Reducing the Cost of Thermal Energy Storage (TES) for Parabolic Trough Solar Power Plants

Program Team - CSP

Presenter: Brian Luptowski

Organization: ABENGOA SOLAR

Contact Info: brian.luptowski@solar.abengoa.com

Date: May 25th, 2010

Overview

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

Timeline

- Project Start Date: February 24, 2009
- Project End Date (Phase 1): July 31, 2010
- 88% Percent complete (Phase 1)

Budget

- Total project funding

	DOE Share	Contractor Share	Total
Phase 1	$499,566	$125,388	$624,954
Phase 2	TBD	TBD	TBD
Phase 3	TBD	TBD	TBD

- Funding received in FY09 (DOE Share) - $138,266.67
- Funding for FY10 (DOE Share) - $672,000.00

Barriers Addressed

- Capital Cost
- Performance
- Technology Risk

Partners

- Project lead – Abengoa Solar Inc.
- Interactions/collaborations – Abener Engineering and Construction Services, LLC

Challenges, Barriers or Problems Addressed

- Capital Cost
  - One of the Solar Program goals is to reduce the cost of thermal energy storage to $15/kWh$_{thermal}$
  - Capital cost of storage could be reduced with new concepts
- Performance
  - Thermal energy storage (TES) is a key performance advantage of CSP
  - TES enables increased annual energy production
  - TES improves dispatchability
- Technology Risk
  - Field testing will be conducted to prove technologies and reduce uncertainty

Relevance

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

- Task 1.1: Development of Baseline Plant Design
  - Develop a performance model of a plant in TRNSYS
  - Assess capital and O&M costs for baseline plant
- Task 1.2: Preliminary Assessment of Alternative TES Concepts
  - Identify capital and O&M costs, performance, reliability, and risks of the following concepts…
    - Advanced molten salt indirect TES system
    - CO_2 working fluid and packed bed TES system
    - Concrete TES system
    - Phase change material
    - Packed bed thermocline
    - CO_2 working fluid and molten salt TES system
    - Molten salt as heat transfer fluid and direct TES system
    - Other TES options
  - Compare TES concepts and select 3 for more detailed analysis

Relevance (cont.)

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

- Tasks 1.3-1.5: Conceptual Design of Three TES Concepts
  - Develop a TES system performance model in TRNSYS and integrate with plant
  - Analyze TES performance
  - Assess capital and O&M costs for TES concept
  - Determine technology issues and risks
- Task 1.6: Economic Assessment
  - Calculate the levelized cost of energy for each concept
  - Rank the TES concepts
  - Select 2 most promising concepts for further study in Phase 2
- Task 1.7: Component and System Development Requirements
  - Assess the component and system development requirements for 2 concepts selected for Phase 2
- Task 1.8: Phase 1 Report and Phase 2 Decision
  - Determine whether Go/No Go criteria is met to warrant further research

Approach

- Task 1.1: Development of Baseline Plant Design
  - Develop advanced simulation tools in TRNSYS which integrate all plant systems to accurately predict hour-by-hour plant performance
  - Contract an experienced EPC company to create detailed cost estimates
- Task 1.2: Preliminary Assessment of Alternative TES Concepts
  - Develop design models for each alternative and used to size each alternative
  - Contract an experienced EPC company to provide guidance creating rough cost estimates
  - Document possible reliability and risk issues
- Tasks 1.3-1.5: Conceptual Design of Three TES Concepts
  - Develop model of TES system in TRNSYS and integrate with all plant systems to accurately predict hour-by-hour plant and TES performance
  - Study simulation results to understand performance
  - Contract an experienced EPC company to create detailed cost estimates
  - Update possible reliability and risk issues

Approach (cont.)

- Task 1.6: Engineering Assessment of Molten Salt Plant
  - Compare plant's levelized cost of energy to rank and select 2 best TES concepts
- Task 1.7: Component and System Development Requirements
  - Select components and issues requiring testing in Phase 2

Accomplishments / Progress / Results Task 1.1

- Task 1.1: Development of Baseline Plant Design
  - Baseline plant selected to be current technology
    - Location: Phoenix, Arizona
    - Size: 140MWe_gross plant
    - Power Cycle: Superheated steam Rankine cycle with reheat
    - Cooling: Wet
    - Field HTF: Therminol VP-1
    - Field Supply: 393 °C (nominal)
    - Field Return: 293 °C (nominal)
    - Collectors: 5.7m aperture
    - Field: “H” configuration, 440 loops
    - Storage: 6 equivalent full load hours, 2-tank indirect
    - Storage Fluid: Binary salt (60% $NaNO_3$, 40%KNO_3)
  - Updates/improvements made to integrated, transient plant model in TRNSYS

Accomplishments / Progress / Results Task 1.2

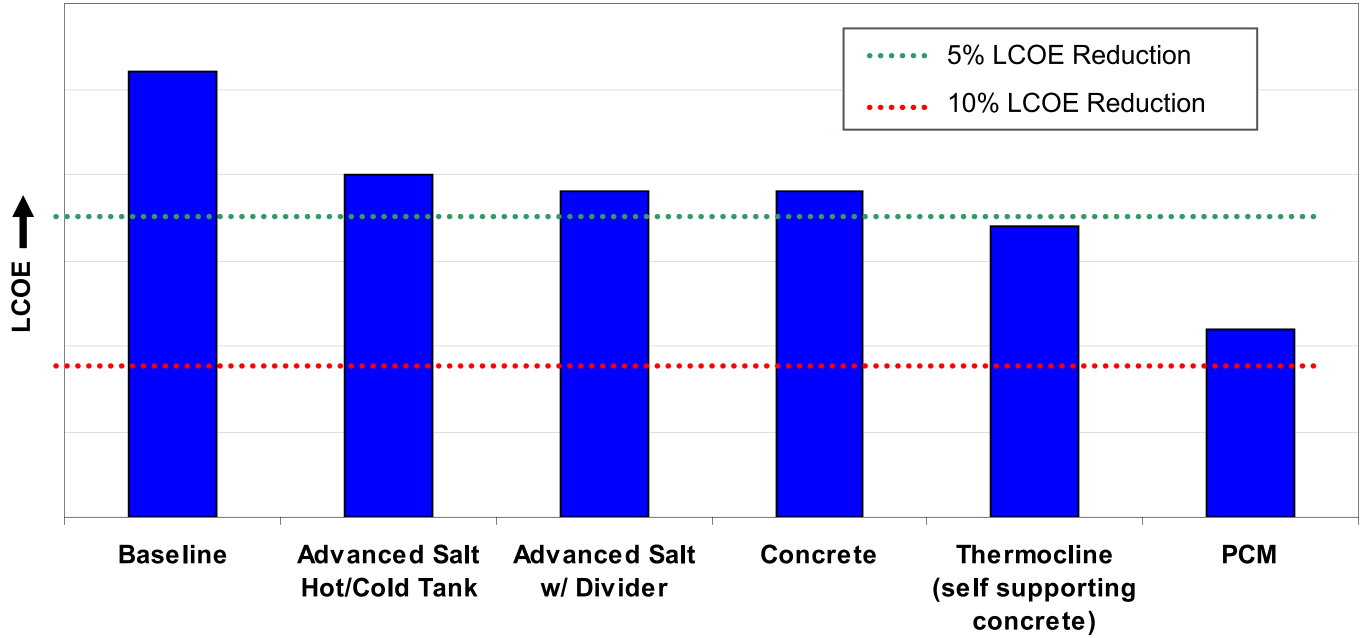
- Task 1.2: Preliminary Assessment of Alternative TES Concepts
  - Maximum LCOE reduction possible due only to TES = 17% (assumes a TES capital cost of $0, but 6 hours of storage)
  - Molten salt HTF with direct TES system was deferred to other DOE project (GO18038)
  - Initially the cost/kWhthermal of storage capacity was compared with baseline
    - CO2 concepts eliminated based cost associated with pressure vessels
    - Steam TES eliminated based on cost associated with pressure vessels and natural gas requirement
    - Oil based thermocline eliminated based cost associated with pressure vessels
  - LCOE calculated for remaining concepts (see next slide)

Accomplishments / Progress / Results
Task 1.2 (cont.)

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

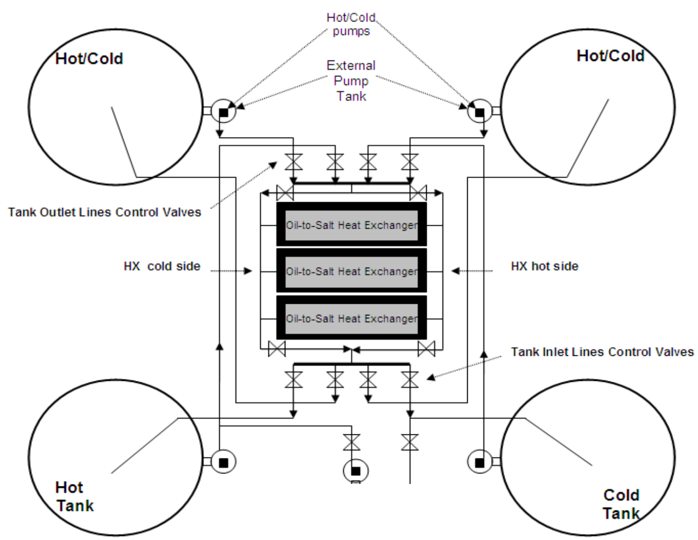
- Task 1.2: Preliminary Assessment of Alternative TES Concepts (cont.)
  - 3 Concepts selected…
    - Advanced Molten Salt Indirect TES (2 variations)
    - Concrete TES
    - Phase Change Material TES
    - Note: Thermocline with self-supporting concrete bed and molten salt deferred to other DOE project (GO18038)

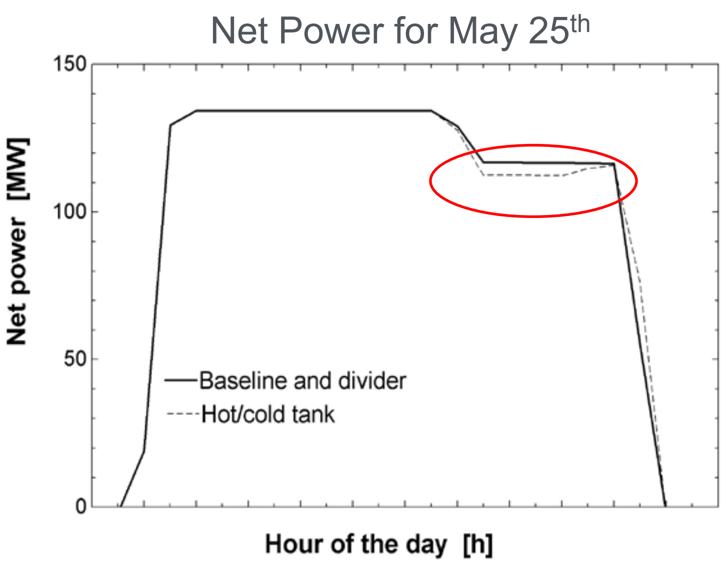
Preliminary Comparison to Baseline TES using LCOE



Accomplishments / Progress / Results Task 1.3

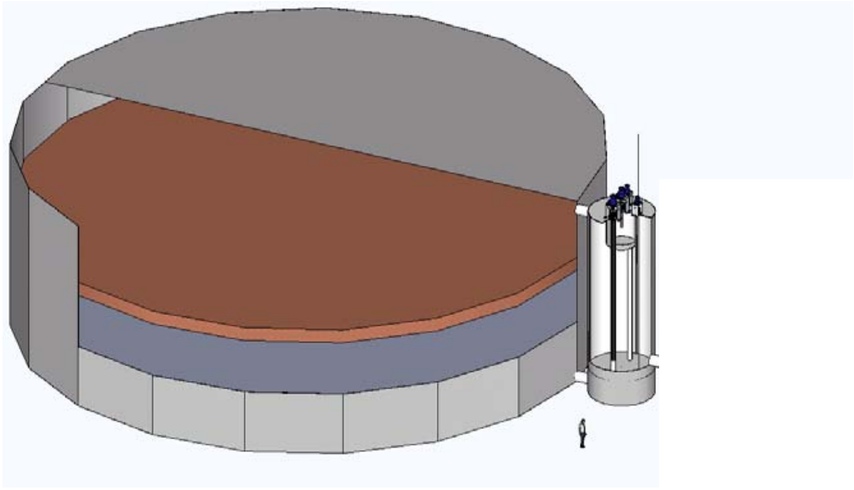
- Task 1.3: Conceptual Design of Advanced Molten Salt Indirect TES
  - Hot/Cold Tank (see figure)
    - Requires 4 tanks vs. 6 tanks for the baseline
    - Performance model developed and integrated into plant model
    - ISSUE: Heal Damping reduces performance from TES and requires over-sizing
    - ISSUE: Partial Charge/Discharge limitations reduce annual energy produced from storage
    - ISSUE: Foundation Thermal Shock increases risk



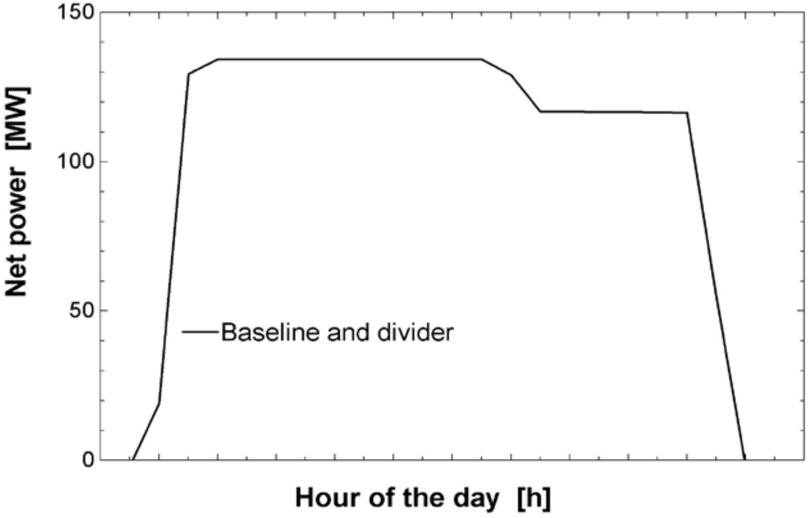


Accomplishments / Progress / Results Task 1.3 (cont.)

- Task 1.3: Conceptual Design of Advanced Molten Salt Indirect TES (cont.)
  - Tank w/ Divider (see figure)
    - Requires 3 tanks vs. 6 tanks for the baseline
    - Performance model developed and integrated into plant model
    - Performance similar to baseline
    - <u>ISSUE: Buoyant Divider</u> poses increase risk and cost/tanks



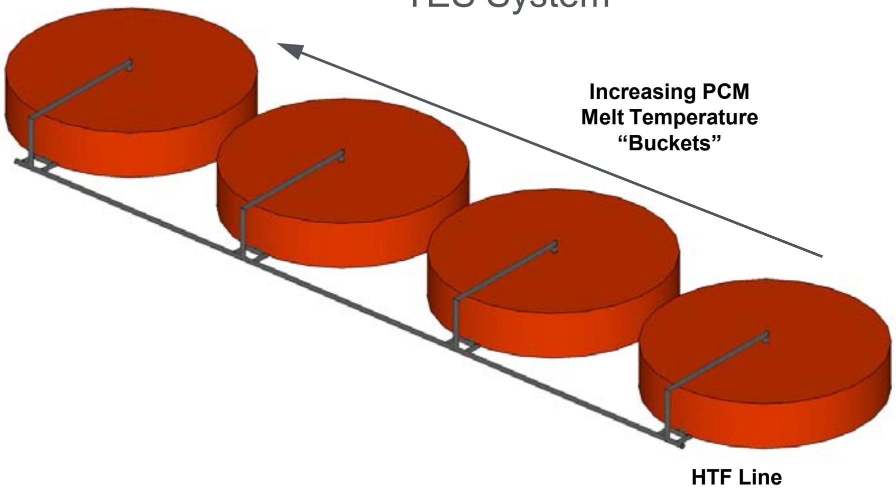
Net Power for May 25th



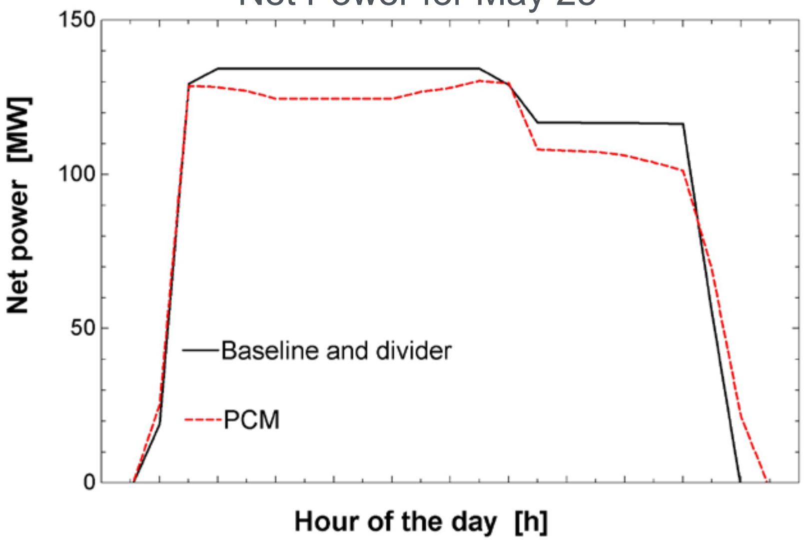
Accomplishments / Progress / Results Task 1.4

- Task 1.4: Conceptual Design of Phase Change Material TES
  - Originally implemented as a shell and tube cascaded system
    - Performance model developed and integrated into plant model
    - ISSUE: Low Conductivity of PCM reduces daily performance
    - ISSUE: Large Number of Pipes required in PCM "buckets" drastically increases HTF volume in plant by over 2X
    - ISSUE: Partial Charge/Discharge limitations reduce annual energy produced from storage
    - ISSUE: Performance Variations In Buckets due to PCM property differences reduces performance and increases material requirements

Representation of a Cascaded PCM TES System



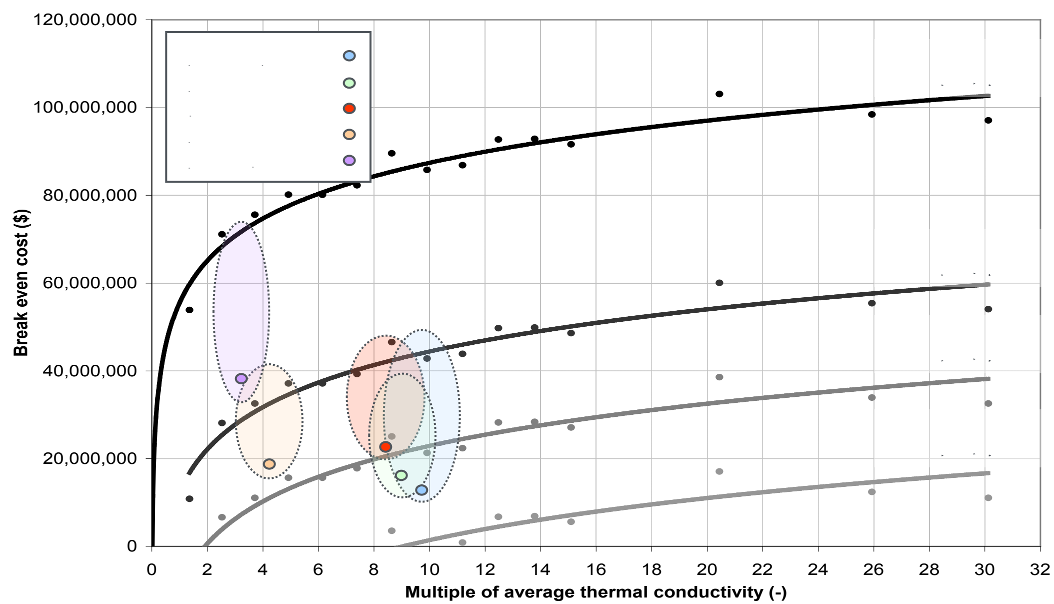
Net Power for May 25th



Accomplishments / Progress / Results Task 1.4 (cont.)

- Task 1.4: Conceptual Design of Phase Change Material TES (cont.)
  - Solutions proposed and currently under investigation to above issues
    - Re-optimized buckets allowing for geometry variation from bucket to bucket to reduce performance variation
    - Investigating replacing HTF tubes with plate design to reduce HTF volume
    - Investigating cost requirements on PCM conductivity enhancement methods
    - Investigating benefits of control over bucket melt temperature and distribution in cascade
    - Investigating PCM encapsulation as a way to improve heat transfer with PCM and increase utilization of PCM material
    - Investigating controls changes to improve performance

Expectable Costs for PCM Conductivity Enhancement

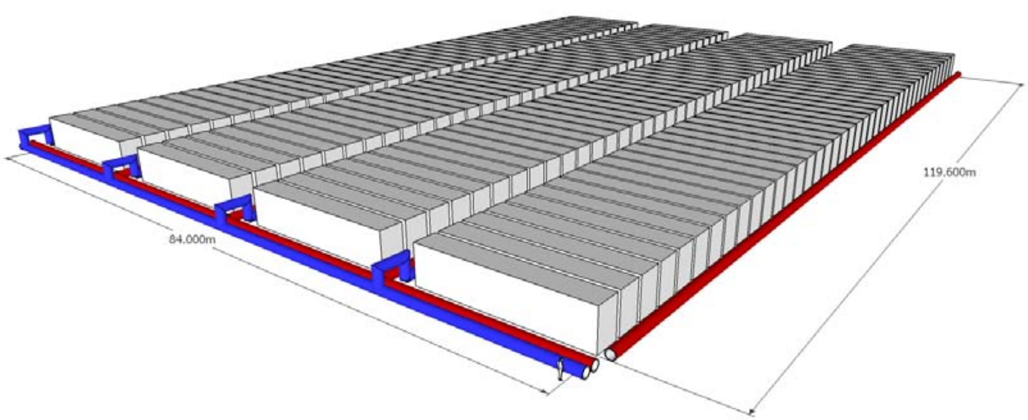


Accomplishments / Progress / Results Task 1.5

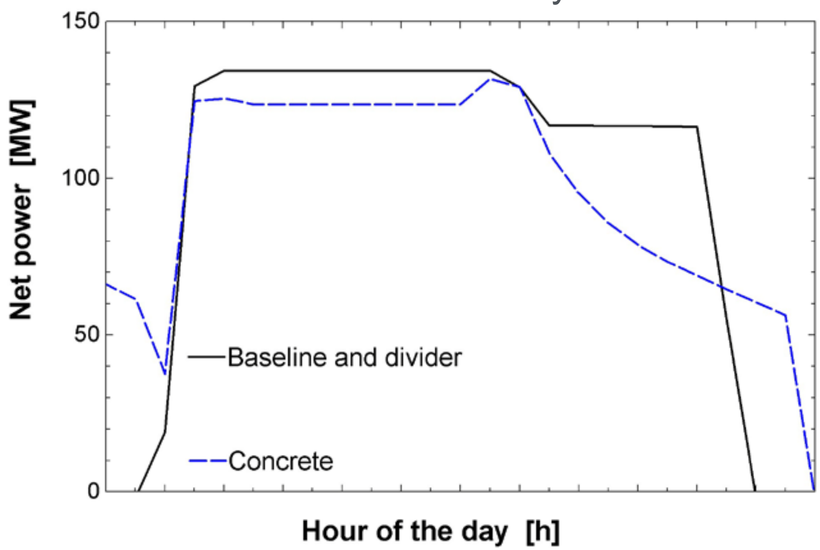
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Task 1.5: Conceptual Design of Concrete TES
  - Based on concrete modules with embedded HTF piping matrix
  - Performance model developed and integrated into plant model
  - ISSUE: Low Conductivity of concrete drastically reduces daily performance
  - ISSUE: Large Number of Pipes required in concrete modules drastically increases total plant HTF volume by almost 3X
  - ISSUE: Partial Charge/Discharge limitations reduce annual energy produced from storage

Representation of a Concrete TES System



Net Power for May 25th



Accomplishments / Progress / Results
Task 1.6

- Task 1.6: Economic Assessment
  - Engineering, procurement, and construction (EPC) cost developed by Abener
  - Theoretical maximum LCOE reduction due to TES ~ 17%
  - New metric proposed for TES comparison captures performance of TES integrated into a plant (TES Cost/Performance Quotient)

$$\text{TES Cost/Performance Quotient} = \frac{\text{EPC Cost of TES (\$)}}{\text{Net Annual Electricity from TES } (kWh_{e\_net(annual)})}$$

	Adv. Salt (Hot/Cold)	Adv. Salt (Divider)	PCM	Concrete
LCOE (% change from baseline)	↓ 1.6%	↓ 2.1%	↓ 7.0%	↑ 11.9%
TES Cost/Performance Quotient (% change from baseline)	↓ 3.5%	↓ 7.0%	↓ 30.0%	↑ 25.4%

Budget Status and Potential for Expansion

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

- Total project funding

	DOE Share	Contractor Share	Total
Phase 1	$499,566	$125,388	$624,954
Phase 2	TBD	TBD	TBD
Phase 3	TBD	TBD	TBD

- Funding received in FY09 (DOE Share) - $138,266.67
- Phase 1 on budget*
- Phase 1 is behind schedule due to limited CSP experience in labor pool delaying staff increases
- No cut in scope as occurred
- Potential for Expansion – a broader range of PCM configurations could be investigated
- Potential for Expansion – application of PCM based storage for direct steam generation (details on next slide)

** pending approval of expense rates*

Future Plans (FY 2011 and beyond)

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

- Critical Milestone - Go/No Go decision to proceed to Phase 2
  - Present a complete conceptual design, analysis and comparison of alternatives
- Phase 2 – Further Evaluation of 2 Concepts
  - Task 2.1: Component Development
  - Task 2.2: Fluid and Thermal Computational Analysis
  - Task 2.3: Integrated Model
  - Task 2.4: Component Testing
  - Task 2.5: Performance and Economic Analysis
- Phase 2 – Scope Increase: Analysis of PCM TES for Direct Steam Generation using simulation tools and EPC estimates
  - PCM TES thermodynamic behavior is well adapted to DSG applications
  - Abengoa has a trough DSG facility operating in Spain for technology development
  - Offers increased leveraging of DOE funds to solve storage challenges for CSP

Future Plans (FY 2011 and beyond) (cont.)

- Critical Milestone - Go/No Go decision to proceed to Phase 3
  - Demonstration of technical and economical feasibility of TES alternatives, as well as reliability of developed components.
- Phase 3 – Field Demonstration of 2 Concepts
  - Task 3.1: Development of a System Final Design
  - Task 3.2: Equipment Procurement
  - Task 3.3: System Installation
  - Task 3.4: System Start-up and Checkout
  - Task 3.5: Operational Testing
  - Task 3.6: Phase 2 Report

Collaborations

- Abengoa Solar Inc.
  - Project Lead, industry
- Abener Engineering and Construction Services, LLC
  - Contractor, industry
  - Providing detailed engineering, procurement, and construction cost estimates for the plant concepts

Mandatory Summary Slide

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

- CO_2, steam, and concrete TES concepts not competitive with baseline
- TES cost reduction limited using liquid molten salt for sensible storage
- Baseline TES performance difficult to achieve with new concepts
- Storage medium can be less than 50% of total TES cost
- Integration into plant and annual performance must be considered when evaluating TES concept potential benefits
- Theoretical maximum LCOE reduction due to TES ~ 17%
- New metric proposed for TES comparison captures performance of TES integrated into a plant (TES Cost/Performance Quotient)
- Potential for 30% TES Cost/Performance Quotient reduction (7% LCOE reduction)
- PCM TES is also applicable to DSG trough technology