BEFORE THE PUBLIC UTILITIES COMMISSION
OF THE STATE OF CALIFORNIA

Order Instituting Rulemaking to Oversee the Resource Adequacy Program, Consider Program Refinements, and Establish Annual Local Procurement Obligations.	Rulemaking 11-10-023 Filed October 20, 2011

COMMENTS OF THE CONCENTRATING SOLAR POWER ALLIANCE ON THE ENERGY DIVISION'S REVISED FLEXIBLE CAPACITY PROCUREMENT PROPOSAL AND FLEXIBLE CAPACITY WORKSHOP

The Concentrating Solar Power Alliance ("CSPA") appreciates this opportunity to provide comments on the issues raised in the January 23, 2013 Workshop and on the revised Energy Division proposal included with the March 11, 2013 Administrative Law Judge's Ruling Resetting Schedule for Comments on Phase 2 Resource Adequacy Issues and Scheduling a Prehearing Conference. CSPA submits the following comments to the California Public Utilities Commission ("Commission") in accordance with the provisions of the March 11 ruling by Administrative Law Judge Gamson.

I. Introduction

The CSPA consists of concentrating solar power ("CSP") developers and suppliers who advocate for the increasing acceptance, adoption and implementation of CSP technology and thermal energy storage. CSPA supports the efforts being undertaken by the Commission and California Independent System Operator ("CAISO") to enhance the existing Resource Adequacy ("RA") program in response to the changing resource mix and operational needs of California's electric power grid. In doing so, the Commission must balance multiple objectives – cost, reliability, the Loading Order and the State's environmental goals and policies, such as the Renewables Portfolio Standard ("RPS") and the California's Global Warming Solutions Act ("AB 32"). This task is made more challenging by the potential retirement of once-through cooling plants. Without proper system planning, the program design and procurement decisions for a new Flexible Capacity Resource Adequacy program ("FCRA") may result in sub-optimal cost outcomes and may degrade progress toward California's energy policy goals.

To be successful in achieving all of these objectives, a Flexible Capacity decision by the Commission must: 1) include a plan to study, 2) design market structures for, and 3) explicitly contemplate participation by unconventional flexible resources, including use limited resources, such as concentrating solar thermal power with thermal energy storage ("CSP with TES"). CSP with TES plants utilize solar energy as fuel for a conventional steam turbine generator, but with the ability to manage the time and amount of electricity generation with the advent of thermal storage systems. By providing both RPS energy and Flexible Capacity, CSP with TES has the potential to be an important component of the California grid's future flexible capabilities and can contribute to a power system with both lower total costs and lower carbon emissions.

Because of the required lead time in development and engineering of large-scale projects, independent energy infrastructure developers and procuring utilities need consistent and accurate operational specifications as soon as possible from an FCRA program, designed appropriately and in coordination with other Commission administered programs and California state policy initiatives. CSPA recommends that unconventional flexible resources, specifically CSP with TES, are incorporated into the FCRA eligibility and counting framework for the 2015 RA year.

II. Concentrating Solar Power with Thermal Energy Storage Provides Flexible Operating Capabilities and RPS Energy

CSP with TES plants are unique renewable energy resources that provide not only clean electric power, but also a range of operational capabilities that support the continued reliability and operational flexibility of electric power systems. CSP plants have been in operation for several decades, with several new large plants coming online in Spain and the U.S. since 2006. Two CSP with TES plants in Nevada and Arizona are to be completed in 2013, and two additional plants are under contract in California. The advent of thermal energy storage allows for the storing of solar energy and optimal dispatch of this energy, as determined by a plant owner or a procuring utility.

CSP with TES plants can resemble a use-limited conventional dispatchable generator. For CSP with TES, the limitations result from its fuel stock, which is dependent on a combination of the daily direct normal solar insolation ("DNI") it receives and its storage system's technical specifications.[1] Energy production from a CSP with TES plant can be dispatched at most any time of the day for economic or reliability purposes, such as ancillary services, multi-hour ramp support and flexi-ramp reserves. These operational capabilities have typically been provided by fossil-fuel generators; provision of these capabilities by CSP with TES plants can help to maintain system reliability as renewable energy penetrations and carbon emissions restrictions increase. Its dispatchability and flexibility characteristics make CSP with TES a logical component of a FCRA program. Moreover, CSP with TES is a non-fossil fuel-based Flexible Capacity resource that can enable the California power system to successfully implement RPS and AB 32. It would be counterproductive to these legislated targets for the Commission to discourage or exclude a preferred resource in the Loading Order, such as CSP with TES, from participation in a FCRA program.

The incorporation of CSP with TES in the California resource portfolio will have the following general impacts on Flexible Capacity requirements:

1. Reduction of the magnitude of net load ramps, especially in the late afternoon, due to shifting out of solar energy production. (See Appendix A for examples of impact of CSP with TES on net load system ramps).
2. Reduction in forecast errors and intra-hourly variability of the aggregate variable energy resource portfolio.
3. Provision of dispatchable energy, fast ramp capabilities and wide operating ranges to serve Flexible Capacity needs.

These attributes and capabilities are central to the CAISO-stated need for Flexible Capacity resources.

[1] CSP with TES is unlike other energy storage devices in that it does not require charging from the grid; however, these plants can be equipped to charge from the grid, to relieve over-generation or otherwise, if warranted and cost-effective to do so.

III. The Flexible Capacity Resource Adequacy Program Should Recognize the Value of Use Limited Resources in its Initial Program Design

The CSPA commends the Energy Division's support for "adequate rules for recognizing the available use limited flexible capacity"[2] and the Joint Parties' support for a "technology agnostic"[3] approach to the FCRA. While the current Energy Division Proposal accepts modifications to the proposed CAISO eligibility rules in order for hydroelectric resources to participate in the FCRA program, incorporation of other use limited resources is deferred for future consideration.

Any facility should be eligible for participation in an FCRA program that has: 1) the operational capabilities to provide meaningful, controllable energy and power output at the important hours of the day and the year, 2) the flexibility to respond to dispatch signals in the required time scales, and 3) the associated telemetry, certification and control systems.

The CSPA believes that there exists sufficient data on the prospective operations of CSP with TES, in California and surrounding states,[4] such that the Commission and the CAISO should: 1) affirm that CSP with TES plants, subject to minimum conditions, will be eligible for FCRA and 2) commit to work with stakeholders to appropriately design FCRA parameters for CSP with TES.

Due to the energy limitations of CSP with TES plants, resulting from solar resource availability,[5] FCRA treatment such as that being proposed for hydroelectric resources by Energy Division, PG&E and the Joint Parties would be needed for CSP with TES. CSPA requests that the Commission and CAISO support a consideration of CSP with TES as an eligible Flexible Capacity resource through this proceeding to finalize resource-specific minimum operational capabilities, scheduling requirements and Effective Flexible Capacity ("EFC") counting methodology.

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[2] "Energy Division Flexible Capacity Procurement Revised Proposal," at p. 7 (Mar. 11, 2013).
[3] "Resource Adequacy and Flexible Capacity Procurement Joint Parties' Proposal," at p. 12 (Oct. 29, 2012).
[4] A number of recent studies (see Appendix C for full reference list) and included in a 2012 CSP Alliance Report ("The Economic and Reliability Benefits of CSP with Thermal Energy Storage: Recent Studies and Research Needs") identify higher energy, ancillary service and capacity benefits of CSP with TES plants, compared to non-dispatchable solar plants. These studies do not explicitly model for the Flexible Capacity attributes outlined by the CAISO, but they offer a platform for conducting such analysis.
[5] CSP with or without thermal energy storage can be hybridized with natural gas, biogas or biomass to enhance the availability of Flexible Capacity capabilities.

CSP with TES has been subjected to detailed technical study over the past few years by U.S. national laboratories to validate aspects of operational performance that can contribute to the necessary analysis for FCRA determinations. The operational characteristics of these plants are well understood, and there are now examples of simulations utilizing CSP with TES that parallel the CAISO's own integration studies at 33% RPS.[6] These plant simulations, using historical and typical meteorological year ("TMY") DNI data, can provide the Commission and the CAISO with the necessary preliminary insight into operating characteristics in order to incorporate CSP with TES into the FCRA program.

CSPA members are willing to work with the Energy Division and stakeholders to help the Commission establish the proper treatment for CSP with TES plants within the FCRA program.

IV. The Costs of the Flexible Capacity Resource Adequacy Program Can be Reduced Through Inclusion of Concentrating Solar Power with Thermal Energy Storage

CSP with TES plants will be optimally and economically dispatched for energy and ancillary services whether or not they are eligible to provide FCRA. During periods of significant system ramps, it can be foreseen that value of these services will be higher, inducing CSP with TES plants to be dispatched. Excluding CSP with TES from participation in an FCRA program may lead to an inaccurate assessment of system needs and capabilities as well as higher FCRA costs than necessary.

The following scenarios pose further potential cost implications of FCRA program structure:

1. When FCRA credit is conferred to an LSE by a CSP with TES plant under a bundled RPS contract, the residual demand to procure from other FCRA resources is reduced, and is thereby likely to reduce the cost of that procurement.

[6] Paul Denholm, Yih-Huei Wan, Marissa Hummon, and Mark Mehos, "An Analysis of Concentrating Solar Power with Thermal Energy Storage in a California 33% Renewable Scenario," Technical Report, NREL/TP-6A20-58186, (Mar. 2013). *See Appendix B for brief description of CSP modeling by NREL.*

2. Even if not eligible for FCRA credit, CSP with TES plants will likely be dispatched more often in real-time system ramps relative to higher variable cost conventional sources. As a result, some higher variable cost units would likely remain idle, but would still receive an FCRA payment.
3. If depressed energy prices become more prevalent as a result of greater penetrations of low or zero variable cost resources, the FCRA payment rate required for conventional generators may increase in order for them to remain in operation as less revenue and profit is expected from energy dispatch.

The resources that could be reasonably expected to be most commonly dispatched in real-time to meet the needs addressed by the FCRA program should also be contemplated in and eligible for the FCRA program. Failure to do so can be expected to increase costs and decrease the efficiency of the energy supply. CSPA recommends the study and verification of net system cost impacts of alternative FCRA portfolios to help ensure that the FCRA program is deployed at least cost.

V. Quantification of Effective Flexible Capacity for Concentrating Solar Power with Thermal Energy Storage will Require a Resource-Specific Methodology

Similar to the proposals for differentiated EFC counting methodology for hydroelectric resources, CSP with TES would need a resource-specific approach that incorporates both technical storage capabilities and fuel, or solar resource, availability. As is the proposed case with hydroelectric resources and cited by participants at the March 20, 2013, workshop, different resources can and should have different eligibility and EFC treatment, so long as they address the fundamental need and purpose of FCRA and any use limitations are accounted for in the counting methodology.

CSPA proposes a prospective EFC rating for CSP with TES on a year-ahead basis, similar to the PG&E proposal for hydroelectric resources. For hydro, the year-ahead EFC is based on reservoir capabilities and operational limitations, and then revised downward closer to the FCRA monthly showings when actual water resources are more certain. For CSP with TES, the EFC could be set based on technical storage capabilities, such as megawatt-hour storage capacity, megawatt discharge capacity and ramping rates, as well as average monthly expectations for DNI. The National Renewable Energy Laboratory's ("NREL") modeling and analysis of the CAISO 33%'s RPS case provides an analytical foundation for estimating the capability of CSP with TES to mitigate net load ramps, which could inform an EFC counting methodology.

An approved EFC counting methodology would need to look at the materiality of differences between year-ahead and updated near-term EFC assessments, as well as any positive correlations between the daily energy availability of CSP with TES plants and the corresponding daily magnitude of maximum net load ramps.

As it pertains to storage resources more broadly, the three hour ramping capability requirement should not be an eligibility criteria, but rather a basis for quantifying the EFC of a storage resource.[7] A storage resource will have a maximum discharge potential, which is measured in capacity (MW), but given its total storage capacity, which is measured in energy (MWh), could ramp to a given output level over three hours or produce at an output level less than its maximum potential. This lower output level could be reflected in the EFC rating. Alternatively, storage resources with less than three hours of discharge capacity at P_{max} could be dispatched in coordination to jointly meet the three hour ramping need, providing their full output over the shorter period of time. To make the most efficient use of a resource portfolio, the EFC should match the capabilities of the resources without artificial constraints that do not fully reflect operational value.

The FCRA program should better reflect the technical capabilities and dynamics of storage resources, including CSP with TES. Disregarding these characteristics could unnecessarily increase the costs of the FCRA program. It would also deter development and deployment of new storage resources, including near-term technology innovations, that could substantially contribute to system reliability, as well as reduce overall energy supply cost and carbon emissions over the long-term.

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[7] The Commission should clarify this point on three hour ramping requirements. The Joint Parties' proposed counting convention for non-use-limited thermal resources suggests EFC is set based on a resource's achievable megawatt range in three hours based on ramping capabilities; whereas, the PG&E proposal for hydro suggest a minimum requirement of six hours of generation capabilities at P_{max}. A requirement of three hours of constant ramping, compared to three hours of P_{max} output, would have a significant impact on quantifying the EFC of a storage-based Flexible Capacity resource.

VI. Resource Adequacy Counting Rules Should be Modified to Appropriately Reflect the Value of the Operational Characteristics of Concentrating Solar Power with Thermal Energy Storage

In order to recognize the true RA values – both generic and flexible – of CSP with TES, the RA counting rules determining a resource's qualifying capacity ("QC") would need to be modified to reflect the operational characteristics of these plants.

The Commission's current exceedence methodology for assessing the net QC of variable wind and solar resources is not entirely applicable to, and discourages the use of, CSP with TES for flexibility and integration purposes. While an exceedence methodology may be appropriate for any "as-available" or "must take" portions of generation, an availability-based QC assessment methodology is more appropriate for periods of dispatchability.

CSP with TES plants can be evaluated for their degree of dispatchability, based on technical storage configurations and projected solar resources, using simulations to evaluate their capacity value, as a percentage of P_{max}. This kind of analysis has been performed recently by NREL and Lawrence Berkeley National Laboratories ("LBNL"). The key finding is that capacity credit, a proxy for QC and stated as a percentage of P_{max}, is a function of the storage capacity, solar field size, steam turbine capacity and CSP technology type. The methodologies and results within these studies may be able to assist in establishing appropriate QC levels for CSP with TES, especially in the context of FCRA program design. CSPA and its members would welcome the opportunity to further discuss an appropriate QC counting methodology for CSP with TES with the Commission and stakeholders.

The modification of the net QC assessment methodology is not necessarily unique to CSP with TES, but would have application to any combination, or hybrid, as-available and dispatchable facilities, i.e., renewable resources co-located with storage or natural gas facilities. A modification of the RA program to apply an availability-based QC assessment, when appropriate, to hybrid facilities will encourage plants with an intermittent fuel source to consider incorporating dispatchable features to further the goal of system reliability inherent in the RA, and prospective FCRA, programs.

VII. The CAISO's Determination of Flexible Capacity Resource Adequacy Requirements Should Consider Concentrating Solar Power with Thermal Energy Storage Plants

As noted previously in these comments, CSP with TES has the ability to and benefit of mitigating the FCRA requirement, as currently proposed by CAISO, because its inclusion in the solar portion of the RPS portfolio inherently lessens system net load ramps.[8] This effect stems from two sources:

1. By substituting CSP with TES for "must-take" solar energy (such as PV or CSP without TES) on an equivalent energy (MWh) basis, the aggregate profile of solar production is "flattened" somewhat by shifting some solar production from the sunlight hours to other hours of the day, illustrated below in Figure 1 and in CSPA and NREL reports.[9,10] This flattening effect inherently reduces the net load ramps caused by the aggregate solar portfolio.
2. Dispatchable energy from a CSP with TES plant provides the Flexible Capacity capabilities needed for the remaining net load ramps.[11]

More detailed illustrations of both of these impacts are shown in Appendix A of this document.

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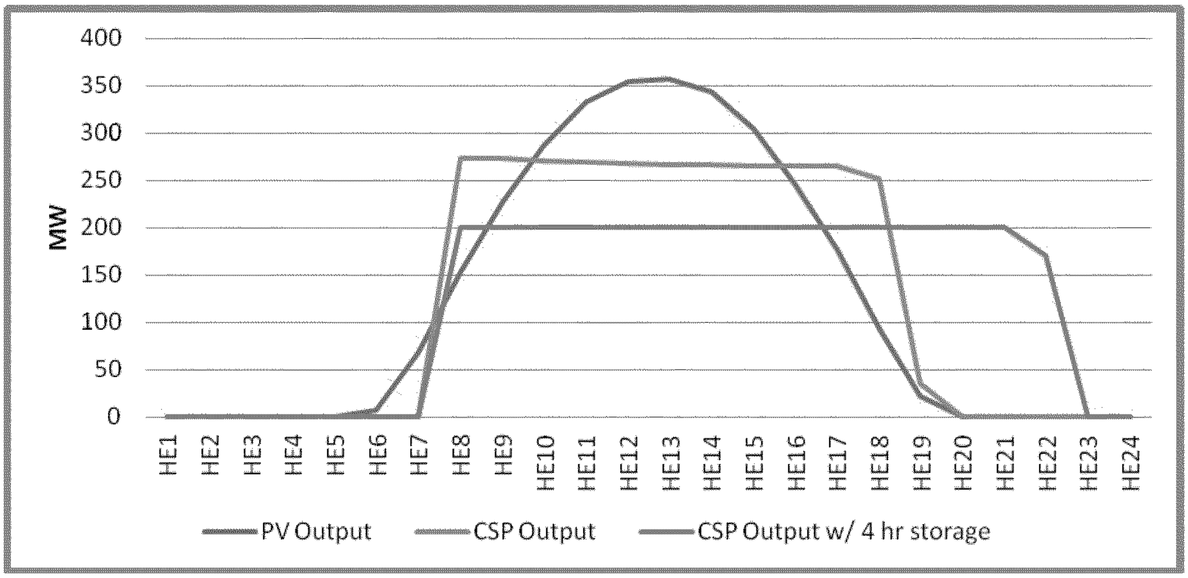
[8] Denholm, P. and M. Mehos, "Enabling Greater Penetration of Solar Power via the Use of CSP with Thermal Energy Storage," National Renewable Energy Laboratory, Technical Report, NREL/TP-6A20-52978, November 2011. See http://www.nrel.gov/csp/pdfs/52978.pdf.

[9] CSP Alliance, The Economic and Reliability Benefits of CSP with Thermal Energy Storage: Recent Studies and Research Needs, December 2012. See http://www.cspa.org/.

[10] Paul Denholm, Yih-Huei Wan, Marissa Hummon, and Mark Mehos, "An Analysis of Concentrating Solar Power with Thermal Energy Storage in a California 33% Renewable Scenario," Technical Report, NREL/TP-6A20-58186, March 2013.

[11] In actual operations, the highest economic value uses of the stored solar energy may or may not correspond to dispatch within the net load ramps. A CSP with TES plant may obtain higher economic value on a particular day by providing ancillary services for a longer set of hours than by producing energy during the net load ramps. Hence, to examine the use of stored solar energy to participate or mitigate in net load ramps requires first simulating the dedication of that energy for that purpose alone. However, CSP with TES owners or schedulers may choose to co-optimize the provision of ancillary services and energy, including in net load ramp hours, but this should not prevent CSP with TES from participation in an FCRA program with must offer obligations based on economic dispatch, including consideration of opportunity costs.

Figure 1: Equivalent energy production profile of 2,970 MWh on a clear day for 200 MW CSP plant with 4 hours of storage, 275 MW CSP plant without storage, and 360 MW fixed-tilt PV plant [12]



The general attributes and specific examples of CSP with TES plant operating profiles demonstrate that these plants can (a) reduce the system need for other Flexible Capacity procurement by reducing variability, net load ramps and forecast errors of the solar portfolio, and (b) provide capabilities to meet the remaining operational needs associated with renewable energy portfolios. Once there is demonstrable regulatory value, and thus economic value, of these plants, developers and utilities can initiate work in earnest to optimize plant design to provide the greatest benefits.

VIII. The Assessment and Allocation of Flexible Capacity Resource Adequacy Requirements Should Reflect Avoidance or Contributions to System Net Load Ramps by Generation Sources

At a minimum, the annual FCRA requirement across the CAISO balancing authority should reflect the mitigating effect on FCRA needs of resources such as CSP with TES. This will incentivize procuring utilities to consider procuring units that provide benefits of avoided costs and participation in

[12] The 4 hours of storage plant configuration and its energy production profile are illustrative and are not reflective of any design or dispatch optimization decisions.

the FCRA program. This reinforcing cycle of procured generation capabilities reducing the quantity and cost of FCRA should be encouraged, and is not unique to CSP with TES. It would signal to both new generation and participating loads that utilities will value behaviors that mitigate net load ramps.

To fully motivate these behaviors by utilities and resource providers, the FCRA requirements for an individual utility should reflect the procurement and load management decisions of the utility. This would manifest in the form of an allocation of FCRA requirements based on a Load Serving Entity's ("LSE") contribution to system-wide maximum net load ramps. CSPA understands that there are significant challenges in this sort of allocation methodology, compared to the Joint Parties' and Energy Division's proposed allocation based on each LSE's share of monthly system peak; however, it would follow cost-causation principles and provide appropriate economic incentives.[13] CSPA recommends that the Commission coordinate with CAISO to develop a methodology to allocate FCRA requirements which better reflects an LSE's contribution to net load ramps and the Flexible Capacity need. This approach more directly signals to LSEs to procure resource portfolios that produce lower total system costs. An alternate methodology need not be implemented for the initial years of the FCRA program, but utilities should be on notice from the outset of the program of an allocation methodology change in a future year.

IX. Flexible Capacity Eligibility and Counting Requirements for Concentrating Solar Power with Thermal Energy Storage Should be Finalized and Effective for the 2015 Resource Adequacy Year

Use limited resources, including renewable generators co-located with storage facilities, such as CSP with TES, should be eligible to participate in the FCRA program for the 2015 RA year, but no later than the 2016 RA year. In order to be eligible, the process to develop eligibility rules and counting methodologies for unconventional flexible resources should begin with the issuance of a Commission decision to include these resources in the FCRA program by a year certain. Such a policy statement is the signal necessary for developer investment and utility support for flexible generation technologies.

[13] "Resource Adequacy and Flexible Capacity Procurement Joint Parties' Proposal," at p. 9 (Oct. 29, 2012).

Inclusion in the 2015 FCRA program provides incentives for storage technologies to be deployed concurrent with the increasing net load ramps identified by the CAISO. It may also result in developers and utilities amending existing contracts to add storage, where mutually beneficial.[14] Furthermore, the 2016 RA year coincides with the likely commercial operation date of CSP with TES plants serving California as well as the current placed-in-service deadline for investment tax credit eligibility for solar technologies. Without action by the Commission in these timeframes, the opportunity for renewable resources with co-located storage facilities, like CSP with TES, to mitigate or assist with net load ramps and participate in FCRA procurement may be foregone for a period of time.

X. Conclusion

CSP with TES plants have the capability to jointly meet renewable energy and carbon policy goals as well as system reliability needs associated with a growing portfolio of variable energy resources. This inclusion of CSP with TES in an FCRA program, as currently outlined by the Energy Division and Joint Parties' Proposals, would require finalization of specific eligibility and counting treatment, including modifications to the existing RA program, before full participation in FCRA by the 2015 RA year. CSP with TES has already been the subject of a number of technical studies on its operational performance, which can form the basis for the development of appropriate rules.

CSPA members are interested in working with the Commission, CAISO and stakeholders to study and design the framework for CSP with TES' inclusion in an FCRA program, including the review and enhancement of independent third party studies on the effects of CSP with TES on capacity requirements, the assessment of the flexible operational capabilities and the quantification of Effective Flexible Capacity. CSPA appreciates the opportunity to comment on the Revised Energy Division Proposal and Flexible Capacity workshops.

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[14] The standard of review treatment for such contract amendments is one of the subjects in an ongoing proceeding before the Commission. *See* Second Assigned Commissioner's Ruling Issuing Procurement Reform Proposals and Establishing a Schedule for Comments on Proposals, CPUC Docket R.11-05-005. CSPA recommends that the Commission consider the integrated impact of Flexible Capacity and Standards of Review decisions.

Respectfully Submitted,

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Appendix A

Concentrating Solar Power with Thermal Energy Storage Mitigates System Ramps

As identified by the CAISO, a key measure of future operational needs is the rate and persistence of system ramps as wind and solar production increases. As noted above, the key new measure of ramping will be the "net load" ramp – the ramp that occurs from the interaction of load variability and the sum of variable wind and solar production. At times, this interaction will significantly exacerbate current system ramps, particularly in the late afternoon when the ramp down of solar production could coincide in key months with increasing load and in some hours, decreasing wind production. At other times, the significant net load ramps could take place in the mid-morning, when solar production increases ahead of the load increase, or even in the overnight hours on high wind days.

To illustrate how the net load ramps change over time with increasing solar penetration, Figure A-1 by Denhom and Mehos (2011) shows that as PV penetration increases incrementally from 0% - 10%, the frequency of high net load ramps, which they define as 4,000 MW/hour and above, greatly increases. Separately, BrightSource evaluated the net load data used in the California ISO 33% RPS simulations to identify in which hours the highest net load ramps take place. Not surprisingly, as shown in

Figure A-2, most of the highest upward net load ramps take place in the late afternoon and early evening, coincident with the solar ramp down and, in some seasons, the evening load pick-up.

Figure A-1: Net Load Ramp Duration Curve in California with PV Penetration from 0% – 10% -- Denholm and Mehos (2011)

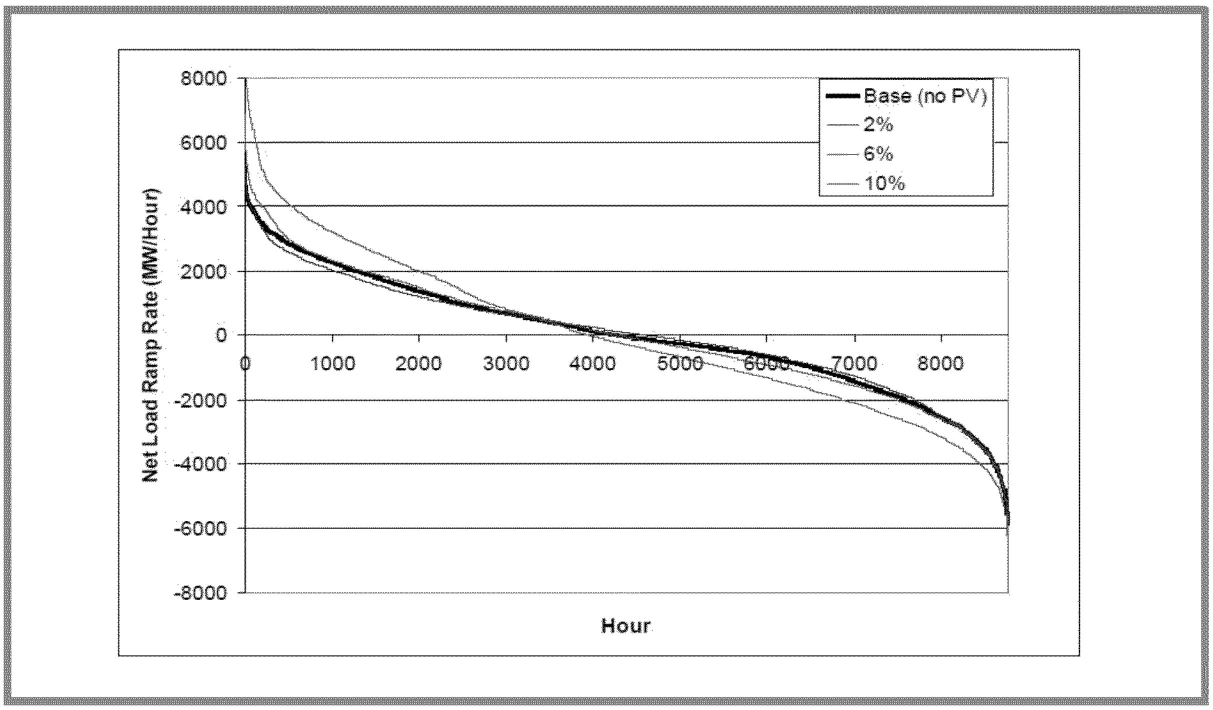

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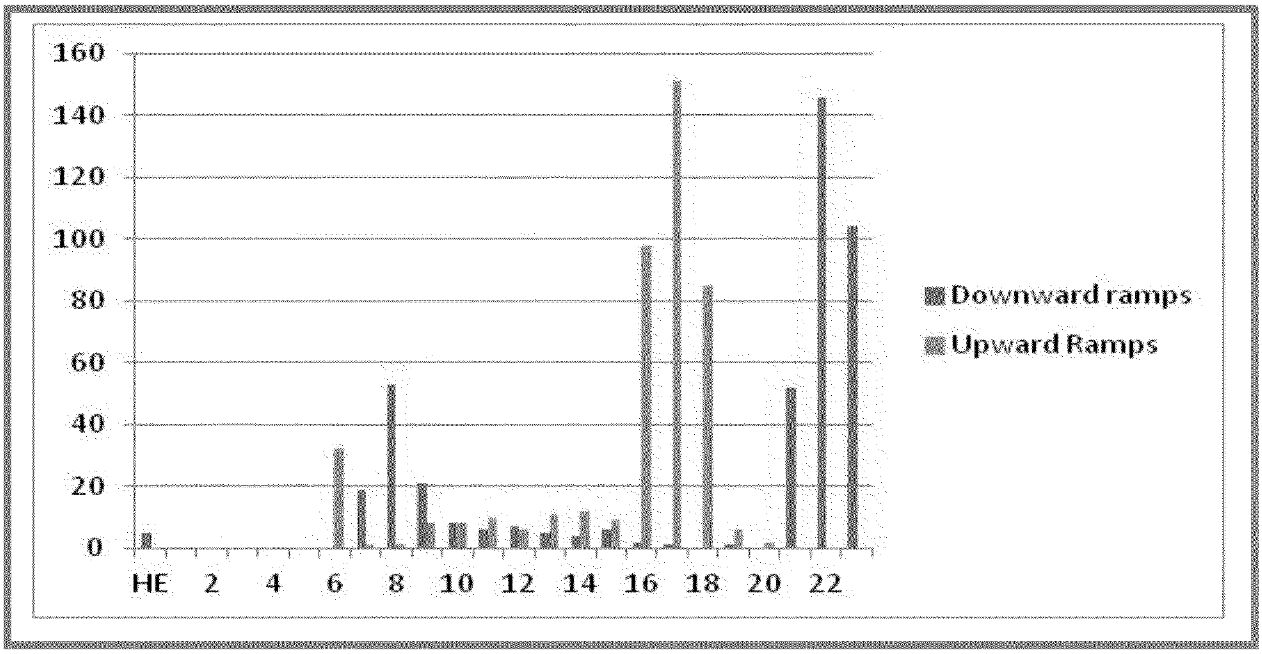
Figure A-2: Top 10% of upward and downward net load ramp hours, by hour of day, from California ISO 2020 Trajectory Case simulation



Source: CAISO (2011) 33% RPS simulation data, with assumptions about net loads by BrightSource.

To illustrate the potential for mitigation of system ramps, BrightSource created a simple optimization model using data from the 33% RPS system simulations conducted by the California ISO. Again, as a starting point, the data sets for the 33% RPS "Trajectory" scenario described above were examined. This scenario had just under 4,000 MW of CSP without storage,[15] allowing the case to be modified by adding thermal storage but without modifying the total CSP generation (MWh). To gain insight into the effect of progressive increases in thermal energy storage within the portfolio, three new CSP portfolios were created, in which first 2,500 MW of CSP was modified first to include 2 hours of thermal storage, the second added 4 hours of storage and the third, 6 hours of storage. The conversion was made so as to maintain equivalent annual energy output, so the capacity (MW) of the storage units was reduced. Table A-1 shows the final adjusted capacity for each case. As a further assumption, in the cases with storage, the storage facility was assumed to be fully charged on each day.

Table A-1: Modifications of the CPUC 33% RPS Trajectory Scenario to include CSP with thermal energy storage

Storage Duration	Change in CSP capacity without storage reduction	Change in CSP capacity with storage addition
2 hour	- 2500 MW	+ 2107 MW
4 hour	- 2500 MW	+ 1816 MW
6 hour	- 2500 MW	+ 1593 MW

[15] The Trajectory case does have one 150 MW plant with thermal st orage, but it was not dispatched in the CAISO simulations.

An actual dispatch model would determine which hours to dispatch the stored thermal energy to maximize market revenues (or avoided fuel costs). In this model, the objective is to illustrate the use of thermal energy storage specifically to affect system ramps, so the available stored thermal energy was dispatched to reduce net load hourly variance.[16] In addition, as shown in the figures below, by substituting CSP with thermal energy storage for CSP without storage but keeping the total energy the same, the solar profile is "flattened" and solar energy is pushed to low or non-sunlight hours, which further reduces the net load ramps.

To identify interesting days, the public California ISO data sets issued for LTPP were searched for days with particularly high net load ramps and other variability during the operating day. The results for three such days are discussed below. Each figure accompanying the example day shows the wind profile for the day (which remains fixed in all cases), the base solar (CSP plus PV) production profile (before adjustment) and the three cases shown above in the Table, as well as the corresponding base hourly load and "net load", allowing with the net loads corresponding to each CSP with thermal storage case.

The examples that follow demonstrate the capabilities of thermal energy storage for individual days, but detailed simulation is needed for more systematic analysis.

[16] That is, the objective function for dispatch of storage was to $\text{minimize} \sum_{h=1}^{24} (l_h - l_{h-1})^2$ where l is the hourly net load and h is the hour (time interval).

Example 1 – Reducing the Late Afternoon Net Load Ramp

The first example shown in Figure A-3 and A-4 was created using the data for an autumn day with fairly stable wind production and high solar production as well as a second peak load after dark. On this day, an extreme "net load" ramp up occurs in Hours 15-18 because of the normal diurnal solar ramp down as well as a simultaneous ramp down in wind production. As can be seen from the generation curves in the lower part of the upper graph, production from thermal energy storage allows solar output to extend into the evening, mitigating the ramp. The lower graph shows a close-up of the gray area of the upper graph, the net load under various scenarios of solar with storage. As can be seen, the steepest ramp occurs in the non-storage case, with the 4- and 6-hour storage cases having similar overall affects on the ramps.

Figure A-3: Example 1(a) - Impact of Thermal Energy Storage on High Late Afternoon Net Load Ramp

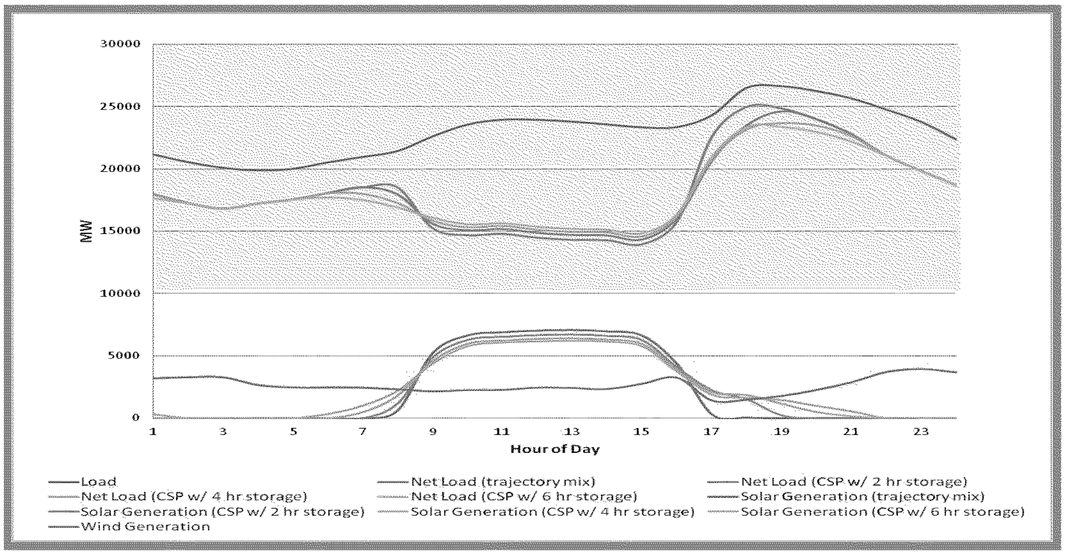
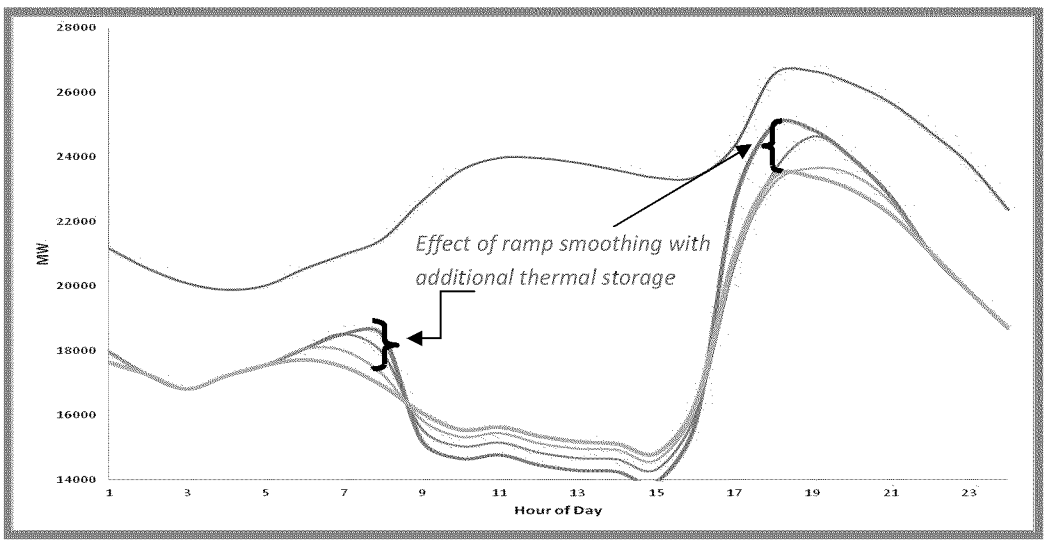


Figure A-4: Example 1(b) - Impact of Thermal Energy Storage on High Late Afternoon Net Load Ramp – ***additional detail on net load ramps***



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Example 2 – Intermittently Cloudy Day, Large Variation in Solar Generation
In the next example, shown in Figures A-5 and A-6, the operational requirements caused by solar output across the day are quite different. Because this is a mid-summer day in which the load curve correlates well with solar production, the morning and afternoon net load ramps are not significantly different from the load ramps. Instead, cloudy weather causes solar production to vary significantly during the day and thus requires reasonably large back-up from other resources. In this day, which uses the data from a mid-summer day, the thermal energy storage has been dispatched primarily to address the large ramp in the afternoon, in Hours 17-20. The figures show the smoothing effect by which solar storage is dispatched quite effectively to reduce system ramp rates, and 4-6 hours of storage is practically able to eliminate the solar ramps. However, there is some small smoothing effect even in morning and midday. Though the midday variation remains, the solution was most improved by reducing the afternoon changes.

Figure A-5: Example 2(a) - Impact of Thermal Energy Storage on High Midday Variability

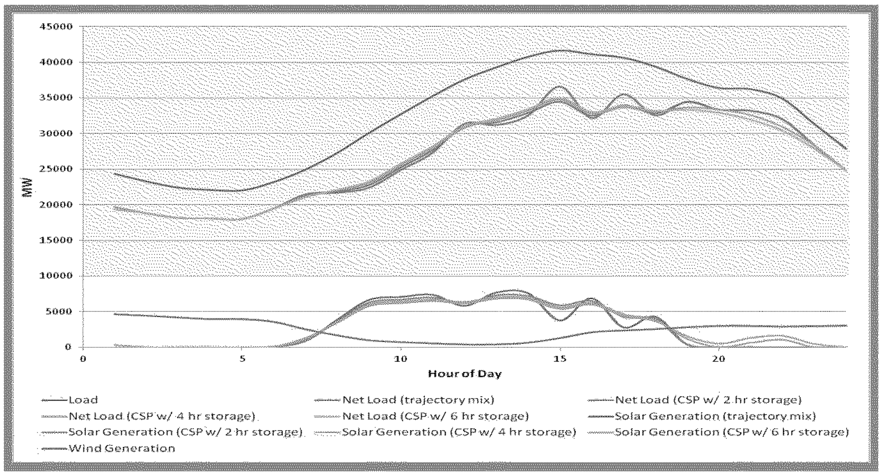
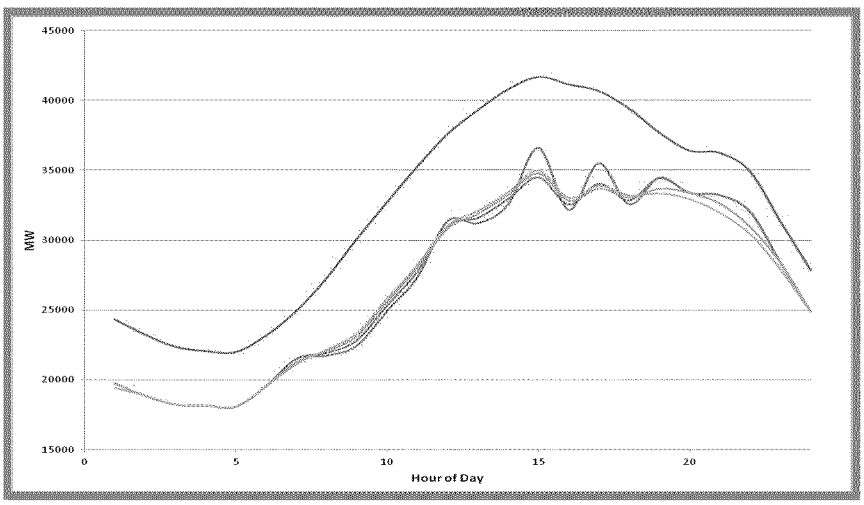


Figure A-6: Example 2(b) - Impact of Thermal Energy Storage on High Midday Variability
additional detail on net load ramps



SB_GT&S_0172397

Example 3 – Rapid Changes in Net Load Ramp Direction

System operators are concerned about predictable but rapid ramps in one direction, but they are even more concerned about rapid, significant ramps that change directions in a short time-interval. This effect was illustrated to some degree in Example 2, but Figures A-7 and A-8 show a more extreme example. On this spring day in California, light load is combined with relatively stable wind output but more variable solar output. Most notably, solar output drops off sharply in the mid-morning, around Hour 9, before recovering in the hour after. The coincidence of the solar ramp down with the morning load ramp up exacerbates the "net load" ramp. This creates a "V" shaped system ramp that first requires other generators to be ramped up rapidly and then immediately ramped down rapidly. Uncertainty about the timing and distribution of the cloud cover that caused this situation would lead to even additional generation being placed on reserve. As the figure shows, energy from thermal storage can be dispatched very effectively against such variability. The net load variation under the storage scenarios is greatly diminished. Because the event is of relatively short duration, even the 2 hour storage system is able to significantly improve the ramp. The additional storage from the 4- and 6-hour systems is mostly dispatched in the later hours of the day – Hours 18-22 – to reduce the net load ramp in those hours.

Figure A-7: Example 3(a) - Impact of thermal energy storage on rapid changes in net load ramp direction

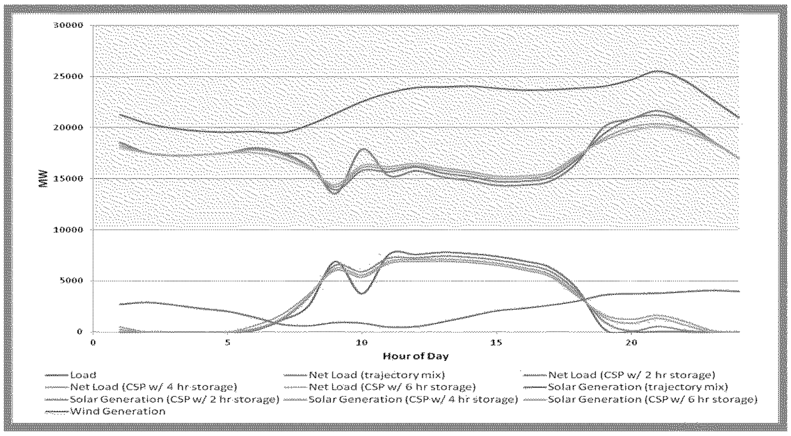
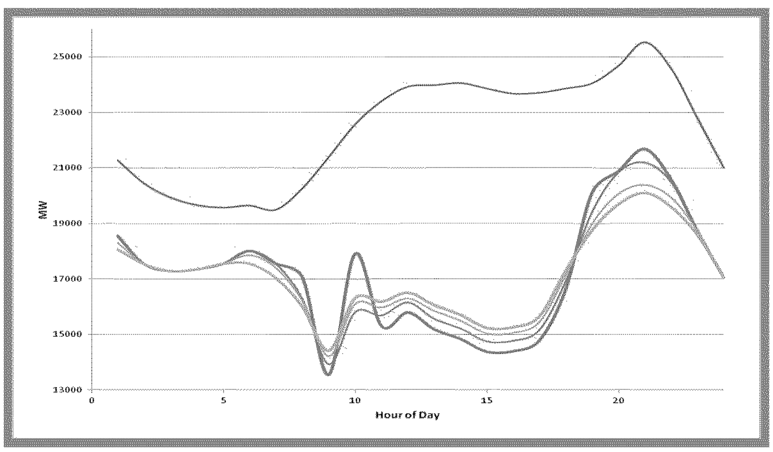


Figure A-8: Example 3(b) - Impact of thermal energy storage on rapid changes in in net load ramp direction – ***additional detail on net load ramps***



Appendix B

Modeling the performance of CSP with thermal energy storage plants is a complex task and a wide variety of tools are used to enable it. Preliminary analyses are often performed using simple thermodynamic models or publicly available tools such as NREL's System Advisor Model (SAM), which was used in Madaeni, et al. (2012) and Denholm et al., (2013).[17,18,19] SAM uses detailed models of the physical characteristics of CSP power plants and their sub-components along with detailed weather data in order to produce output profiles for the plant. The models in SAM have been reviewed publicly and many have been econometrically fit to the performance of real existing CSP plants.

At more advanced stages of plant design, engineers will typically use a detailed engineering model that reflects their specific CSP design. Depending on the model, it may be able to predict not only energy output, but also dynamic plant variables such as start-up times, ramp rates, and other state-dependent characteristics.

The weather input to such models is of critical importance. The production by CSP plants is sensitive not only to direct normal irradiance but also ambient temperature, wind speed, humidity, and a host of other weather phenomena. NREL and NOAA provide "typical meteorological year" or TMY data for many cities around the US and world.[20] This data does not represent any particular year's observations but is instead synthesized from many years' observations to represent a "typical" year. Such data is a good starting point, but for robust economic analysis of a plant, highly local data – ideally obtained over several years from a weather station on the site of interest – is desired. Such data is generally not available and by definition requires years to collect, so engineers and project developers resort to other methods, such as extrapolating from nearby weather stations, using satellite data, or some combination thereof.

As such, predicting the output capability of a CSP plant with thermal energy storage is a more complex task than doing so for a variable solar plant (i.e., without storage), or a fully dispatchable plant. However, if the storage capacity is sufficient, the resulting capability can be much closer to that of the dispatchable plant, than a conventional solar plant.

[17] The SAM model is available at https://sam.nrel.gov/.
[18] Madaeni, S.H., R. Sioshansi, and P. Denholm, "How Thermal Energy Storage Enhances the Economic Viability of Concentrating Solar Power," *Proceedings of the IEEE*, 2011.
[19] Paul Denholm, Yih-Huei Wan, Marissa Hummon, and Mark Mehos, "An Analysis of Concentrating Solar Power with Thermal Energy Storage in a California 33% Renewable Scenario," Technical Report, NREL/TP-6A20-58186, March 2013
[20] See http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/.

Appendix C

Referenced and Relevant Concentrating Solar Power Reports

CSP Alliance, The Economic and Reliability Benefits of CSP with Thermal Energy Storage: Recent Studies and Research Needs, December 2012. See http://www.cspa.org/.

Paul Denholm, Yih-Huei Wan, Marissa Hummon, and Mark Mehos, "An Analysis of Concentrating Solar Power with Thermal Energy Storage in a California 33% Renewable Scenario," Technical Report, NREL/TP-6A20-58186, March 2013

Denholm, P. and M. Mehos, "Enabling Greater Penetration of Solar Power via the Use of CSP with Thermal Energy Storage," National Renewable Energy Laboratory, Technical Report, NREL/TP-6A20-52978, November 2011. See http://www.nrel.gov/csp/pdfs/52978.pdf.

Denholm, P., S. H. Madaeni and R. Sioshansi, "Capacity Value of Concentrating Solar Power Plants," National Renewable Energy Laboratory, Technical Report, NREL/TP-6A20-51253, June 2011. See http://www.nrel.gov/docs/fy11osti/51253.pdf.

Madaeni, S.H., R. Sioshansi, and P. Denholm, "How Thermal Energy Storage Enhances the Economic Viability of Concentrating Solar Power," *Proceedings of the IEEE*, 2011.

Mills, A., and R. Wiser, "Changes in the Economic Value of Variable Generation at High Penetration Levels: Pilot Case Study of California", June 2012b, Lawrence Berkeley National Laboratory, LBNL-5445E. See http://eetd.lbl.gov/ea/emp/reports/lbnl-5445e.pdf.