U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Solar Power Tower R&D

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CSP: Tower R&D

Gregory J. Kolb
Sandia National Laboratories
gjkolb@sandia.gov (505) 844-1887

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

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Timeline

- Start: October 1st , 2009
- End: Ongoing program activity

Power Tower R&D is now an official R&D Agreement at DOE after a several year absence

Budget

- FY10 budget is $1050K
  - 760 K received so far
- FY09 budget was $233K (conducted as a task within CSP Advanced Concepts R&D Agreement)

Barriers

- Barriers addressed
  - Technology Risk
  - Capital Cost Reduction
  - Improved Performance

Partners

- Interactions/ collaborations
  - Power Tower Industry
    - Solar Reserve/Rocketdyne
    - Brightsource
    - eSolar
    - SENER
    - Abengoa
  - DLR (German Nat'l Lab)

Accomplishments Reported at 2009 Peer Review

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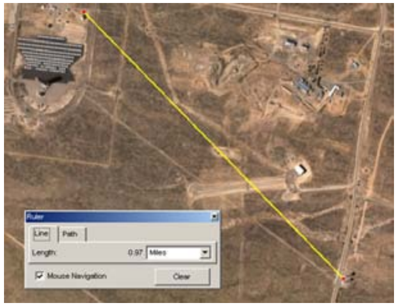
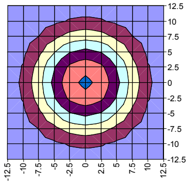
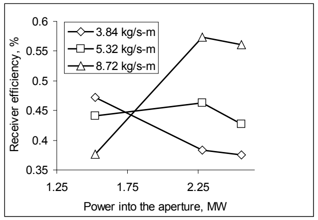
- 1-mile heliostat test
  - SolarReserve
- Steam receiver model upgrade
  - eSolar, Brightsource, Abengoa

- Performance modeling software training/intercomparison
  - Rocketdyne and eSolar
- Solid-particle receiver test
  - H_2 production and Hi-T power cycles







Steam Receivers

- Resurrection of steam receiver technology
  - PS-10 MW_e on grid 6/07, PS-20 5/09 (Abengoa)
  - 5 MW_e, 2-tower plant on utility grid 7/09 (eSolar)
  - 5 MW_t thermal-only demonstration since late 08 (Brightsource)
  - Lessons learned from 10 MW_e Solar One, shutdown in 1988
  - Steam receivers perceived as “low risk,” many PPA’s announced

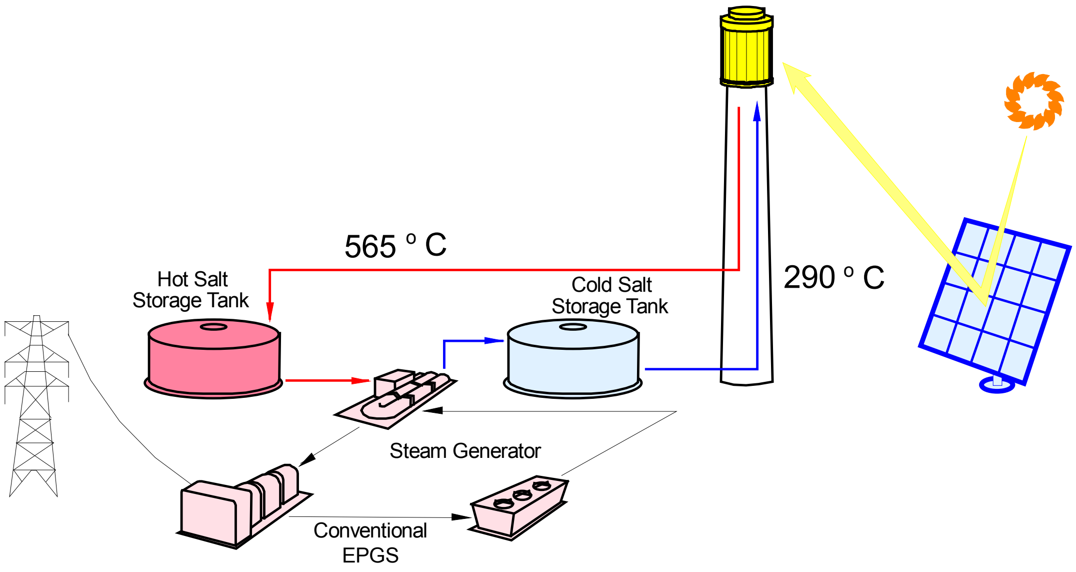
eSolar

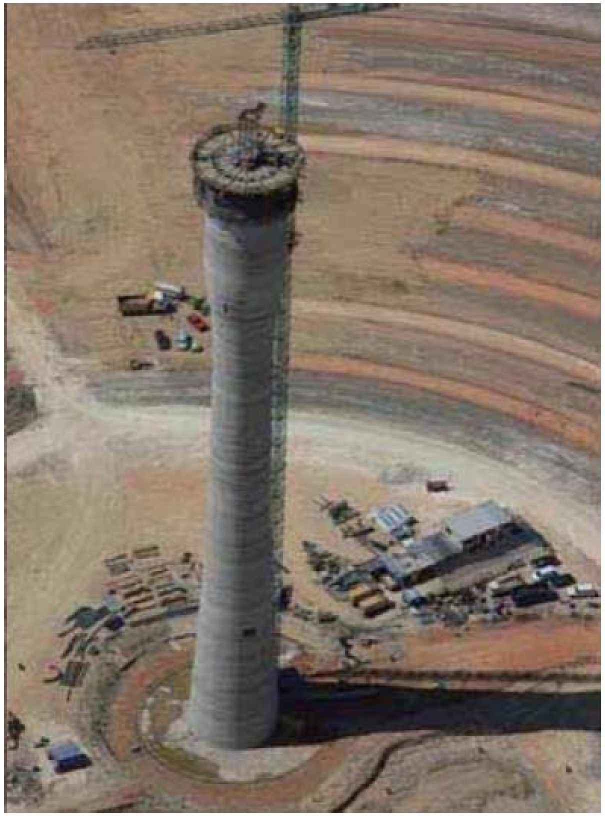
Brightsource

Abengoa

Molten Salt Receivers

- SENER 17 MW_e Gemsolar project now under construction
  - 2650 heliostats, 116 m^2 each
  - 120 MW_t receiver (3X scaleup from Solar Two), 140 m tower
  - 15 hrs of storage (6X scaleup)
  - Startup in 2011 (Torresol)
- Solar Reserve's receiver is 540 MWt
  - PPAs announced





Approach: R&D must reduce commercial project risk, reduce cost, and improve performance

R&D Tasks

1. Power Tower Plant Analysis
   - Develop Tower R&D Roadmap
   - Analysis of next generation power towers
   - Software tool development and industry training
2. Heliostat Analysis
   - New CAD models to include gravity and wind effects on performance
   - Develop tracking software with self correcting features to achieve <1mrad tracking accuracy
3. Advanced Heliostat Development
   - Support testing and performance optimization of industry heliostats
   - Design reviews and field performance tools
   - Rapid alignment tools

Relevance of Tower R&D

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- Financial risk of new tower plants perceived to be high
  - Only 35 MW of commercial towers now operating
  - Sandia is performing tests and evaluations with industry to reduce risk
  - Near-term R&D
- Heliostat cost and performance dominate economics of tower plants
  - Heliostats account for ~50% of tower plant capital cost
  - Each power tower company is developing their own heliostat, each having their own advantages and disadvantages
  - Near-term R&D
- Tower plant heat-to-electricity efficiency can be improved
  - Increase from 42% to 48% (Mid-term R&D)
  - Eventually increase to >50% conversion efficiency (Long-term R&D)

Technical Accomplishments Since Last Peer Review

- Task 1: Power Tower Analysis
- Task 2: Heliostat Analysis
- Task 3: Advanced Heliostat Development

Tower Roadmap

Power Tower Road Map meeting conducted at Sandia's NSTTF March 24 and 25, 2010.

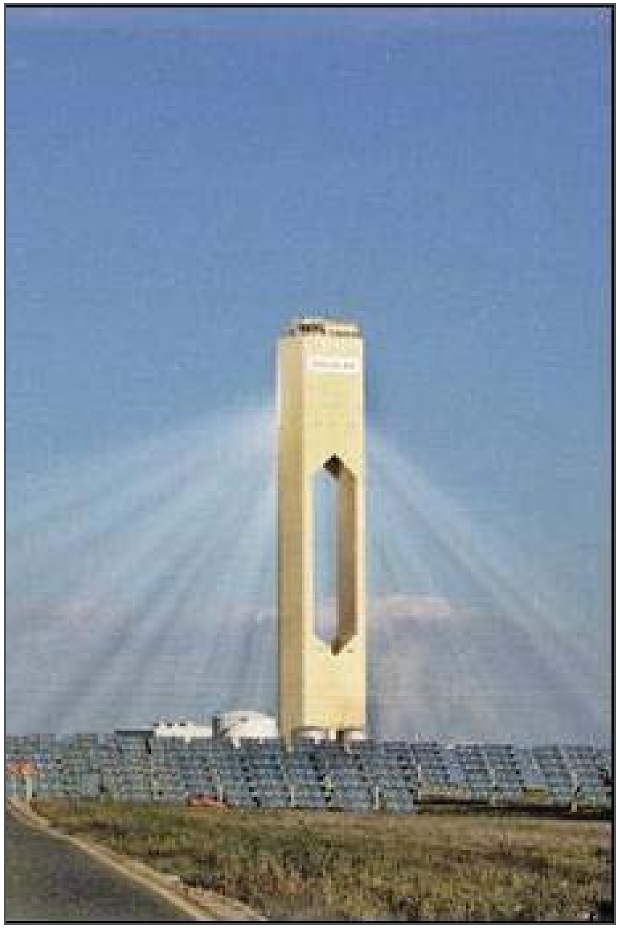
Purpose: to start development of a technology road map to accelerate the commercial deployment of Power Towers.

- address technology development issues,
- reduce the cost of Power Tower systems and components, and
- discuss non-technical issues that could accelerate deployment.

Task 1: Power Tower Plant Analysis

DOE will use the Power Tower roadmap to

- evaluate current projects,
- identify new Funding Opportunity topics,
- advise laboratory research,
- guide DOE CSP budget requests, and
- support the development of DOE's next Program Plan for the Solar Energy Technology Program.



trmanci@sandia.gov

Task 1: Power Tower Plant Analysis

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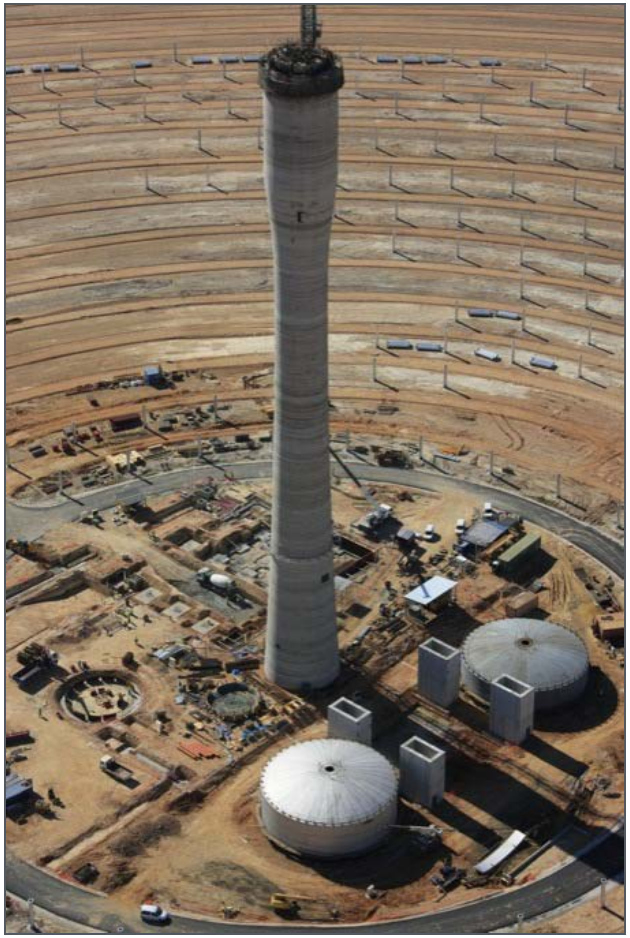


ROADMAP ATTENDEES

SENER Eng, San Francisco, CA
BrightSource Energy, Inc.,
SolarReserve, Santa Monica, CA
Worley Parsons, Golden, CO 80401
Black&Veatch Overland Park, KS
Rocketdyne, Canoga Park CA
eSolar. Pasadena, CA
Abengoa Solar, Denver, CO.
Sargent & Lundy, Chicago, IL
EPRI, Albuquerque, NM
NREL, Golden, CO
DOE HQ, Washington, DC
Sandia Nat. Labs. Albuquerque, NM

Roadmap Process and Schedule

a) *Determine baseline and goals for component costs and performance,*	***Preliminary evaluation with ongoing analysis.***
b) *Identify technology improvement opportunities (TIOs),*	***Preliminary evaluation with ongoing analysis.***
c) *Assess and prioritize TIOs,*	***Preliminary evaluation with ongoing analysis.***
d) *Develop a draft Power Tower Road Map for review by industry, and*	***Draft available in mid June 2010.***
e) *Publish final Power Tower Road Map.*	***Final draft scheduled by late July early August.***

Roadmap Baseline Subsystem Costs and Plausible Goals

	Solar Field	Solar Receiver	Thermal Storage	Power Block	Steam Generation	O&M
Baseline (prelim.)	$200/m^2$	$200/kW	$30/kWh$_t$	$1000/kW	$280-350/kW$_e$	$65/kWyr
Plausible Goal	$120/m^2$	$170/kW	$20/kWh$_t$	$800/kW$_e$	$250/kW$_e$	$50/kWyr

Roadmap Technology Improvement Opportunities (TIO)

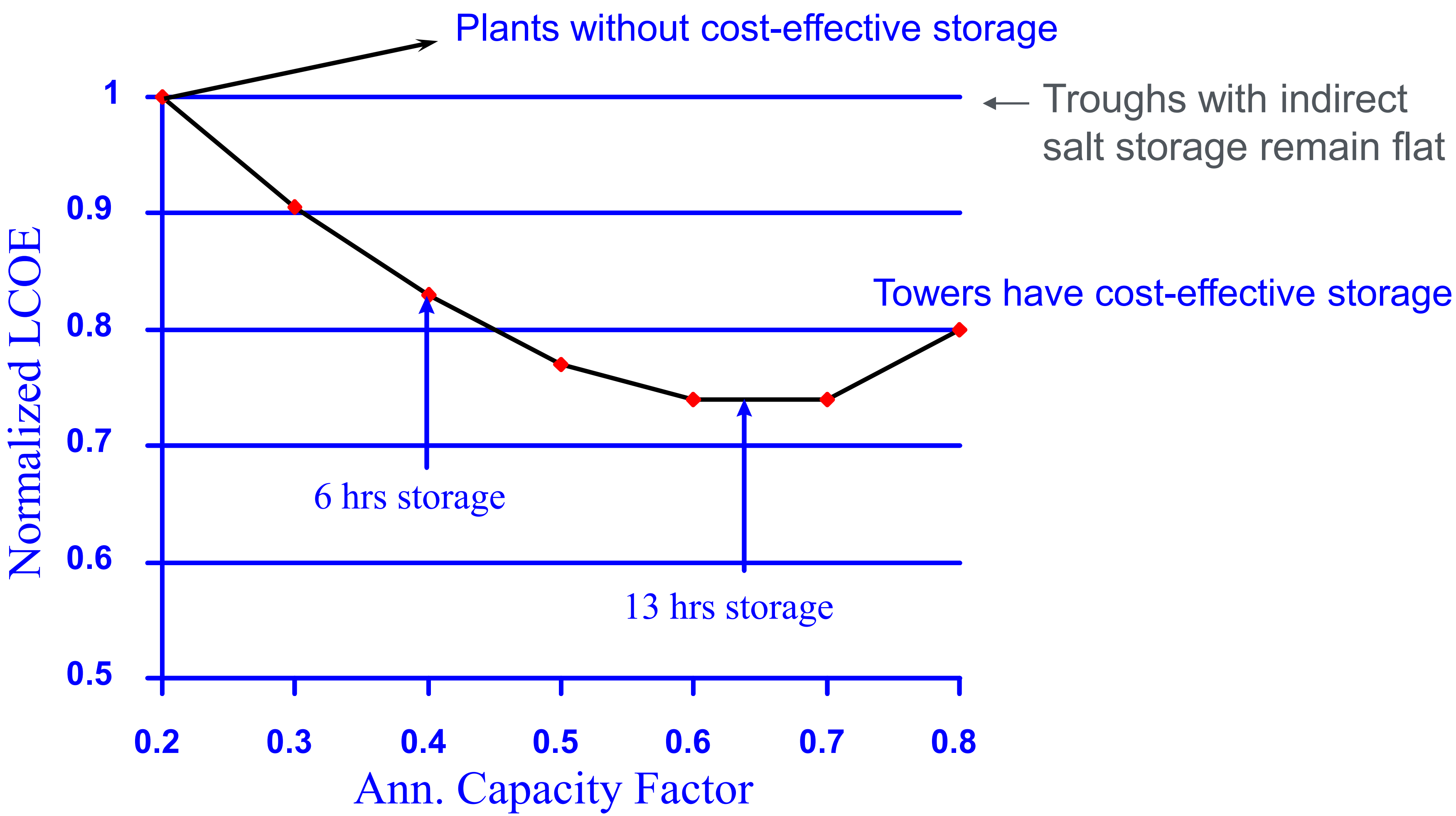
Solar Field	Solar Receiver	Thermal Storage	Power Block/Balance of Plant
- Drives and controls - Impact of wind loads - Anti-fouling/cleaning of glass - Need for a manufacturing funding opportunity announcement (FOA) - Optical testing of a complete assembly - Optimization of structure, facet, etc.	- Receiver materials testing data base - Selective absorbers - High temperature receivers (600-700°C) - Tall tower acceptance - Flux measurements - Hybrid and steam receivers - Receiver thermal loss measurement and mitigation	- High temperature storage (alternative fluids, containment, single-tank ratcheting, etc.) - Valves and non-welded flanges - Hybridization system study - Solid storage for steam - Education: value of storage - Phase change material	- Low water use cooling - (Ultra) supercritical steam cycles - Supercritical CO2 / advanced power cycles - High efficiency hybrid configurations - Designs for rapid temperature changes - Reduction of parasitic loads

Sandia's initial evaluation of Roadmap cost goals suggest that Tower LCOE can be reduced by >40%

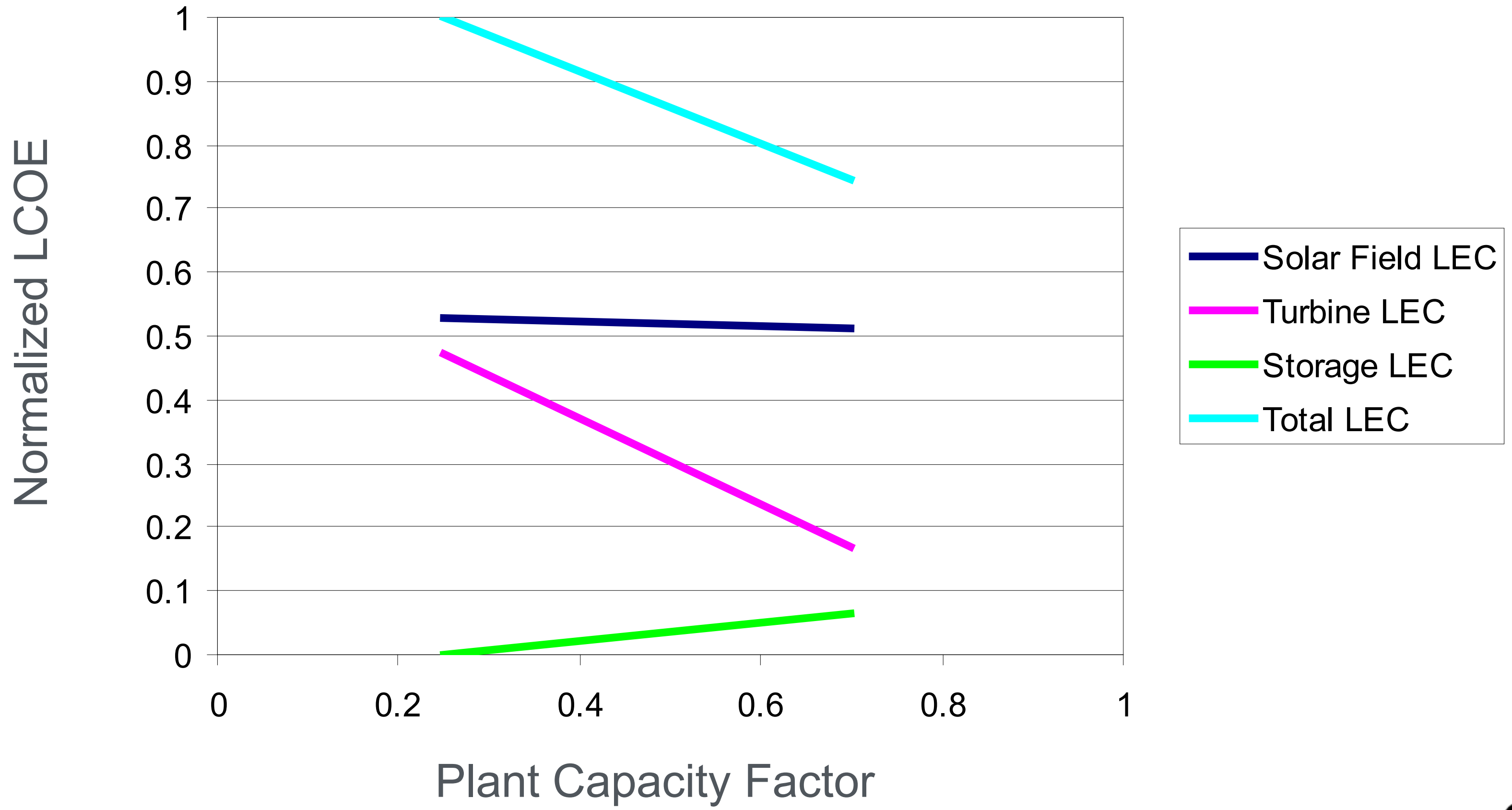
Task 1: Power Tower Plant Analysis

- Tower vs. Trough analysis conducted by Sandia/NREL and presented to DOE in February 2010
  - First side-by-side comparison since Sargent and Lundy study
  - Sandia/NREL concluded that original Sargent and Lundy economic comparison has not changed significantly (in a relative sense)
  - New investigation at near “base-load” capacity factors (70%) concluded that tower LCOE should be ~35% lower than troughs in the near term
    - 13 to 15 hrs of storage is needed for base load
    - Storage cost for towers is nominally 3X lower than troughs
    - Tower capacity factor is more uniform throughout the year than troughs

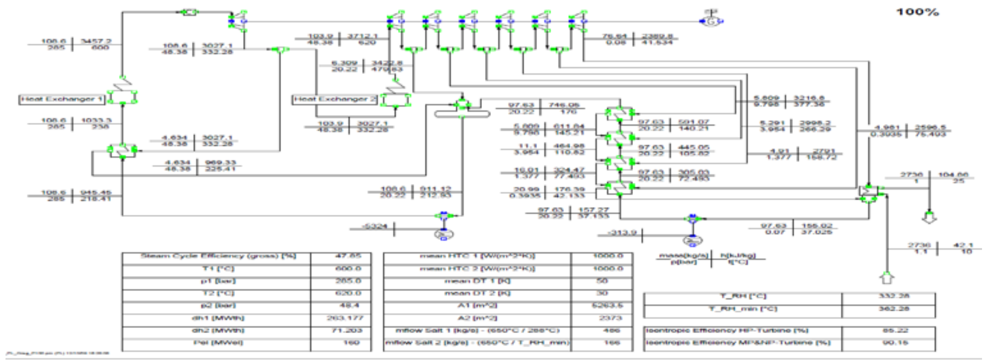
In a molten salt power tower, LEC is reduced by adding up to 13 hours of storage



Power Tower LEC is reduced up to 25% for a given power block by adding storage and increasing the solar field size to increase plant capacity factor

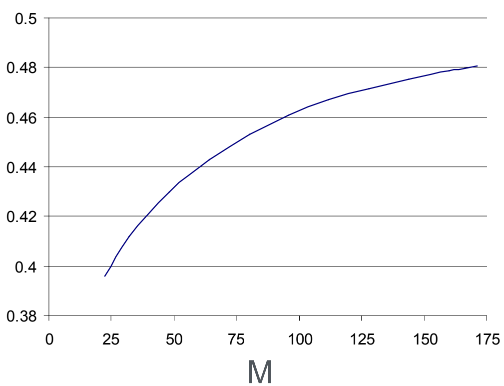


- Next generation tower study is underway
  - Raise salt temperature from 565 °C to 650 °C
    - Increase Rankine efficiency from 42% to 48%
    - Reduce storage cost by increasing ΔT

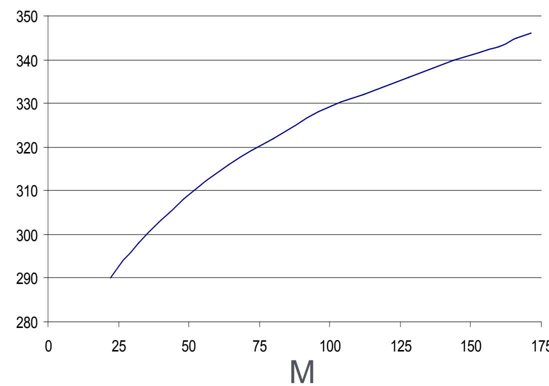


IPSEpro Model By DLR

48% Rankine η at full power

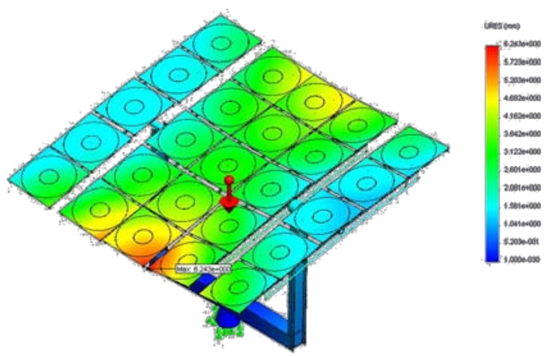


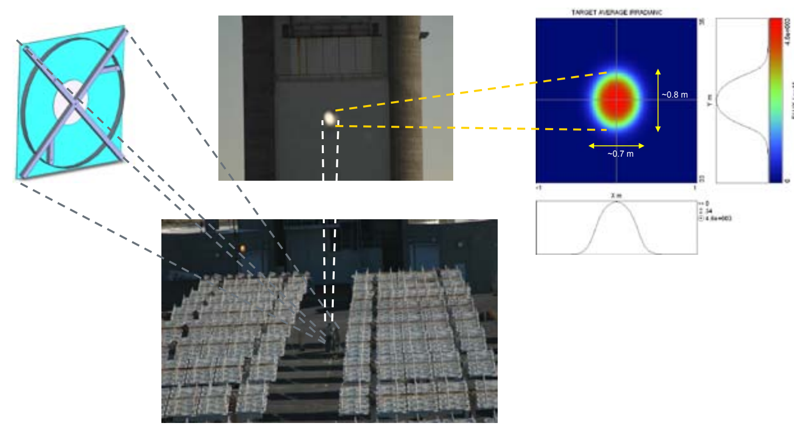
ΔT increased 24% at full power



Task 2: Heliostat Analysis

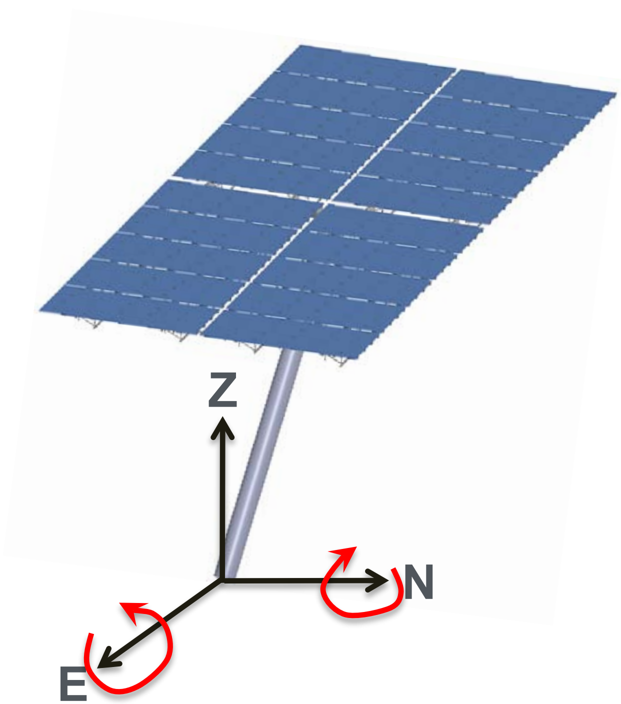
- Initial CAD model of NSTTF heliostat completed
  - SolidWorks finite-element model
  - CosmosWorks analysis of wind and gravity
  - ASAP ray-trace optics model
  - Methodology developed by CSP Advanced Concepts Agreement



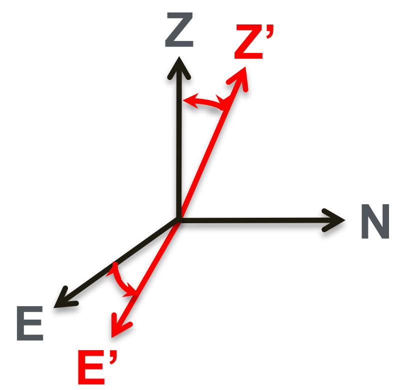


- Initial error-correcting heliostat tracking software developed
  - Compensates for heliostat manufacturing and installation errors such as pedestal tilt, non-orthogonal structure, encoder offsets
  - Technique first described by Baheti & Scott (1980) with modifications by recent Stirling Dish R&D

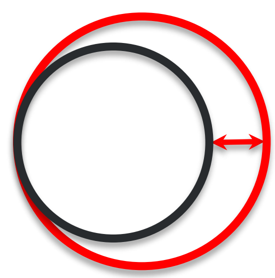
Heliostat Tracking Error Sources



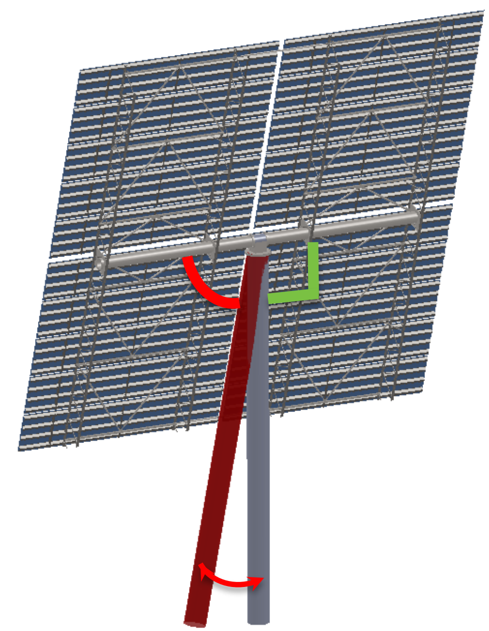
Pedestal Tilt



Reference Bias



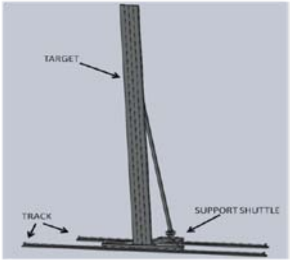
Drive Wheel Diameter Error

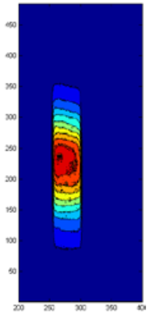


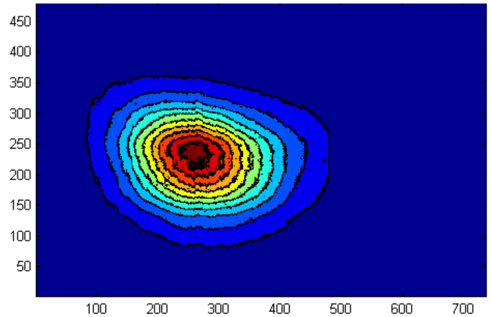
Axis Non-Orthogonality

Task 3: Advanced Heliostat Development

- Supported the installation of Rocketdyne heliostats at NSTTF
  - 62 m^2 heliostat
  - 1st generation heliostat test completed
  - Three 2nd generation units now being installed
- Total field flux mapping tool under development
  - Moving wand
  - Stitching software







Tower R&D Schedule and Milestones

Milestones	Task #	Date
1. Provide analysis training to 3 or more organizations from US industry	1	8/31/10
2. Complete draft of SAND report summarizing system analysis of new power tower concepts capable of ≥650 °C	1	9/30/10
3. Complete CAD models of NSTTF heliostats	2	2/18/10
4. Validate models of heliostats	2	9/30/10
5. Complete initial development of heliostat flux characterization tool	3	7/31/10
6. Develop initial heliostat slope-error and alignment methods	3	9/30/10

Future Plans (FY 2011 and beyond)

- Expand R&D collaboration with power tower companies to reduce technical risk of 1st commercial projects
  - During design phase
  - During startup, test, and evaluation phases
- Develop and implement an R&D plan for the labs that address the TIO's identified in the March 2010 Roadmap Meeting
- Perform analysis and test prototype hardware to support development of next-generation power towers
  - Raise operating temperature from today's 565 ^{o}C, to 650 ^{o}C and beyond
  - Improve thermal conversion efficiency from today's 42% to 48% and beyond

Summary

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- After a several year lapse, Power Tower R&D is once again a principal agreement within the DOE solar program
- Commercial interest in power towers is growing strong and DOE R&D funding was increased by a factor of 5 in 2010
- 5 commercial tower companies came together for the first time at Sandia to help develop a technology Roadmap
- Heliostat issues dominate the cost and performance of power tower projects and most of the DOE program is devoted to heliostats
- If towers can surpass financial/technical risk hurdles, they are predicted to achieve lower LCOEs than troughs, especially for plants with near base-load capacity factors
- The technology to support next-generation towers (650 ^{o}C, 48% efficient) is very plausible and within reach