Low Cost Heliostat Development

DOE – CSP

Program Review

May 17, 2011

Stephen Kusek

HiTek Services, Inc.

7234 Hwy. 431 South

Owens Cross Roads AL, 35763

(256)539-0380

kusek@hitek-services.com

HiTek Services, Inc.

Presentation Outline

- Project
  - Description
  - Objectives
  - Impact
  - Challenges
  - Heliostat Size Analysis
  - Heliostat Development
  - Key Results
  - Summary
  - Future Work

Project Description

- This project will develop a methodology and provide an example analysis to find an optimal heliostat size using minimal heliostat cost as the objective function for a 100MW_e baseload solar electric power plant. A heliostat of this size will be designed, fabricated, and tested incorporating lessons learned from the 1970's to today.
- There are two primary study areas:
  1. Heliostat Size Analysis
  2. Heliostat Development
     1. Reflector
     2. Drive Unit
     3. Tracking Control

Project Objectives

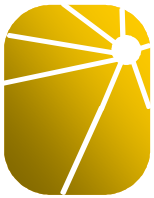
The four primary objectives are:

1. Develop the means for determining the optimal size of a heliostat in terms of applied forces, moments, manufacturing learning curve effects, O&M, and optical efficiency,
2. Develop a low-cost, long-life, monolithic composite mirror support structure,
3. Develop a low-cost, long-life azimuth chain drive , and
4. Develop a low-cost, long-life tracking control subsystem.

Project Impact

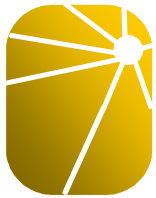
- Demonstrating a Methodology for Determining a Minimal-Cost Heliostat
- Comparing the Results to Past Work to Verify a Shift in Heliostat Size Expectation
- Demonstrating the Performance and Estimating the Cost of a Heliostat of a Size Suggested by this Methodology

Challenges



- Understanding the “Real” Details Behind Previous Cost Studies
- Developing Well Founded Cost Algorithms
- Keeping Heliostat Development Costs Affordable with an Unknown Heliostat Size at the Program Start
- Scaling Up Our Previous Drive Work
- Affordably Controlling this Many Heliostats

Heliostat Size Analysis

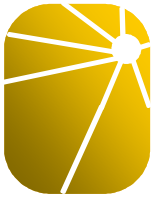


- Heliostats of various sizes have been built since the early 1970's
- Each overall solar plant architecture brings some generic and some specific requirements
- The general trend has been to build larger and larger heliostats
- The goal of this task is to ascertain a heliostat size that minimizes cost for a generic 100MW_e baseload central receiver plant

Analysis Approach

- Start by using previous studies and existing data that are recast into three cost categories
  1. Hardware with costs that vary linearly with area (e.g., mirrors)
  2. Hardware with costs that vary with the three-halves power law (e.g., structure)
  3. Hardware with fixed costs no matter the heliostat size (e.g., encoders, control PCB)
- Once that various heliostat elements are assigned to their category, and costs are determined as a function of area, calculate a cost for various heliostat sizes
- Perform an initial sizing analysis to set an early heliostat size that can be used to initiate subsequent heliostat design tasks
- Add cost and model fidelity as project progresses to refine the size computation

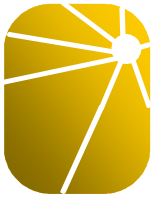
Cat. 1 – Constant $ Per Unit Area



- Primary Cost Driver for this Category
  - Mirror and mirror substrate
  - Typically the mirror is a glass second surface mirror and the mirror is bonded either to a substrate or directly to a support structure
  - As an example, the ATS heliostat used a 1mm mirror bonded to a 3mm glass substrate. Here the mirror, adhesive, and glass substrate costs are all essentially constant per unit area for a given plant size.

The mirrors are an important cost factor but not the major cost parameter

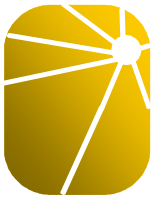
Cat. 2 – Size Dependant Costs



- Primary Cost Drivers for this Category
  - Reflector Support Structure
  - Drives
  - Drive Motors
  - Pedestal
  - Foundation
  - Net Present Value of Operations & Maintenance Costs

This is the major cost category

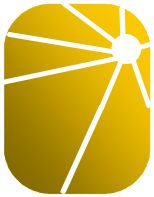
Cat. 3 – Fixed Cost



- Primary Cost Drivers for this Category
  - Processors
  - Encoders
  - Limit Switches

Minor cost category until the heliostat size becomes “small”

Initial Analysis



- Use cost data from the Sandia Heliostat Cost Reduction Study (June 2007)
- Recast the published costs into the three cost categories
- Create the cost equations as a function of area so that the cost per unit area is $167.50 for a 148$m^2$ heliostat
- Create an installed cost per unit area curve versus heliostat area
- Reallocate costs between categories and calculate changes

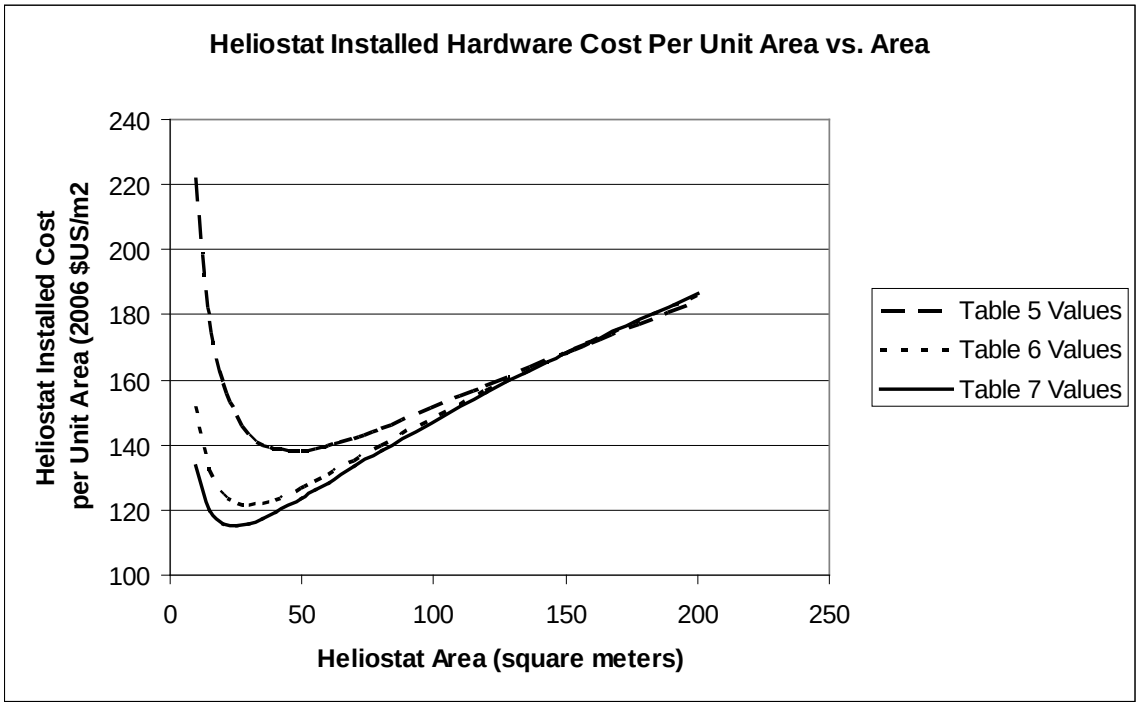
Sample Cost – Table 5

ALLOCATION FOR 5000 UNITS/YR	148 m2 ATS Glass/Metal Heliostat Price Per Unit Area	CATEGORY 1 Costs/Area That Are Constant Irrespective of Heliostat Area or Number of Heliostats	CATEGORY 2 Costs/Area Dependent on Imposed Moment	CATEGORY 3 Costs/Area That Are Constant for Each Heliostat Irrespective of Area (i.e., depend on number)
Mirror Module	$ 26.50	$ 26.50		
Support Structure	$ 23.32		$ 23.32	
Drive	$ 48.65		$ 48.65	
Drive Electrical	$ 2.67		$ 1.33	$ 1.34
Controls	$ 2.09		$ 1.05	$ 1.05
Pedestal	$ 18.66		$ 18.66	
Field Wiring	$ 8.14	$ 2.71	$ 2.71	$ 2.71
Foundation	$ 2.56		$ 2.56	
Field Alignment/Checkout	$ 6.97	$ 3.49		$ 3.49
Total Installed Cost/Area	$ 139.56	$ 32.70	$ 98.28	$ 8.58
Overhead/Profit (20%)	$ 27.91	$ 6.54	$ 19.66	$ 1.72
Total Installed Price/Area	$ 167.47	$ 39.24	$ 117.93	$ 10.29
Fraction Category to Total Cost 5000 ATS 148 m2 Heliostats		0.234	0.704	0.061

Data Based Upon Sandia Report SAND2007-3293, June 2007

HiTek Services, Inc.

Initial Sizing Results



Minimum Cost

Table 5 Values ~40m^2

Table 6 Values ~30m^2

Table 7 Values ~20m^2

HiTek Services, Inc.

Heliostat Development

- Plant Design
  - 100MW_e
  - 75% Capacity Factor
- Assumptions
  - 10% System Efficiency
  - 7.5 kWhr/m^2/day Average Daily Energy To Mirrors
  - 10% Startup/Shutdown Energy Loss
- Total Mirror Area **Calculated** at **2.7 Million m^2**

Quick Computation for Needed Mirror Area

How Many Heliostats?

Design Assumptions

1. Constant Mirror Size (about 5’ x 5’)
2. Stay “Near” a 1.2 Aspect Ratio

Design-1		
Mirror Wide	3	
Mirrors High	2	
Heliostat Width	4.68	m
Heliostat Height	2.95	m
Aspect Ratio	1.59	
Heliostat Area	13.8	m2
Number of Heliostats	193237	

Design-2		
Mirror Wide	4	
Mirrors High	3	
Heliostat Width	6.24	m
Heliostat Height	4.42	m
Aspect Ratio	1.41	
Heliostat Area	27.6	m2
Number of Heliostats	96761	

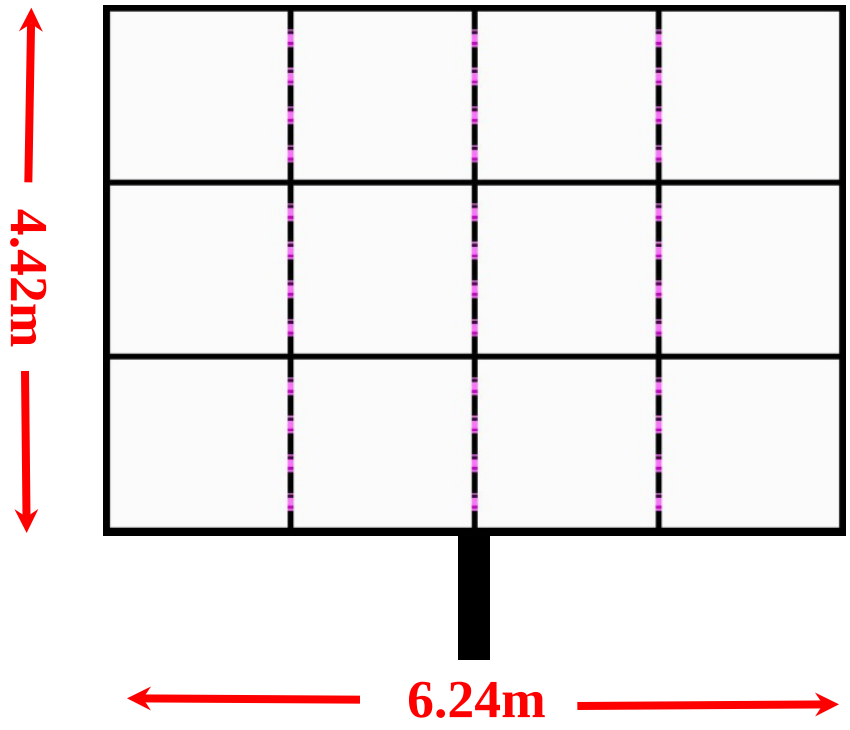
Design-3		
Mirror Wide	5	
Mirrors High	4	
Heliostat Width	7.79	m
Heliostat Height	5.89	m
Aspect Ratio	1.32	
Heliostat Area	45.9	m2
Number of Heliostats	58057	

Design-4		
Mirror Wide	6	
Mirrors High	5	
Heliostat Width	9.35	m
Heliostat Height	7.37	m
Aspect Ratio	1.27	
Heliostat Area	68.9	m2
Number of Heliostats	38704	

Need to Control Tens of Thousands of Heliostats

Heliostat Requirements

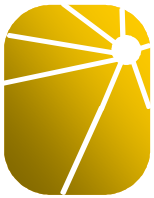
- The Preliminary Load Design Specifications/Conditions are:
  - Area is $28m^2$
  - Face Up Wind Stow Position
  - Go To Wind Stow When a 30mph Gust is Observed
  - Heliostat Must Drive to the Wind Stow Position in a 50 mph Wind Gust at any Orientation
  - Survive 90mph Gusts at the Wind Stow Position



Key Results

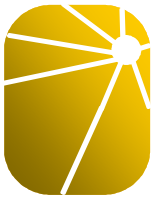
- Using the Data Developed in SAND2007-3293, the Initial Analysis Shows an Optimal Heliostat Size Between 20 to 40 m^2.
  - Contrary to Traditional Trend Towards Larger & Larger Heliostats
  - In Step with Recent Efforts by eSolar and BrightSource

Summary



- 100MW$_e$ Baseload Plant Sized
- Initial Cost Optimization Completed and Report Drafted
- Initial Heliostat Size Defined
- Heliostat Development Initiated
  - Azimuth Drive System Sized
  - Control Architecture Developed
  - Control Hardware Defined & Priced

Phase 1 - Future Work



- Continue Adding Detail and Refining Cost Algorithms and Resulting Optimal Heliostat Size
- Fabricate & Test a Representative Mirror Support Structure Segment
- Fabricate & Test a Representative Azimuth Drive
- Fabricate & Test Representative Control Electronics