Exhibit A
SCOPE OF WORK

TECHNICAL TASK LIST

Task #	CPR	Task Name
1	N/A	Administration
2		Define Grid Relevant Economics
3	X	Plant-Level Thermodynamic Modeling of Multiple CSP-TES Configurations
4	X	Parameter Based Optimization
5		Model Grid Linkages and Demonstrate CSP-TES Dynamic Performance
6	X	Develop CSP-TES Models for Market Simulation
7		Simulate Market Outcomes
8		Technology Transfer Activities

KEY NAME LIST

Task #	Key Personnel	Key Subcontractor(s)	Key Partner(s)
1	None	Redhorse Corporation – DVBE , UC Davis	
2		UC-Davis	CAISO
3		Terrafore, Redhorse Corporation – DVBE, UC Davis ,Alexander Mitsos	CAISO
4		Redhorse Corporation – DVBE, UC Davis ,Alexander Mitsos	CAISO
5			CAISO
6			
7		Redhorse Corporation – DVBE, UC Davis ,Alexander Mitsos	
8		Redhorse Corporation – DVBE, UC Davis ,Alexander Mitsos	

GLOSSARY

Specific terms and acronyms used throughout this work statement are defined as follows:

Acronym	Definition
ACE	Area Control Error
CA ISO	California Independent System Operator
CO_2	Carbon Dioxide
CPR	Critical Project Review
CSP	Concentrating Solar Power

Acronym	Definition
Energy Commission	California Energy Commission
IHR	Internal heat rate
LCOE	Levelized Cost of Electricity
LFR	Linear Fresnel Reflector
MW	Megawatt
PAC	Project Advisory Committee
PIER	Public Interest Energy Research
PCM	Phase Change Material
RPS	Renewable Portfolio Standards
TES	Thermal Energy Storage
UCC.1	Uniform Commercial Code (Financing Statement)
WECC	Western Electricity Coordinating Council

Problem Statement

Thermal storage systems have the potential to greatly enhance the grid dispatch and electricity market characteristics of concentrated solar power installations, especially in California, which is a world leader in solar energy capacity. Successfully configuring and controlling coupled concentrating solar power (CSP)-thermal energy storage (TES) systems could allow their deployment as a substitute for conventional generation or pumped hydro, with commensurate reliability, emissions, and peak generation. In contrast, the CSP systems without storage currently online in California are not positioned to deliver that level of performance due to intermittency, ramping, and lack of firm dispatch capability. While developers and operators of CSP systems may have substantial operating experience that can guide plant-level storage system decisions, they typically lack the grid-wide perspective to maximize net benefits to the California system and market. Conversely, grid operators and regulators may bring the broader perspective, but without significant coupled CSP-TES capacity online may have deferred analysis of how to best integrate these systems onto the existing. End-to-end system modeling spanning from the plant to the grid can bridge the gap.

This project will bring together a coordinated team that draws on substantial technical expertise with plant-level operations, grid control, thermodynamic and economic modeling, and system optimization to build an end-to-end system model of coupled CSP-TES systems that seamlessly incorporates operationally relevant thermodynamics, transients grid control algorithms, and market-driven economics. The systems modeling approach will move beyond the emphasis on academic models of CSP and thermal systems, which may not capture the operational realities of bringing these technologies online, while also linking them through control algorithms to the grid and market realities of California. California is at the forefront of solar implementation, thermal technologies continue to evolve, and experts on grid control have traditionally spent little time analyzing renewable technologies, there has been little work to develop a full system model before and few attempts to find the optimal technology and control combination for the grid. The system modeling framework will fill this gap, and model outcomes will give plant developers guidance about how to optimize their systems to meet the needs of the grid, while simultaneously giving grid operators and regulators guidance on how to integrate CSP-TES into their systems. Ultimately, this will result in a more efficient, more reliable, economically beneficial system as CSP and storage penetration increases.

Goals of the Agreement

The goal of this Agreement is to define the benefits, costs, and impacts of increasing penetrations of coupled CSP-TES to the California electricity grid, along with the system configurations and control strategies needed to optimize economic and engineering performance. This will include seamlessly linking transient (dynamic) thermodynamic models of several key CSP-TES configurations, grid control, and electricity markets to achieve results which encompass generation, transmission, and sale of stored solar thermal energy.

Objectives of the Agreement

The objectives of this Agreement are to:

- Determine the most economically effective CSP-TES configurations of existing technologies;
- Define the reduction of area control error caused by the intermittency of concentrating solar generation from adding optimal storage configurations;
- Determine the market effectiveness of adding substantial coupled CSP-TES capacity to the California Grid.

TASK 1.0 ADMINISTRATION

MEETINGS

Task 1.1 Attend Kick-off Meeting

The goal of this task is to establish the lines of communication and procedures for implementing this Agreement.

The Contractor shall:

- Attend a "kick-off" meeting with the Energy Commission Contract Manager, the Contracts Officer, and a representative of the Accounting Office. The Contractor shall bring their Project Manager, Contracts Administrator, Accounting Officer, and others designated by the Energy Commission Contract Manager to this meeting. The administrative and technical aspects of this Agreement will be discussed at the meeting. Prior to the kick-off meeting, the Energy Commission Contract Manager will provide an agenda to all potential meeting participants.

  The administrative portion of the meeting shall include, but not be limited to, the following:

  - Terms and conditions of the Agreement
  - CPRs (Task 1.2)
  - Match fund documentation (Task 1.7)
  - Permit documentation (Task 1.8)

  The technical portion of the meeting shall include, but not be limited to, the following:

  - The Energy Commission Contract Manager's expectations for accomplishing tasks described in the Scope of Work;
  - An updated Schedule of Deliverables
  - Progress Reports (Task 1.4)
  - Technical Deliverables (Task 1.5)
  - Final Report (Task 1.6)
  - Establish the PAC (Task 1.10)
  - PAC Meetings (Task 1.11)

  The Energy Commission Contract Manager shall designate the date and location of this meeting.

Contractor Deliverables:

- An Updated Schedule of Deliverables
- An Updated List of Match Funds
- An Updated List of Permits
- Schedule for Recruiting PAC Members

Energy Commission Contract Manager Deliverables:

- Final Report Instructions

Task 1.2 CPR Meetings

The goal of this task is to determine if the project should continue to receive Energy Commission funding to complete this Agreement and if it should, are there any modifications that need to be made to the tasks, deliverables, schedule or budget.

CPRs provide the opportunity for frank discussions between the Energy Commission and the Contractor. CPRs generally take place at key, predetermined points in the Agreement, as determined by the Energy Commission Contract Manager and as shown in the Technical Task List above and in the Schedule of Deliverables. However, the Energy Commission Contract Manager may schedule additional CPRs as necessary, and any additional costs will be borne by the Contractor.

Participants include the Energy Commission Contract Manager and the Contractor, and may include the Energy Commission Contracts Officer, the PIER Program Team Lead, other Energy Commission staff and Management as well as other individuals selected by the Energy Commission Contract Manager to provide support to the Energy Commission.

The Energy Commission Contract Manager shall:

- Determine the location, date and time of each CPR meeting with the Contractor. These meetings generally take place at the Energy Commission, but they may take place at another location.
- Send the Contractor the agenda and a list of expected participants in advance of each CPR. If applicable, the agenda shall include a discussion on both match funding and permits.
- Conduct and make a record of each CPR meeting. One of the outcomes of this meeting will be a schedule for providing the written determination described below.
- Determine whether to continue the project, and if continuing, whether or not to modify the tasks, schedule, deliverables and budget for the remainder of the Agreement, including not proceeding with one or more tasks. If the Energy Commission Contract Manager concludes that satisfactory progress is not being made, this conclusion will be referred to the Energy Commission's Research, Development and Demonstration Policy Committee for its concurrence.
- Provide the Contractor with a written determination in accordance with the schedule. The written response may include a requirement for the Contractor to revise one or more deliverable(s) that were included in the CPR.

The Contractor shall:

- Prepare a CPR Report for each CPR that discusses the progress of the Agreement toward achieving its goals and objectives. This report shall include recommendations and conclusions regarding continued work of the projects. This report shall be submitted along with any other deliverables identified in this Scope of Work. Submit these documents to the Energy Commission Contract Manager and any other designated reviewers at least 15 working days in advance of each CPR meeting.
- Present the required information at each CPR meeting and participate in a discussion about the Agreement.

Contractor Deliverables:

- CPR Report(s)
- CPR deliverables identified in the Scope of Work

Energy Commission Contract Manager Deliverables:

- Agenda and a List of Expected Participants
- Schedule for Written Determination
- Written Determination

Task 1.3 Final Meeting

The goal of this task is to closeout this Agreement.

The Contractor shall:

- Meet with the Energy Commission to present the findings, conclusions, and recommendations. The final meeting must be completed during the closeout of this Agreement.

  This meeting will be attended by, at a minimum, the Contractor, the Energy Commission Contracts Officer, and the Energy Commission Contract Manager. The technical and administrative aspects of Agreement closeout will be discussed at the meeting, which may be two separate meetings at the discretion of the Energy Commission Contract Manager.

  The technical portion of the meeting shall present findings, conclusions, and recommended next steps (if any) for the Agreement. The Energy Commission Contract Manager will determine the appropriate meeting participants.

  The administrative portion of the meeting shall be a discussion with the Energy Commission Contract Manager and the Contracts Officer about the following Agreement closeout items:

  - What to do with any state-owned equipment (Options)
  - Need to file UCC.1 form re: Energy Commission's interest in patented technology
  - Energy Commission's request for specific "generated" data (not already provided in Agreement deliverables)
  - Need to document Contractor's disclosure of "subject inventions" developed under the Agreement
  - "Surviving" Agreement provisions, such as repayment provisions and confidential deliverables
  - Final invoicing and release of retention
- Prepare a schedule for completing the closeout activities for this Agreement.

Deliverables:

- Written documentation of meeting agreements and all pertinent information
- Schedule for completing closeout activities

REPORTING

See Exhibit D, Reports/Deliverables/Records.

Task 1.4 Monthly Progress Reports

The goal of this task is to periodically verify that satisfactory and continued progress is made towards achieving the research objectives of this Agreement.

The Contractor shall:

- Prepare progress reports which summarize all Agreement activities conducted by the Contractor for the reporting period, including an assessment of the ability to complete the Agreement within the current budget and any anticipated cost overruns. Each progress report is due to the Energy Commission Contract Manager within 10 working days after the end of the reporting period. Attachment A-2, Progress Report Format, provides the recommended specifications.

Deliverables:

- Monthly Progress Reports

Task 1.5 Test Plans, Technical Reports and Interim Deliverables

The goal of this task is to set forth the general requirements for submitting test plans, technical reports and other interim deliverables, unless described differently in the Technical Tasks. When creating these deliverables, the Contractor shall use and follow, unless otherwise instructed in writing by the Energy Commission Contract Manager, the latest version of the PIER Style Manual published on the Energy Commission's web site:

http://www.energy.ca.gov/contracts/pier/contractors/

The Contractor shall:

- Unless otherwise directed in this Scope of Work, submit a draft of each deliverable listed in the Technical Tasks to the Energy Commission Contract Manager for review and comment in accordance with the approved Schedule of Deliverables. The Energy Commission Contract Manager will provide written comments back to the Contractor on the draft deliverable within 10 working days of receipt. Once agreement has been reached on the draft, the Contractor shall submit the final deliverable to the Energy Commission Contract Manager. The Energy Commission Contract Manager shall provide written approval of the final deliverable within 5 working days of receipt. Key elements from this deliverable shall be included in the Final Report for this project.

Task 1.6 Final Report

The goal of this task is to prepare a comprehensive written Final Report that describes the original purpose, approach, results and conclusions of the work done under this Agreement. The Energy Commission Contract Manager will review and approve the Final Report. The Final Report must be completed on or before the termination date of the Agreement. When creating these deliverables, the Contractor shall use and follow, unless otherwise instructed in writing by the Energy Commission Contract Manager, the latest version of the PIER Style Manual published on the Energy Commission's web site:

http://www.energy.ca.gov/contracts/pier/contractors/

The Final Report shall be a public document. If the Contractor has obtained confidential status from the Energy Commission and will be preparing a confidential version of the Final Report as well, the Contractor shall perform the following subtasks for both the public and confidential versions of the Final Report.

Task 1.6.1 Final Report Outline

The Contractor shall:

- Prepare a draft outline of the Final Report.
- Submit the draft outline of Final Report to the Energy Commission Contract Manager for review and approval. The Energy Commission Contract Manager will provide written comments back to the Contractor on the draft outline within 10 working days of receipt. Once agreement has been reached on the draft, the Contractor shall submit the final outline to the Energy Commission Contract Manager. The Energy Commission Contract Manager shall provide written approval of the final outline within 5 working days of receipt.

Deliverables:

- Draft Outline of the Final Report
- Final Outline of the Final Report

Task 1.6.2 Final Report

The Contractor shall:

- Prepare the draft Final Report for this Agreement in accordance with the approved outline.
- Submit the draft Final Report to the Energy Commission Contract Manager for review and comment. The Energy Commission Contract Manager will provide written comments within 10 working days of receipt.

  Once agreement on the draft Final Report has been reached, the Energy Commission Contract Manager shall forward the electronic version of this report for Energy Commission internal approval. Once the approval is given, the Energy Commission Contract Manager shall provide written approval to the Contractor within 5 working days.
- Submit one bound copy of the Final Report with the final invoice.

Deliverables:

- Draft Final Report
- Final Report

MATCH FUNDS, PERMITS, AND ELECTRONIC FILE FORMAT

Task 1.7 Identify and Obtain Matching Funds

The goal of this task is to ensure that the match funds planned for this Agreement are obtained for and applied to this Agreement during the term of this Agreement.

The costs to obtain and document match fund commitments are not reimbursable through this Agreement. While the PIER budget for this task will be zero dollars, the Contractor may utilize match funds for this task. Match funds shall be spent concurrently or in advance of PIER funds during the term of this Agreement. Match funds must be identified in writing, and the associated commitments obtained before the Contractor can incur any costs for which the Contractor will request reimbursement.

The Contractor shall:

- Prepare a letter documenting the match funding committed to this Agreement and submit it to the Energy Commission Contract Manager at least 2 working days prior to the kick-off meeting:
  1. If no match funds were part of the proposal that led to the Energy Commission awarding this Agreement and none have been identified at the time this Agreement starts, then state such in the letter.
  2. If match funds were a part of the proposal that led to the Energy Commission awarding this Agreement, then provide in the letter:
     - A list of the match funds that identifies the:
       - Amount of each cash match fund, its source, including a contact name, address and telephone number and the task(s) to which the match funds will be applied.
       - Amount of each in-kind contribution, a description, documented market or book value, and its source, including a contact name, address and telephone number and the task(s) to which the match funds will be applied. If the in-kind contribution is equipment or other tangible or real property, the Contractor shall identify its owner and provide a contact name, address and telephone number, and the address where the property is located.
     - A copy of the letter of commitment from an authorized representative of each source of cash match funding or in-kind contributions that these funds or contributions have been secured.
- Discuss match funds and the implications to the Agreement if they are significantly reduced or not obtained as committed, at the kick-off meeting. If applicable, match funds will be included as a line item in the progress reports and will be a topic at CPR meetings.

- Provide the appropriate information to the Energy Commission Contract Manager if during the course of the Agreement additional match funds are received.
- Notify the Energy Commission Contract Manager within 10 working days if during the course of the Agreement existing match funds are reduced. Reduction in match funds may trigger an additional CPR.

Deliverables:

- A letter regarding Match Funds or stating that no Match Funds are provided
- Letter(s) for New Match Funds
- A copy of each Match Fund commitment letter
- Letter that Match Funds were Reduced (if applicable)

Task 1.8 Identify and Obtain Required Permits

The goal of this task is to obtain all permits required for work completed under this Agreement in advance of the date they are needed to keep the Agreement schedule on track.

Permit costs and the expenses associated with obtaining permits are not reimbursable under this Agreement. While the PIER budget for this task will be zero dollars, the Contractor shall show match funds for this task. Permits must be identified in writing and obtained before the Contractor can incur any costs related to the use of the permits for which the Contractor will request reimbursement.

The Contractor shall:

- Prepare a letter documenting the permits required to conduct this Agreement and submit it to the Energy Commission Contract Manager at least 2 working days prior to the kick-off meeting:
    1. If there are no permits required at the start of this Agreement, then state such in the letter.
    2. If it is known at the beginning of the Agreement that permits will be required during the course of the Agreement, provide in the letter:
        - A list of the permits that identifies the:
            - Type of permit
            - Name, address and telephone number of the permitting jurisdictions or lead agencies
        - Schedule the Contractor will follow in applying for and obtaining these permits.
- The list of permits and the schedule for obtaining them will be discussed at the kick-off meeting, and a timetable for submitting the updated list, schedule and the copies of the permits will be developed. The implications to the Agreement if the permits are not obtained in a timely fashion or are denied will also be discussed. If applicable, permits will be included as a line item in the progress reports and will be a topic at CPR meetings.

- If during the course of the Agreement additional permits become necessary, then provide the appropriate information on each permit and an updated schedule to the Energy Commission Contract Manager.
- As permits are obtained, send a copy of each approved permit to the Energy Commission Contract Manager.
- If during the course of the Agreement permits are not obtained on time or are denied, notify the Energy Commission Contract Manager within 5 working days. Either of these events may trigger an additional CPR.

Deliverables:

- A letter documenting the Permits or stating that no Permits are required
- Updated list of Permits as they change during the Term of the Agreement
- Updated schedule for acquiring Permits as it changes during the Term of the Agreement
- A copy of each approved Permit

Task 1.9 Electronic File Format

The goal of this task is to unify the formats of electronic data and documents provided to the Energy Commission as contract deliverables. Another goal is to establish the computer platforms, operating systems and software that will be required to review and approve all software deliverables.

The Contractor shall:

- Deliver documents to the Energy Commission Contract Manager in the following formats:
  - Data sets shall be in Microsoft (MS) Access or MS Excel file format.
  - PC-based text documents shall be in MS Word file format.
  - Documents intended for public distribution shall be in PDF file format, with the native file format provided as well.
  - Project management documents shall be in MS Project file format.
- Request exemptions to the electronic file format in writing at least 90 days before the deliverable is submitted.

Deliverables:

- A letter requesting exemption from the Electronic File Format (if applicable)

PAC

Task 1.10 Establish the PAC

The goal of this task is to create an advisory committee for this Agreement.

The PAC should be composed of diverse professionals. The number can vary depending on potential interest and time availability. The exact composition of the PAC may change as the need warrants. PAC members serve at the discretion of the Energy Commission Contract Manager.

The PAC may be composed of qualified professionals spanning the following types of disciplines:

- Researchers knowledgeable about the project subject matter
- Members of the trades who will apply the results of the project (e.g., designers, engineers, architects, contractors, and trade representatives)
- Public Interest Market Transformation Implementers
- Product Developers relevant to project subject matter
- U.S. Department of Energy Research Manager
- Public Interest Environmental Groups
- Utility Representatives
- Members of the relevant technical society committees

The purpose of the PAC is to:

- Provide guidance in research direction. The guidance may include scope of research; research methodologies; timing; coordination with other research. The guidance may be based on:

  -technical area expertise

  -knowledge of market applications

  -linkages between the agreement work and other past, present or future research (both public and private sectors) they are aware of in a particular area.

- Review deliverables. Provide specific suggestions and recommendations for needed adjustments, refinements, or enhancement of the deliverables.
- Evaluate tangible benefits to California of this research and provide recommendations, as needed, to enhance tangible benefits.
- Provide recommendations regarding information dissemination, market pathways or commercialization strategies relevant to the research products.

The Contractor shall:

- Prepare a draft list of potential PAC members that includes name, company, physical and electronic address, and phone number and submit it to the Energy Commission Contract Manager at least 2 working days prior to the kick-off meeting. This list will be discussed at the kick-off meeting and a schedule for recruiting members and holding the first PAC meeting will be developed.
- Recruit PAC members and ensure that each individual understands the member obligations described above, as well as the meeting schedule outlined in Task 1.11.
- Prepare the final list of PAC members.
- Submit letters of acceptance or other comparable documentation of commitment for each PAC member.

Deliverables:

- Draft List of PAC Members
- Final List of PAC Members
- Letters of acceptance, or other comparable documentation of commitment for each PAC Member

Task 1.11 Conduct PAC Meetings

The goal of this task is for the PAC to provide strategic guidance to this project by participating in regular meetings or teleconferences.

The Contractor shall:

- Discuss the PAC meeting schedule at the kick-off meeting. The number of face-to-face meetings and teleconferences and the location of PAC meetings shall be determined in consultation with the Energy Commission Contract Manager. This draft schedule shall be presented to the PAC members during recruiting and finalized at the first PAC meeting.
- Organize and lead PAC meetings in accordance with the schedule. Changes to the schedule must be pre-approved in writing by the Energy Commission Contract Manager.
- Prepare PAC meeting agenda(s) with back-up materials for agenda items.
- Prepare PAC meeting summaries, including recommended resolution of major PAC issues.

Deliverables:

- Draft PAC Meeting Schedule
- Final PAC Meeting Schedule
- PAC Meeting Agenda(s) with Back-up Materials for Agenda Items
- Written PAC meeting summaries, including recommended resolution of major PAC issues

TECHNICAL TASKS

The Contractor shall prepare all deliverables in accordance with the requirements in Task 1.5. Deliverables not requiring a draft version are indicated by marking "(no draft)" after the deliverable name.

Task 2 DEFINE GRID-RELEVANT ECONOMICS

The goal of this task is to define the systems model requirements and baseline, and to define viable optimization criteria that incorporate economic behavior of the California market and multiple operational scenarios.

The Contractor shall:

- Analyze the potential for CSP-TES revenues in the California market. These may include:
  - Payments for energy at hourly prices
  - Payments and costs for real time dispatch/imbalance energy at real time settlement prices
  - Prices for applicable ancillary services provided such as regulation, spinning and quick start reserve, and possibly in the future frequency / governor response.
- Include in the analysis the following scenarios:
  - Revenues with today's energy and ancillaries prices
  - Anticipated prices under future high-renewables portfolios
  - Prices under high CSP–TES penetrations with positive impacts as anticipated in this study
- Define the impact that the aggregate CSP-TES penetration could have on market economics overall
- Establish common requirements for the all components of the end-to-end modeling systems (such as load profiles)
- Describe technology development trajectories and corresponding economic potential, and solicit PAC guidance
- Prepare a white paper to include but not be limited to:
  - Detailing system modeling requirements
  - Optimization criteria
  - Envelope of market scenarios
- A full technical description is to be included in the Final Report

Deliverables:

- Define Grid Relevant Economics White Paper (no draft)

Task 3 PLANT-LEVEL THERMODYNAMIC MODELING OF MULTIPLE CSP-TES CONFIGURATIONS

The goal of this task is to develop mathematical models that represent the thermal dynamic behavior of ten commercially relevant thermal energy storage systems. These component models will then configure into various CSP-TES designs used to generate electrical power to the grid.

The Contractor shall:

- Finalize the selection of ten commercially relevant thermal energy storage systems. Broadly, these will focus on sensible heat thermal energy storage and energy storage using phase change materials (PCMs). The preliminary list of thermal energy storage systems is to include but not be limited to:
    - Sensible heat thermal energy storage using:
        - Two-tank (hot and cold) fluids (molten salt, oil) with direct heat storage. This system uses the same storage media as the heat transfer fluid in CSP
        - Two tank (hot and cold) fluids (molten salt, oil) with indirect heat exchange. This system uses different fluid for heat transfer in CSP (for example, silicone oil) and for storage (for example, molten salt)
        - Passive sensible heat stored in solid media such as high thermal capacity concrete
        - Single tank thermocline storage (hot fluid and cold fluid stratified due to density differences). The storage medium is dual media (for example rock and oil or solid and molten salt)
        - Single tank thermocline storage liquid only (for example molten salt or oil).
        - Single tank thermocline storage with actively managed thermal stratification1
    - Phase change thermal energy that uses latent heat of fusion in low cost, readily available materials (for example, inorganic salt mixtures, metal alloys)
        - A macro-encapsulated packed bed of tubes containing PCM
        - A packed bed of small spheres (~5mm) encapsulating a PCM
        - A Cascaded PCM storage (similar to a or b with different PCMs)
        - Actively managed phase change thermal storage

[1] This technology is under development at Terrafore

- Define a baseline concentrating solar power plant. Using the system requirements from Task 2 define the baseline system design to include the solar collector size, thermal energy storage size and turbine cycle parameters. As a first step, use the commercial system design parameters available in literature or through contacts in the industry. The output of this subtask is the design equations for three CSP systems – Trough, Tower and linear Fresnel reflector (LFR). The baseline will rely on specifications from Task 2 for the megawatt (MW) output from CSP, hours of storage or hours of operation at design MW on a design day or annual energy output required from the CSP plant.
- Develop mathematical representations for various TES systems:
    - Conduct a literature search to evaluate the available models for various thermal storage systems
    - Develop mathematical equations, correlations for heat transfer, sizing equations for the selected ten thermal storage systems (identified above)
    - Code and test the equations in Matlab for appropriateness of outputs to meet the system requirements for grid-wise impact study
- Develop & exercise Matlab code for components to size the CSP-TES system and then simulate the dynamic and diurnal (dailydaily) behavior of the system:
    - Design steady state design day operation outputs for selected CSP systems
    - Implement the previously developed mathematical representations into Matlab
    - Test the code with a baseline system design of the CSP system for design day and selected day conditions
    - Prepare a memorandum specifying completion of Matlab code
- Develop and exercise Simulink code for various CSP system configurations using the math models from this task to include and not be limited to:
    - Simulation models
    - Code in Simulink to simulate with an external weather file or input file
    - Simulation code for all systems for design day operation
    - Simulation runs for a year of operation for a selected system
- Integrate the models with market simulation code to study grid dispatch and dispatch characteristics. Establish interface requirements, build the code, and exercise the integrated code for at least two configurations
- Prepare a white paper to include but not be limited to:
    - Detailed theoretical equations to be used for all CSP-TES configurations
    - Engineering model results
    - Brief description and specifying completion of Matlab and Simulink codes
- A full technical description is to be included in the Final Report
- Participate in CPR as per Task 1.2

Deliverables:

- Memorandum Specifying Completion (no draft)
- Plant-Level Thermodynamic Modeling of Multiple CSP-TES Configurations White Paper (no draft)
- CPR Report

Task 4 PARAMETER BASED OPTIMIZATION

The goal of this task is to select a subset of the highest-value configurations from Task 3 and optimize the underlying engineering model parameters against economic targets defined in Task 2, in order to prepare for developing control algorithms in Task 5.

The Contractor shall:

- Apply optimization criteria developed in Task 2 to CSP-TES configuration models
- Specify the subset of CSP-TES configurations most likely to maximize benefit criteria under various scenarios specified in Task 2
- Use linear and/or non-linear mathematical dynamic optimization techniques to define optimal plant-level engineering parameters for the selected subset of CSP-TES configurations. Note that the optimization formulation to be used depends on the model requirement
- Perform sensitivity tests to establish the reasonable performance “envelope” for each selected CSP-TES configuration
- Prepare a white paper to include but not be limited to:
    - Optimization criteria,
    - Best performing subset
    - Established performance envelope for each selected CSP-TES configuration
- Prepare a full technical description is to be included in the Final Report
- Participate in CPR as per Task 1.2

Deliverables:

- Parameter Based Optimization White Paper (no draft)
- CPR Report

Task 5 MODEL GRID LINKAGES and DEVELOP CONTROL ALGORITHMS

The goal of this task is to quantitatively link the dynamic engineering models of selected high-value CSP-TES configurations to an established grid control simulation framework. A second goal of this task is to define and implement appropriate control algorithms that leverage previously optimized engineering parameters and the dynamic tendencies to optimal CSP-TES configurations for dispatch.

The Contractor shall:

- Use the simulation tool KERMIT as used in a prior Energy Commission and California Independent System Operator (CAISO) project on renewables integration and storage to model grid linkages of CSP-TES
- Integrate into KERMIT the developed models of CSP configurations including TES and gas co-firing
- Establish a portfolio of CSP plants (location, capacities, and configurations) for each scenario of simulations representative of high CSP penetrations
- Use target days actual weather to represent expected variation in solar flux at the plants' locations across seasons
- Use earlier and ongoing data for wind, load, photovoltaic development, conventional dispatch, and CAISO schedules to complete the use of calibrated dynamic simulations of the California grid, operations, and markets
- Add dynamic models of the steam turbines, governor and governor controls, and plant control systems to each CSP-TES model. KERMIT will represent the frequency response and interconnected system dynamic performance of the grid (tie flows and Area Control Error) as well as the automatic generation control response to area control error (ACE) including all these critical physical parameters and effects. The response of the CSP plants to dispatch and regulation instructions from CAISO will be represented fully. At the conclusion of this task each CSP configuration and planned or assumed facility will be represented in the dynamic simulation at a level of dynamic and economic fidelity comparable to that routinely achieved by conventional generation models
- Prepare a white paper to include but not be limited to, Structure of high fidelity KERMIT model of California grid in the Western Electricity Coordinating Council (WECC) interconnection
- A full technical description is to be included in the Final Report

Deliverables:

- Model Grid Linkages and Develop Control Algorithms White Paper (no draft)

Task 6 DEVELOP MARKET SIMULATION MODELS of CSP-TES

The goal of this task is to develop economic and constraint models of CSP-TES for use in market simulations and dispatch. Models will include incremental costs, limits, rate limits, start-up shut-down costs, and a shadow price methodology for use in dispatching thermal storage charging and discharging.

The Contractor shall:

- Develop a unit commitment type model for CSP production including limits, rate limits, an IHR type model of solar insolation conversion to steam and electric power.
- Develop a shadow price model for "dispatch" of thermal energy storage – charging and discharging, in conjunction with CSP production
- Use this model to represent CSP-TES plants in market simulation and dispatch

- Prepare a white paper to include but not be limited to: theoretical framework for developing unit commitment models of CSP and TES

- A full technical description is to be included in the Final Report
- Participate in CPR as per Task 1.2

Deliverables:

- Develop Market Simulation Models of CSP-TES White Paper (no draft)
- CPR Report

Task 7 SIMULATE MARKET OUTCOMES

The goal of this task is to simulate and analyze the market response to optimized, dispatch-controllable CSP-TES resources using one of a number of possible market simulation tools.

The Contractor shall:

- Use a market simulation/dispatch tool to develop hourly day-ahead energy schedules as expected for future renewable penetration development including the economics of conventional generation as expected in future scenarios. Increased ancillary services levels will be an input requirement to market simulation runs based on prior and ongoing investigation of ancillary requirements under high renewable portfolio standards (RPS) penetration overall
- Use CSP with and without TES in the market simulations to demonstrate the value of thermal storage for managing CSP ramping and variability, and the benefits of this to system economics and dynamic performance. Note that some of the economic benefits are expected from reduced system ancillary requirements to manage CSP ramping; these savings can be validated in the market simulation
- Use the conventional unit production and heat rates to calculate fuel consumption and Carbon Dioxide ($CO_{2)}$ emissions and demonstrate the impact of CSP-TES on CO_2 emissions
- Configure the CSP plants with thermal storage and sizing of solar and steam components so as to allow the plants to provide ancillary services. Allow these plants to “bid” ancillary service provisions as inputs to the market simulations using bid costs derived from Task 2 (capital recovery and opportunity costs) and use the improvements in system economics and emissions to demonstrate the value of CSP-TES for helping integrate other renewable resources
- Prepare a white paper to include the outlining the following analysis and model results:
    - Analysis and demonstration of the economic and reliability impact (in terms of system ACE performance) of CSP-TES plant configurations, used to manage CSP ramping and variability
    - Analysis and demonstration of the economic and reliability impact of CSP-TES configuration resizing to allow ancillaries provision by CSP plants to help integrate other renewables

- Demonstration of the improvement in system emissions of CO_2 as a result of decreased stand by operation of conventional generation when CSP ramping and variability are managed as well as when CSP plants are able to provide increased ancillary services

- A full technical description of the model results is to be included in the Final Report

Deliverables:

- Simulated Market Outcomes White Paper (no draft)

Task 8 TECHNOLOGY TRANSFER ACTIVITIES

The goal of this task is to develop a plan to make the knowledge gained, experimental results and lessons learned available to key decision-makers.

The Contractor shall:

- Prepare a Technology Transfer Plan. The plan shall explain how the knowledge gained in this project will be made available to the public. Key elements from this report shall be included in the Final Report for this project
- Conduct technology transfer activities in accordance with the Technology Transfer Plan. These activities shall be reported in the Monthly Progress Reports
- Indicate the intended use and users of the project results

Deliverables:

- Technology Transfer Plan