Sandia Advanced Concepts

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Sandia Advanced Concepts

Concentrating Solar Power

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Overview

Timeline

- March 2009 – Sep. 30, 2010

Budget

- FY10: $1.9M
  - 1: Advanced Trough Analysis: $200K
  - 2: Optical Methods: $500K
  - 3: Advanced Modeling*: $550K
  - 4: Solid Particle Receiver*: $200K
  - 5: Molten Salt Heat Transfer*: $150K
  - 6: Selective Absorbers for Tower Receivers*: $250K
  - 7: FOA Support: $50K
- FY09: ~$500K

*new task in FY10

Barriers

- Barriers addressed
  - **Capital Cost** (E): Understand factors impacting LCOE and how to address them
  - **Performance** (G): Increase performance through improved modeling, design, and technology development
  - **Technology Risk** (I): Reduce risks through model development, validation, & testing

Partners

- **Industry**
  - SkyFuel, Abengoa, PWR, US Solar
- **Universities**
  - NM Tech, NM State, UNM, SDSU, Georgia Tech, U. Arizona
- **National and International Labs and Institutions**
  - NREL, DLR, California Energy Commission, Transportation Research Board (National Academies)

Relevance to DOE CSP Multi-Year Program Plan

- Barrier (E): Need to reduce costs of CSP technologies
  - Identify factors (technology improvement opportunities) that are most important to LCOE
    - Advanced modeling for total CSP system analysis*
      - Improved understanding of system behavior
      - Quantification of uncertainties and likelihood of achieving cost and performance metrics
      - Identification and ranking of the most important parameters and processes to focus R&D
  - Advanced technologies (solid particle receiver, selective absorbers)

*2009 Peer Review Panel wrote that this "has the potential for both NEAR and LONG term impact by focusing the development of the CSP roadmap on critical technology issues" and should "be incorporated as a central part of program planning for the overall CSP program."

Relevance to DOE CSP Multi-Year Program Plan

- Barrier (G): Need to improve performance of CSP technologies
  - Solid particle receivers / higher temperature systems
    - More efficient power cycles; cheaper thermal storage
  - Selective absorbers for tower receivers
  - Improved optical analysis and performance
    - Advanced analysis and alignment methods for heliostats, troughs, and dishes
  - Increased efficiencies and capacity factors for baseload CSP applications (FOA support)

Relevance to DOE CSP Multi-Year Program Plan

- Barrier (I & D): Need to reduce risks of new CSP technologies and increase number of installed systems
  - Develop advanced modeling and validation techniques that integrate structural, optical, and thermal processes for better predictive capabilities
  - Implementation of salt in the field for reliable thermal storage
    - Review lessons learned from Solar Two; provide report on requirements for molten salt applications regarding piping, valves, heat exchangers, and power cycles
  - Certification of CSP plants requires visual resource and safety assessments
    - Provide quantified glint/glare analysis to reduce uncertainties associated with anecdotal data

Technical Approach

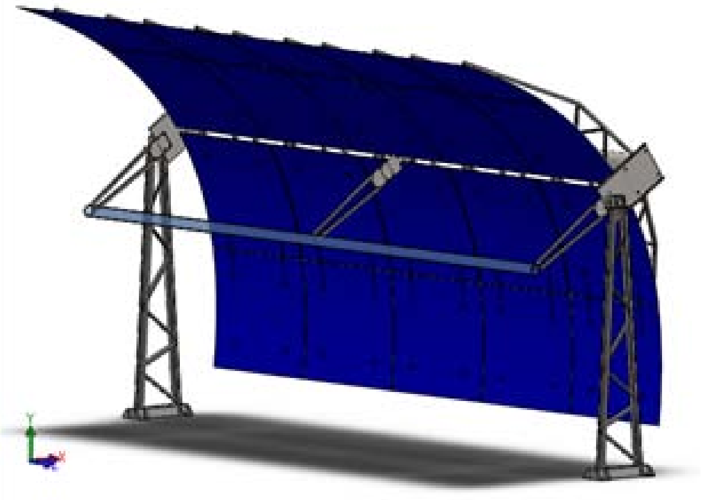
- Develop cross-cutting tools, models, and technologies that address near- and long-term R&D needs to improve CSP cost, performance, and risk
  - **Understand** (structural/optical/thermal processes)
  - **Predict** (probabilistic performance assessments)
  - **Improve** technology and designs (solid particle receiver, selective absorbers)

Technical Accomplishments*

- Task 1: Advanced Trough Analysis
- Task 2: Optical Methods
- Task 3: Advanced Modeling
- Task 4: Solid Particle Receiver
- Task 5: Molten-Salt Heat Transfer
- Task 6: Selective Absorbers for Tower Receivers

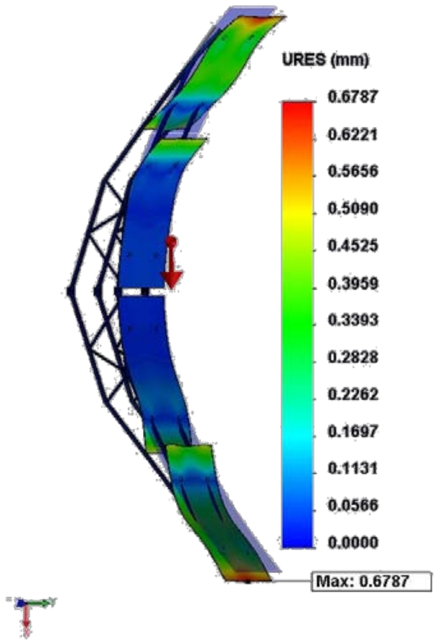
*Over 20 publications since the last peer review (see publications list in supplemental slides)

- **Objectives and Approach**
  - Evaluate performance of larger aperture troughs for cost reduction
    - Fewer collectors or reduced pumping requirements
  - Develop finite element analyses of troughs with gravity loading and determine impact on optical performance
  - Determine optimal ratio of aperture to receiver size
    - Optics, pressure loss, heat loss
- **Collaborators**
  - SkyFuel, Abengoa, NM Tech (undergraduate student intern), NM State (graduate student intern; Master's project)

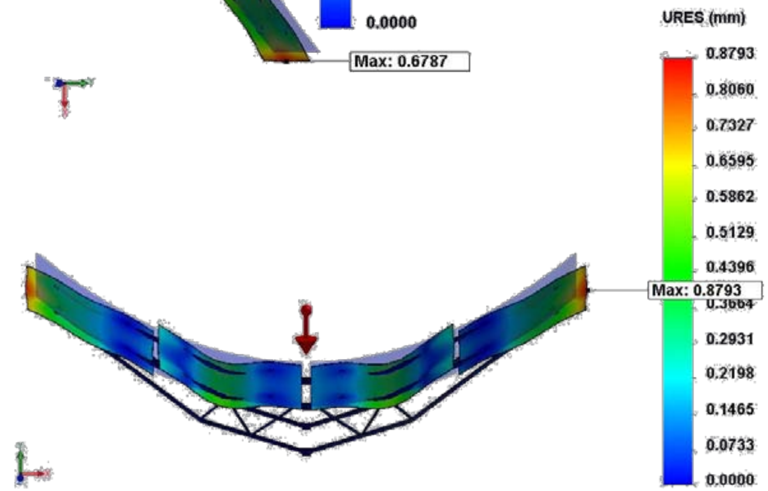


Simulation of LS-2 trough collector

- **Accomplishments**
  - Established collaboration with SkyFuel on analysis of their large-aperture SkyTrough collector
    - Evaluating optical performance issues using FEA
  - Established collaboration with Abengoa on structural/optical analysis of their large-aperture trough collector
  - Evaluated effects of gravity loading on LS-2 trough (ASME 2010)



Simulated bending of trough mirrors due to gravity in different orientations



Task 1: Advanced Trough Analysis

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- **Key Points**
  - Larger aperture troughs have the potential to reduce costs
    - Higher concentration ratios can achieve same thermal energy with half the collectors
    - Larger apertures with same concentration ratio (larger receiver tubes) can reduce costs associated with pumping (lower pressure loss)
  - Gravity and wind loads can cause bending that impact optical performance
  - Structural/optical/thermal analysis of large-aperture troughs will enable better understanding and improved designs
- **Future Work**
  - Continue and increase collaborations to evaluate large-aperture trough designs; provide suggestions for design improvements and optimal aperture/receiver ratio
  - Design and test large-aperture trough

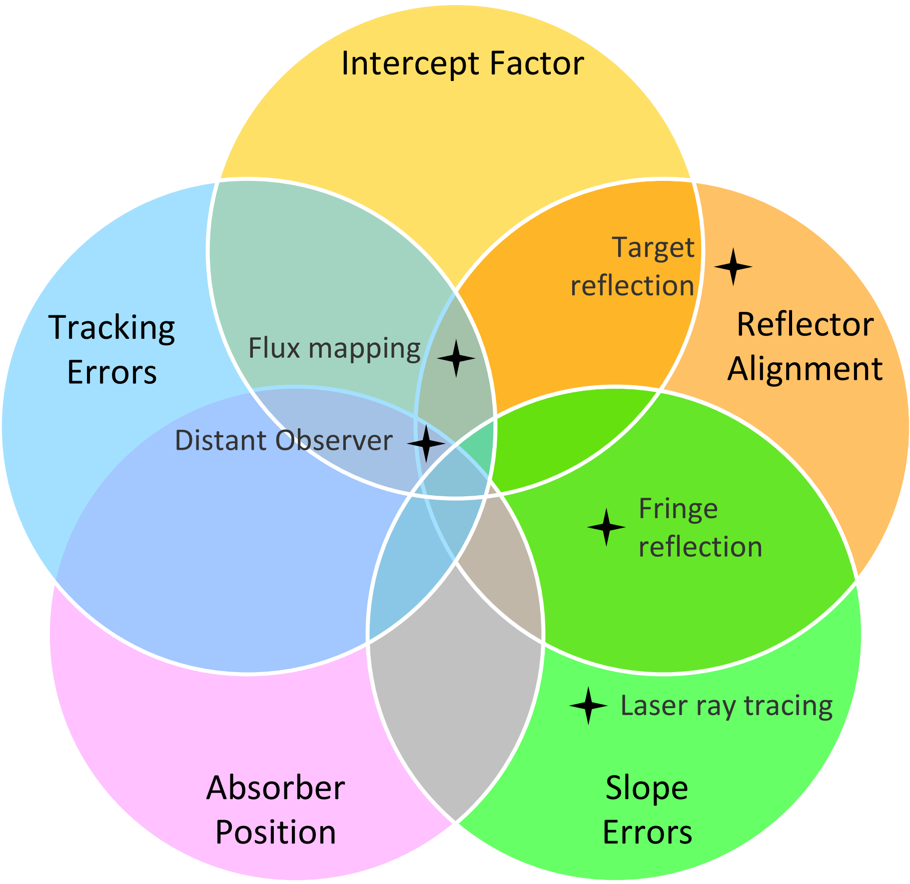
Technical Accomplishments*

- Task 1: Advanced Trough Analysis
- Task 2: Optical Methods
- Task 3: Advanced Modeling
- Task 4: Solid Particle Receiver
- Task 5: Molten-Salt Heat Transfer
- Task 6: Selective Absorbers for Tower Receivers

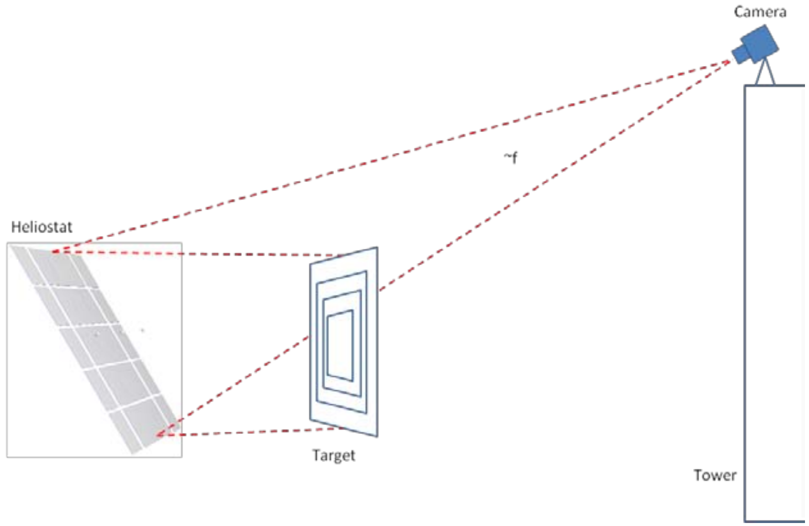
*Over 20 publications since the last peer review (see publications list in supplemental slides)

Task 2: Optical Methods

- **Objectives and Approach**
  - Develop tools and analyses to improve optical assessments and performance of CSP collectors and systems
  - Identify optical needs and address gaps
- **Collaborators**
  - NREL (optical tools), PWR (heliostat optical analysis)



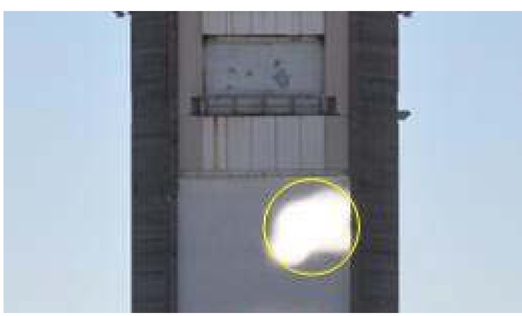
- **Accomplishments**
  - Four ASME ES2010 papers
    - Solar patch irradiance boundary condition for computational fluid dynamics modeling
    - Analytical flux model
    - Heliostat alignment
    - Dish optical error impact
  - Level 3 Milestone: optical methods meeting with NREL and DOE
  - Development of optical tools matrix
    - Toolkit for industry



Target reflection method for heliostat alignment

Task 2: Optical Methods

Before alignment



After alignment

Task 2: Optical Methods

- **Key Points**
  - Optical performance is critical to CSP performance
  - Tools and analyses developed here will provide industry with improved optical assessments and performance of CSP collectors and systems
- **Future Work**
  - Establish optical methods lab
  - Continue to refine and improve analysis methods to more efficiently and accurately predict optical performance
  - Continue development and improvement of alignment and characterization methods to improve optical performance and reduce costs associated with collectors
    - Automate heliostat alignment process via software controls

Technical Accomplishments*

- Task 1: Advanced Trough Analysis
- Task 2: Optical Methods
- Task 3: Advanced Modeling
- Task 4: Solid Particle Receiver
- Task 5: Molten-Salt Heat Transfer
- Task 6: Selective Absorbers for Tower Receivers

*Over 20 publications since the last peer review (see publications list in supplemental slides)

Task 3: Advanced Modeling

- **Objectives and Approach**
  - Develop stochastic methods for system modeling
    - Quantification of uncertainties and likelihood of achieving cost and performance metrics
    - Identification and ranking of the most important parameters and processes to focus R&D
  - Understand and predict effects of gravity, wind, and thermal loads on collector and receiver systems
    - Develop tools and methods for integrated structural/optical/thermal process modeling
  - Reduce uncertainties for CSP certification by providing quantified glint/glare analysis and testing
- **Collaborators**
  - NREL, SkyFuel, Abengoa, PWR, California Energy Commission, Transportation Research Board

Task 3: Advanced Modeling

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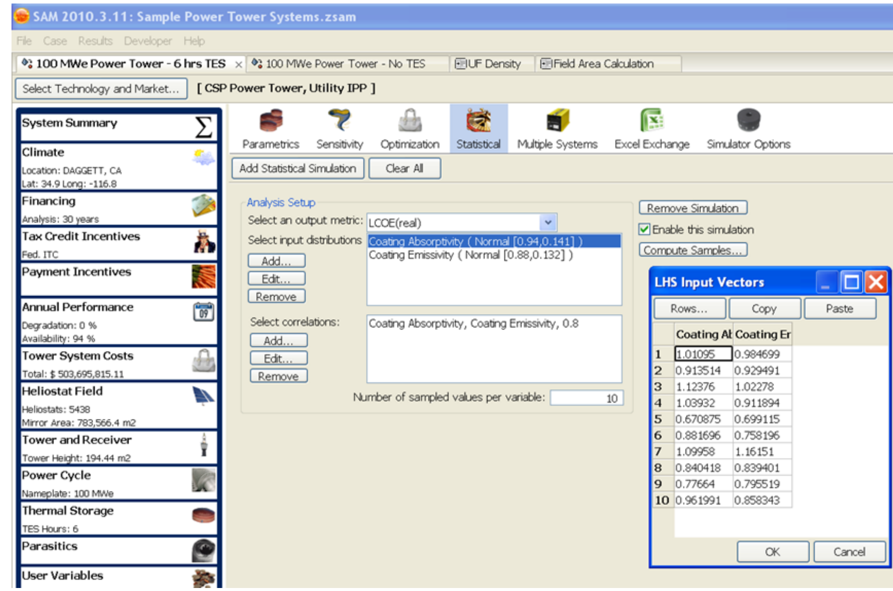
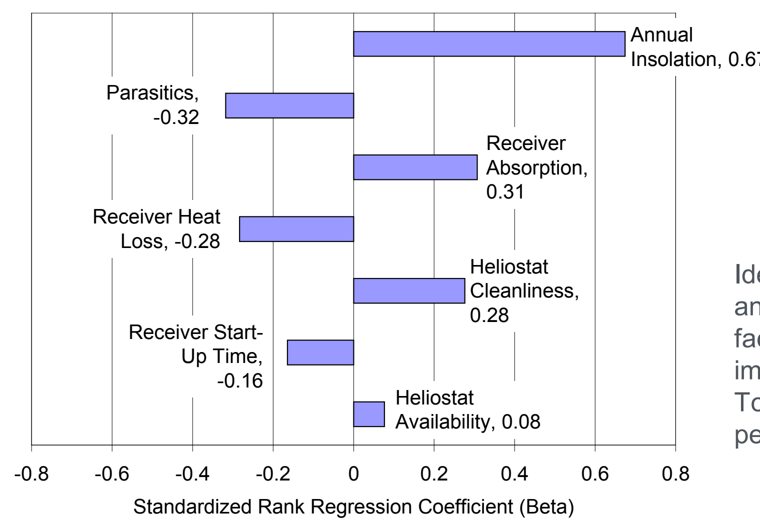
- **Accomplishments** (1 of 3)
  - Developed probabilistic methods for CSP system analysis
    - Applied to power towers (ASME 2009)
    - Developed method to account for uncertainty in insolation (SolarPACES 2009)
      - Use CDF of 30-year data instead of TMY
    - Implementation in Solar Advisor Model (SAM) (SolarPACES 2010)



Implementation of Latin Hypercube Sampling into SAM



Identification and ranking of factors important to Tower performance

Task 3: Advanced Modeling

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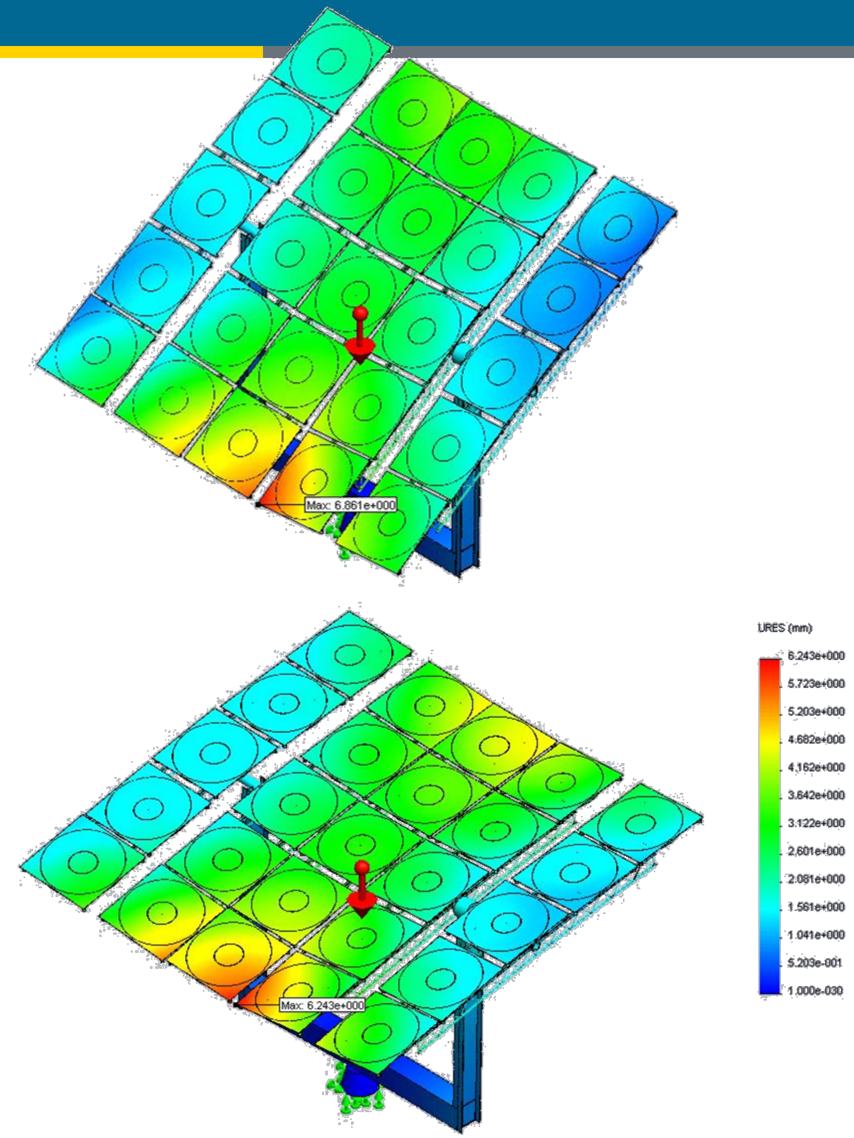
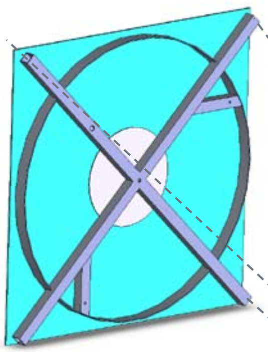
- **Accomplishments** (2 of 3)
  - Developed methods to integrate deformed shapes from gravity and wind loads into ray-tracing analysis
    - Sun shape and limb darkening
    - Slope errors at multiple scales
      - Small-scale distortions
      - Larger-scale errors from loads

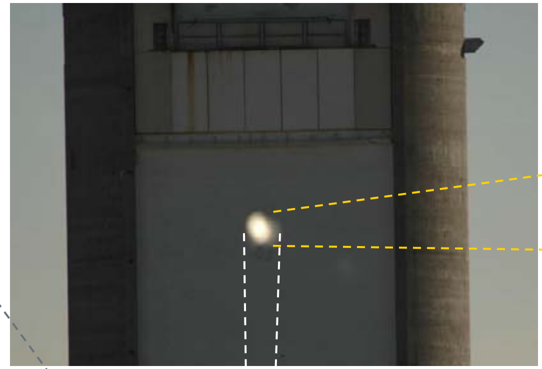


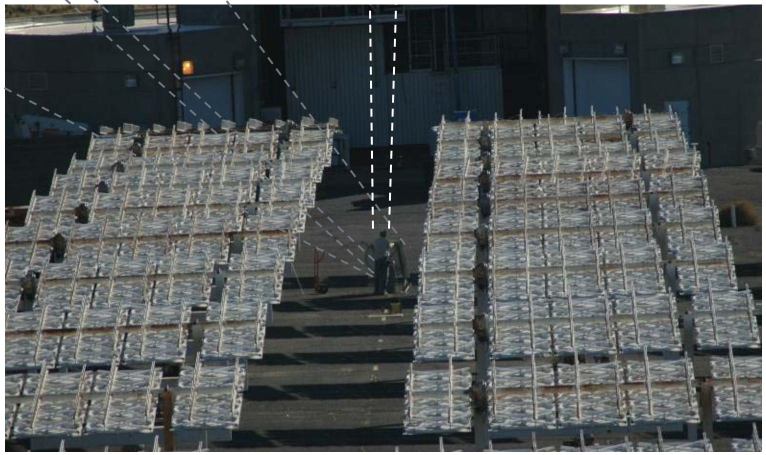
Gravity-induced deformation of NSTTF heliostat in different orientations

Single Facet Testing for Model Validation

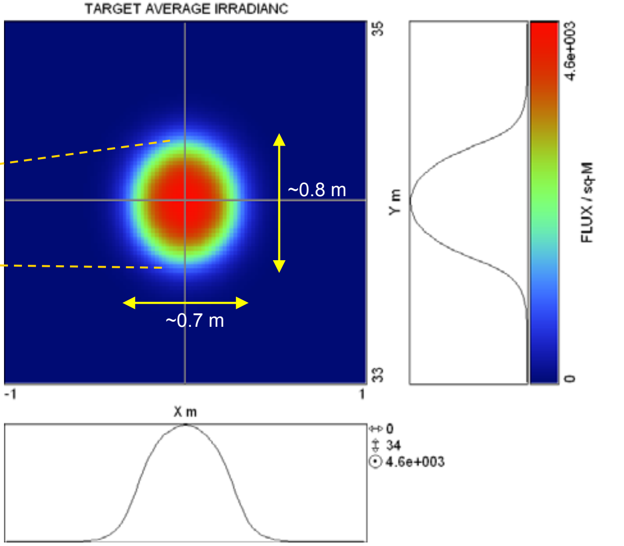


Test





Model



Task 3: Advanced Modeling

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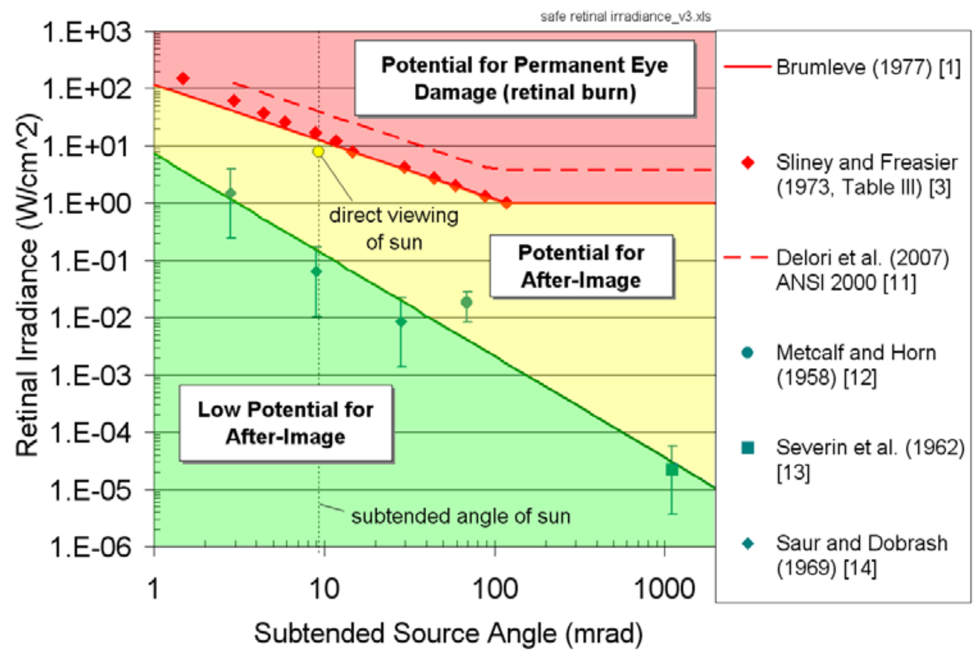
- **Accomplishments** (3 of 3)
  - Developed quantified analysis and testing of glint/glare from CSP collectors
    - Level 3 Milestone: ASME 2010
    - SolarPACES 2009
  - Analysis is being used by California Energy Commission and Transportation Research Board
    - TRB/ACRP Synthesis 11-03/Topic S10-06 “Investigating Safety Impacts of Energy Technologies on Airports and Aviation”

Specular and diffuse sources of glint and glare (top); safety metrics (below)



Task 3: Advanced Modeling

- **Key Points**
  - Probabilistic models enable:
    - Quantification of uncertainties and likelihood of achieving cost and performance metrics
    - Identification and ranking of the most important parameters and processes to focus R&D
  - Integrated structural/optical/thermal models enable:
    - Better understanding of the effects of gravity, wind, and thermal loads on collector and receiver systems
    - Improved designs to mitigate impacts of off-normal conditions
  - Glint/glare analysis and testing reduce uncertainties for certification
- **Future Work**
  - Continued implementation and simulation of probabilistic models
  - Perform validation of structural/optical models via testing of collectors
  - Work with CEC, TRB, Navy, and others to reduce uncertainty of glint/glare impacts from CSP systems

Technical Accomplishments*

- Task 1: Advanced Trough Analysis
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*Over 20 publications since the last peer review (see publications list in supplemental slides)

Task 4: Solid Particle Receiver

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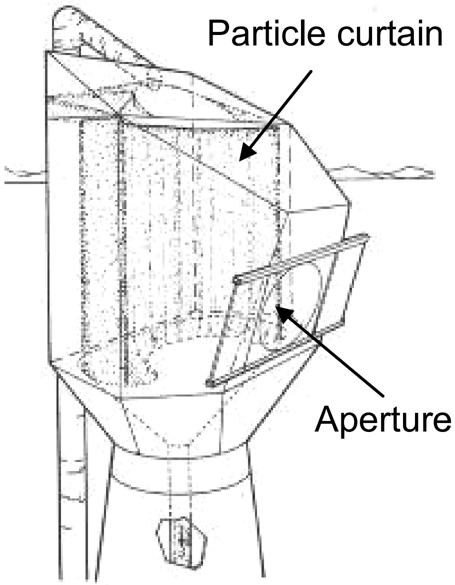
- **Objectives and Approach**
  - Develop and analyze designs for high-temperature solid particle receivers
  - Utilize computational fluid dynamics for rigorous analysis of irradiation, particle transport, convective and radiative heat transfer
- **Collaborators**
  - DLR (alternative designs; performance assessment), Georgia Tech (sand shifter)



Alternative solid particle receiver designs

Task 4: Solid Particle Receiver

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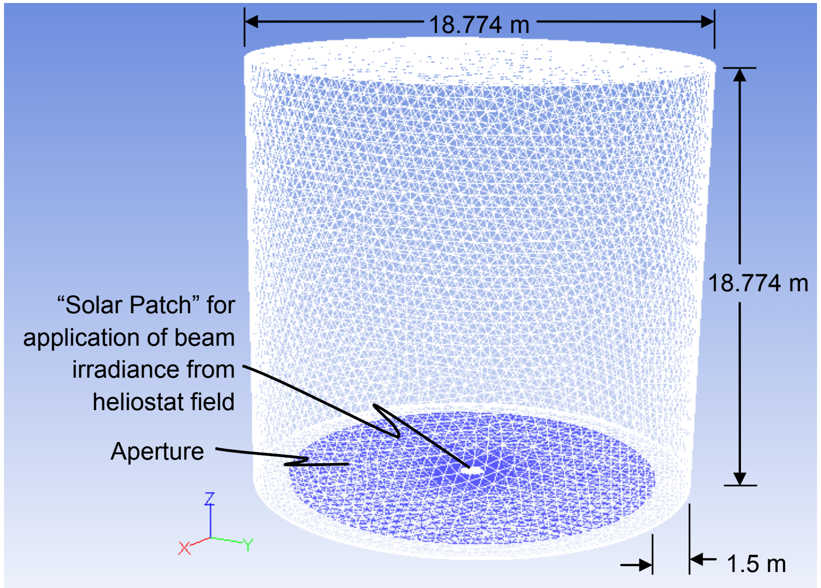
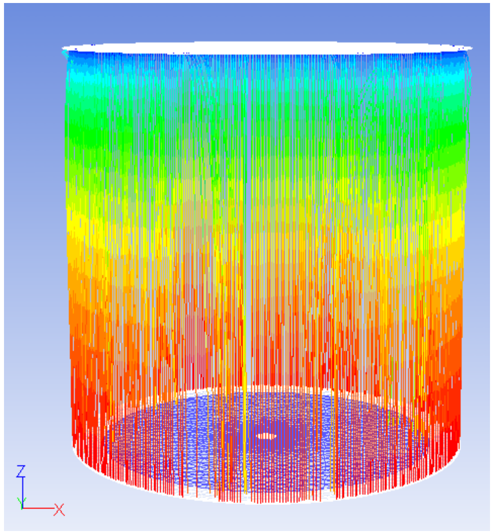
- **Accomplishments**
  - Validated CFD model of prototype solid particle receiver (ASME 2009)
  - Performed parametric analyses using validated model (SolarPACES 2009)
  - Collaborated with DLR on performance evaluation of alternative designs (SolarPACES 2010)
    - Efficiency (% power absorbed by particles) = 89%
    - Convective Losses (through aperture) = 5%
    - Radiative Losses (through aperture) = 6 %





CFD model of face-down solid particle receiver design

Task 4: Solid Particle Receiver

- **Key Points**
  - High-temperature particle receivers enable more efficient power cycles and cheaper thermal storage; reduces LCOE
  - Alternative designs have been evaluated to investigate thermal efficiencies and trade-offs
- **Future Work**
  - Continue evaluation of face-down and C-shaped particle-receiver designs using validated models from past work
  - Develop performance and economic analysis of entire system, including heat exchangers (sand-shifter) and storage methods
    - Build on FOA activities by US Solar/Georgia Tech investigating sand-shifter technology
  - Evaluate alternative particle receiver designs (e.g., particle receiver for high-temperature air-Brayton cycle; SDSU)

Technical Accomplishments*

- Task 1: Advanced Trough Analysis
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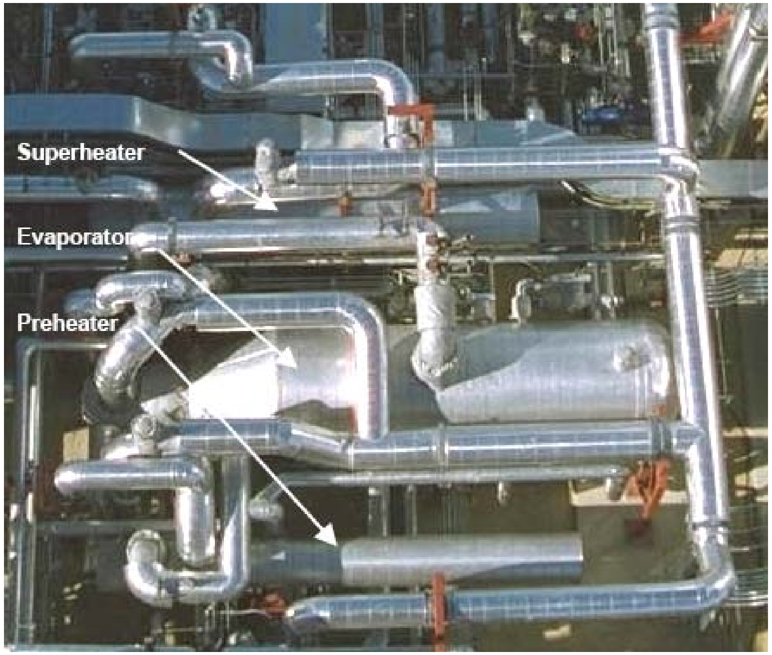
- Task 5: Molten-Salt Heat Transfer
- Task 6: Selective Absorbers for Tower Receivers

*Over 20 publications since the last peer review (see publications list in supplemental slides)

Task 5: Molten Salt Heat Transfer

- **Objectives and Approach**
  - Establish requirements and recommendations for molten salt applications regarding piping, valves, heat exchangers, and power cycles
  - Review lessons learned from Solar Two and current literature
  - Write report on technical issues, design requirements, operation, and research needs regarding the use of molten salt for standard and advanced power cycles



Solar Two steam generation system

Task 5: Molten Salt Heat Transfer

- **Accomplishments**
  - Reviewed Solar Two reports
  - Reviewed literature and current technologies relevant to molten-salt applications
  - Evaluated power cycles amenable to high-temperature molten-salt applications

Solar Two
Problems/Issues Cited
Kelly (2000) and Pacheco (2002)

• **Design problems**	**49**
– **Incorrect design**	
• **Operational problems**	**15**
– **Incorrect operating procedure.**	
– **Process control issue**	
• **Materials problems**	**20**
– **Corrosion**	
– **Welds**	
– **Gaskets**	
– **Valve seats**	
• **Heat tracing problems**	**8**
– **Incorrect heat trace scheme**	
– **Insulation issue**	
• **Equipment failure**	**2**
– **Salt plugging (non corrosion problems)**	

Task 5: Molten Salt Heat Transfer

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- **Key Points**
  - Use of molten salt is important for thermal storage (troughs and towers)
  - Results of this report will enable companies to review lessons learned, design requirements, and recommendations in one source regarding molten-salt applications
- **Future Work**
  - Complete final report on technical issues, design requirements, operation, and research needs regarding the use of molten salt for standard and advanced power cycles

Technical Accomplishments*

- Task 1: Advanced Trough Analysis
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- Task 6: Selective Absorbers for Tower Receivers

*Over 20 publications since the last peer review (see publications list in supplemental slides)

Task 6: Selective Absorbers

- **Objectives and Approach**
  - Identify selective absorber coatings and application methods suitable for tower receivers
    - Higher temperatures (>600C)
    - Stable in air
  - Evaluate optical properties of various formulations
    - Want high solar absorption (>0.9) and low thermal emissivity (<0.4-0.5)
  - Evaluate thermal-spray methods
- **Collaborators**
  - NREL
  - Sandia
    - Materials Lab, Thermal Spray Research Lab, Primary Standards Lab

Solar Two receiver

Task 6: Selective Absorbers

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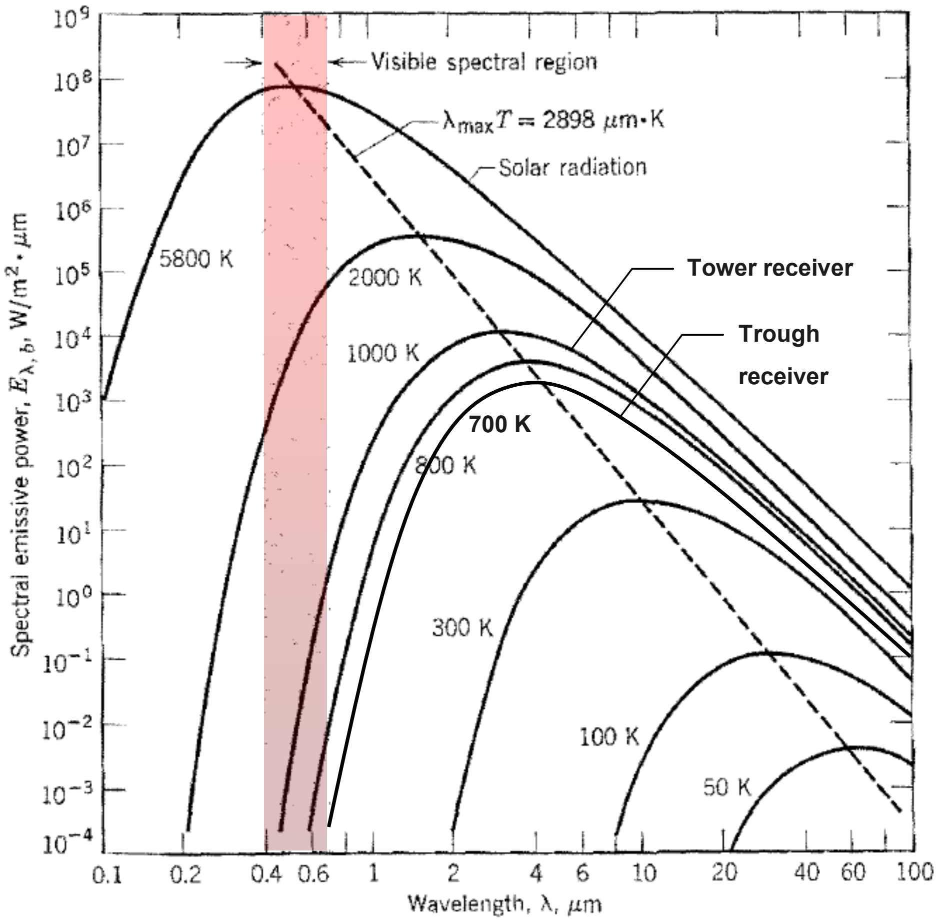
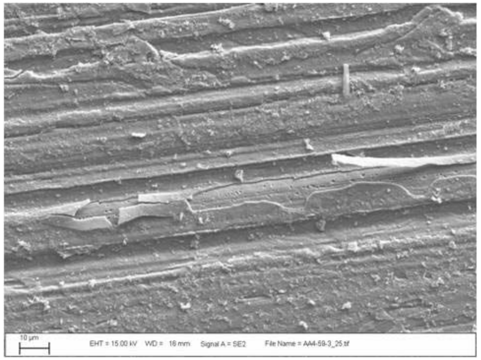


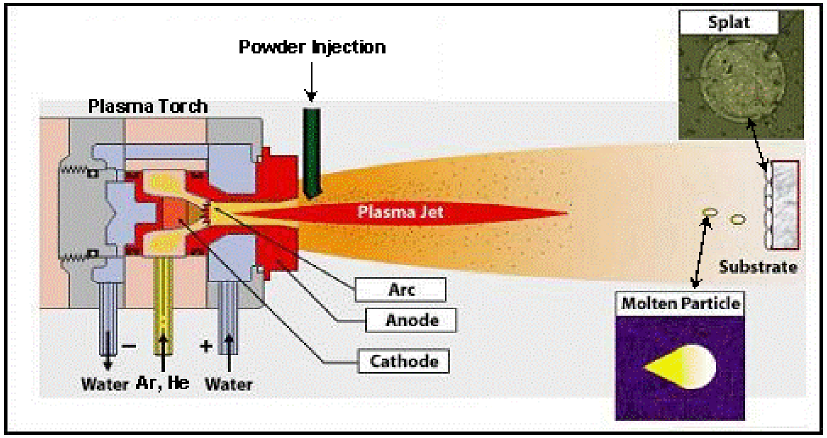
Spectral blackbody emissive power as a function of wavelength and temperature (adapted from Incropera and DeWitt, 1985).

Task 6: Selective Absorbers

- **Accomplishments**
  - Synthesized and characterized a variety of metal oxide coatings prepared via solution methods
  - Demonstrated thermal-spray application of coatings
    - Alternative to chemical vapor deposition (CVD)
    - Commercial process applicable to large scales
  - Evaluated structural and optical characteristics properties of coatings
    - XRD, SEM, diffuse reflectance, solar-weighted absorptivity, emissivity at 80 C
  - Collaborated with NREL to identify promising materials used in trough applications



Scanning electron microscope (SEM) image to investigate morphology of different coatings



Air-plasma thermal spraying process for absorber coatings

Task 6: Selective Absorbers

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- **Key Points**
  - Reducing the thermal emission while maintaining a high solar absorptivity will improve the efficiency of receivers and reduce LCOE
  - Tower receivers face additional challenges of high temperatures (>600C) and exposure to air
  - Thermal-spray application of several materials looks promising
    - Looking for materials with net solar absorption (solar absorption minus thermal emission) to be greater than existing materials (e.g., Pyromark paint)
- **Future Work**
  - Continue evaluation of different coating materials
  - Build on past work from NREL (troughs)
  - Down-select promising candidates based on net solar absorption and perform high-temperature thermal cycling
  - Use thermal-spray application to coat receiver tubes and test in the field (solar furnace or tower)

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Milestones (all included in DOE Corporate Planning System)

Milestones

Milestone ID	Title	Plan Complete	Actual Complete	Importance	Status
40736	Design and analysis of large-aperture trough.	9/30/2010		5-Field Project Mgr	On Track
43662	Organize and conduct a Sandia/NREL/DOE meeting on Optical Methods.	2/26/2010	2/8/2010	3-Pgm Mgr	Complete
43663	Write report on glint analysis and testing	5/30/2010	2/1/2010	3-Pgm Mgr	Complete
44035	Develop integrated optical/CAD methods to investigate performance of collectors.	6/30/2010		5-Field Project Mgr	On Track
44036	Integrate probabilistic modeling in SAM.	6/30/2010		5-Field Project Mgr	On Track
44037	Model and analysis of improved solid particle receiver design(s).	7/31/2010		5-Field Project Mgr	On Track
44038	Report on technical issues, design requirements, operation, and research needs regarding the utilization of molten salt for standard and advanced power cycles.	8/31/2010		5-Field Project Mgr	On Track
44039	Preliminary evaluation of selective absorbers for power tower receivers.	9/30/2010		5-Field Project Mgr	On Track

Collaborations

- **Industry**
  - SkyFuel, Abengoa, PWR, US Solar
- **Universities**
  - NM Tech, NM State, UNM, SDSU, Georgia Tech, U. Arizona
- **National and International Labs and Institutions**
  - NREL, DLR, California Energy Commission, Transportation Research Board (National Academies)

Future Research

- See previous slides for <u>specific</u> future research
- Future research will continue to develop cross-cutting tools, models, and technologies that address near- and long-term R&D needs to improve CSP <u>cost</u>, <u>performance</u>, and <u>risk</u>
  - **Understand** (structural/optical/thermal processes)
  - **Predict** (modeling and analysis)
  - **Improve** technology and designs (solid particle receiver, selective absorbers)

Summary of Key Points

- Advanced Concepts develops cross-cutting tools, models, and technologies that address near- and long-term R&D needs to improve CSP cost, performance, and risk
- FY10 activities are on schedule and within budget
  - Task 1: Advanced Trough Analysis
  - Task 2: Optical Methods
  - Task 3: Advanced Modeling
  - Task 4: Solid Particle Receiver
  - Task 5: Molten-Salt Heat Transfer
  - Task 6: Selective Absorbers for Tower Receivers
  - Task 7: Advanced FOA Support
- Numerous collaborations with industry, universities, and labs
- Future work will emphasize improved coupled-process models, testing and validation of models, and technology improvements (high-temperature receivers, selective absorbers)