe of power plants. The price of the ATS was $164/m^2$ and $126/m^2$, respectively. The lower price at the higher production rate is primarily due to a lower cost azimuth drive; at the higher rate more automation would be incorporated into the factory that produces the drive. The installed price of the SM at the same production levels was $180 and $143/m^2$, respectively. Despite the fact that the SM heliostat weighs ~830 kg less than the ATS and is easier to align in the field, it still costs more due to the use of costly stainless steel in the membrane and supporting ring. Also, the fabrication of a single large membrane from available one meter widths is cumbersome and adds to the price. However, the SM heliostat has several optical advantages that are worth ~$10/m^2$ on a system basis. Thus, the effective price of the SM heliostat is $170 and $133/m^2$, respectively.

3.2 Heliostat TIOs

TIOs were identified at 2 workshops involving 30 international experts in heliostats and manufacturing. The group identified 6 R&D projects that can lead to significant cost reduction.

<u>Less conservative azimuth drive</u> The azimuth drive is the most significant heliostat cost contributor. It appears the design of the azimuth drive may be too conservative and lower cost drive could be developed given a better understanding of the wind loads and torques on the heliostat drive. Significant cost

reduction can also be achieved through highly-automated production-line manufacturing techniques. A production line does not currently exist. A 33% price reduction (~\$8/m^2) is targeted.

Pipe-in-pipe azimuth drive The brainstorming group explored different approaches to the conventional gear-type drive historically built by Winsmith and Flender. At the White Cliffs plant in Australia, a pipe-in-pipe approach was successfully used to position relatively small (~7 m^2) solar dishes. In this concept, azimuth motion is achieved by rotating a pipe within the fixed pedestal. The driving motor is located at the bottom of the pedestal and the wind loads on the drive are distributed along the length of the pipes, as opposed to a single point within the conventional drive. Cost reductions relative to a gear-type drive appear feasible because manufacturing of the pipe-in-pipe could be simpler. A 33% price reduction relative to the current conventional azimuth drive (~\$8/m2) is targeted.

Large carousel type SM heliostat A large heliostat like this has been operating in Spain. Analysis conducted in the 1990s indicate the cost of this heliostat should be significantly lower than a glass-metal heliostat built by a Spanish company. However, the concrete foundation for this heliostat is too complex and costly. Precast concrete foundations that "roll off a truck" were thought to be a possible low-cost solution. A >10% capital cost reduction relative to the ATS is targeted. This appears feasible because it weights ~50% less than the ATS. Combining this with the performance improvement of ~\$10/m^2 described in the previous section should result in an overall cost reduction of ~20%.

Large single fabric-based SM facet Today's SM facets are created by welding multiple strips of stainless steel across a ring. This is complex and cumbersome. The experts thought that significant cost reduction for the facet could be achieved if the stainless steel strips were replaced with a single large piece of fabric. Besides eliminating expensive stainless steel, connection to the outer ring could be greatly simplified by using an "embroidery-hoop" method, i.e. 2 concentric hoop are press fit to form the connection between the material and the ring. The fabric must not leak air to maintain the vacuum within the facet plenum and would need to be impregnated with a sealer. A ~\$7/m^2 relative to the carousel heliostat described above appears feasible.

Mega heliostat Arizona Public Service currently operates 2-axis PV concentrators that are 320 m^2. This device could be converted to a heliostat. At this size the use of hydraulic-type azimuth and elevation drives appears to be justified. The group generally concluded that hydraulic drive systems are more complex and require more maintenance than mechanical drive systems. However, they are very strong and could be the preferred low-cost approach for mega heliostats. Engineering scaling laws indicate the cost of this heliostat could be \$21/m^2 less than the ATS heliostat. However, the optical quality of the mega heliostat will be worse and the optical penalty is ~\$3/m2. Thus, the net cost reduction is ~\$18/m2.

Water-ballasted heliostat Students at New Mexico Tech are exploring innovative "water-ballasted" heliostats. Heliostat tracking is achieved by pumping water between chambers located on the back of the mirror. This eliminates the use of costly gear drives.

4. Conclusions

There are 4 main conclusions:

1) Heliostat price is strongly dependent on production rate. The key to achieving reasonable production rates is for a solar company to obtain multiple power-purchase agreements from electric-utility companies over a several year period. For example, a solar-dish developer (SES Inc.) has recently signed agreements with 2 utilities to deploy up to 1750 MW. With these agreements in hand SES can now justify a highly automated production facility. Like SES, a power-tower developer needs to sign multiple power-purchase agreements. However, if the SES projects proceed as planned, the power tower developer could benefit because the dish azimuth drive is nearly identical to the heliostat azimuth drive.

2) The ATS heliostat is the current low-cost baseline in the USA. It is cost efficient from a manufacturing point of view. Except for the azimuth drive it uses common parts that are already mass produced. It has successfully operated for 20 years.

3) Large heliostats are more cost efficient than small ones. Like most engineered systems heliostats benefit from "economies of scale." Thus, large heliostats cost less on a \$/m^2 basis than very small ones.

4) R&D should be able to reduce the heliostat price by at least \$17/m^2. A price reduction from \$126/m^2 to \$109/m^2 was estimated by evaluating TIO's proposed by 30 heliostat and manufacturing experts. Continued price reduction from \$109/m^2 to ~\$90/m^2 is expected through learning during the deployment of the initial 9 GW of power plants over a decade or more.

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