CSP Thermal Energy Storage Value Workshop Summary

May 29, 2012

Overall Summary

Attendance (attached) reflected balance between state agencies, industry and modeling teams, but limited utility participation. The day's agenda (also attached) highlighted NREL's study update, which included sample results for some benefit categories. NREL identified a need for a document describing operating performance characteristics of concentrating solar power (CSP) plants. NREL also noted that its CSP modeling effort leverages parallel work on Phase II of the Western Wind and Solar Integration Study, which should perhaps be on everyone's radar.

Four other storage/grid integration studies were also discussed at the workshop. The suite of five on-going studies provides a more complete set of answers than any single study. However, none of the studies is yet addressing the question of how and whether fleets of storage coupled CSP plants would open a wider window for higher and more operationally manageable penetration of the likely overall mix of wind and solar resources contributing to California's future electricity supply. A key issue is the ability of existing models to quantify the value of flexibility made possible by dispatchable CSP, given that current CSP plants do not deliver such flexibility, and current California market structures do not value it. Currently there is limited impetus to deploy thermal energy storage (TES) as part of CSP plants and therefore limited opportunity to validate related value streams.

The Project Advisory Committee's (PAC) response to the NREL study update and overviews of the other studies raised a number of questions, including the general question of alternative ways of providing the flexibility dispatchable CSP affords. It appears NREL's integration study efforts will continue through 2012 and beyond, raising the question of what sensitivities should be addressed following completion of the current work on CSP/TES baseline benefits.

The early afternoon planning session of the workshop highlighted the differences between incremental plant benefits at low penetration and CSP fleet benefits at high penetration. The following operational value session of the workshop identified a large number of models and assumption validation issues, suggesting the need for continued dialog among modelers and between modelers and plant owners and system operators. Workshop planners had tentatively decided to expand the PAC's purview to include related studies as well as the primary NREL study and to broaden industry representation on the PAC. This decision was generally supported by attendees.

Workshop Goal: The goal of the one day workshop was to increase the communication between analysts modeling California's electric grid and the PAC. In

the absence of coordination, the analysts could come to such varying conclusions that none of their results would be seen as credible by stakeholders and policy makers. It would also be less likely that the analysts' results would answer all of the most urgent and important questions.

The workshop brought five organizations that are modeling the California electric grid (NREL, KEMA, CAISO, EPRI, and LBNL) together with PAC members representing the CPUC, CAISO, California electric utilities, the California CSP industry and several other stakeholders. The agenda was designed to provide a forum for discussion.

Workshop Logistics: The workshop was held on April 23, 2012 in Sacramento at the Sacramento Municipal Utility District's Service Center. Approximately 25 people attended the workshop in person. A webinar was set up so people who could not travel could listen to the discussion and see the presentations. Several people took advantage of the webinar.

Study Overviews & Discussion

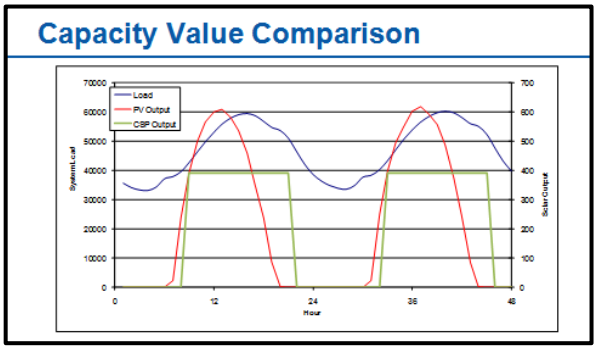
Paul Denholm, NREL: The goal of NREL's study is to quantify the benefits of thermal storage as a function of variable renewable resource penetration in the California electric system. The study has progressed slower than originally planned due to the use of highly detailed grid models having high temporal resolution and the size and complexity of the California electric system. Another impediment has been the loss of staff that had been assisting the modeling effort. The PLEXOS model requires about 80 hours of computer time for a yearly simulation of each planning scenario.

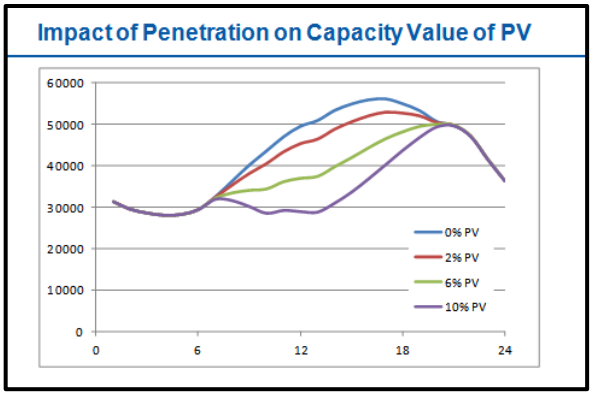
In order to manage the computational complexity, Paul's team is piloting the model on the much less complicated Colorado/Wyoming grid (assuming CSP in the San Luis Valley) to validate model set-up. Once NREL's results look reasonable, Paul's team will apply the model to California and the surrounding region. Paul expects to have a draft report on his Colorado results in June. The more comprehensive study focused on California is targeted to be complete in August/September.

The NREL workshop presentation focused mainly on study methodology. Paul did not present any results from modeling of the Colorado grid. He showed how the PLEXOS model dispatches power from CSP storage (in the summer it dispatched power to match an early evening peak and in the winter it dispatched power to match morning and evening peaks). This is important because previous studies have been unable to model optimal use of CSP storage (e.g. Western Wind and Solar Integration Study and the CAISO 33% study).

Paul also showed a simulation where CSP with storage resulted in the grid using much less power from combustion turbines, enhancing its energy value. Another chart, however, showed that if natural gas wholesale prices were to remain at the

recent ten year low point near $2/MMBTU (about one third the level five years ago), the energy value of storage coupled CSP would be very low.[1]





Paul showed two charts (right) that showed a typical summer day demand curve for a southwestern utility and the effect of various levels of PV penetration on net demand served by non-PV system resources over a twenty-four hour day. The top chart helps understand the effect of capacity factor on maximum capacity value, i.e. adding TES allows for an increased power block capacity factor, but lowers the capacity value per unit of solar field and per unit of energy produced. The bottom chart shows that peak summer demand shifts to evening as PV penetration increases and suggests that the mid-day effective capacity of PV on the day in question decreases as PV penetration on the grid reaches 10% of annual electricity delivered

A benefit of the NREL analysis effort is the opportunity the modeling team has to coordinate with NREL analysts working on the Western Wind and Solar Integration Study, Phase 2.[2]

Andrew Mills, LBNL: Andrew gave a summary of an LBNL study that is about to be published ("Changes in the Economic Value of Variable Generation with Increasing Penetration Levels: A Pilot Study of California"**)**. The objective of the study was to evaluate the economic benefits of wind, single-axis tracking PV, and CSP with and without six hours of storage. The study focused on marginal economic value instead of average value (indicates value of next increment of generation not the average) and made simplified dispatch decisions.

Andrew had a series of charts that showed the marginal economic value of energy as the penetration level increased. For CSP with storage (lower right), the energy

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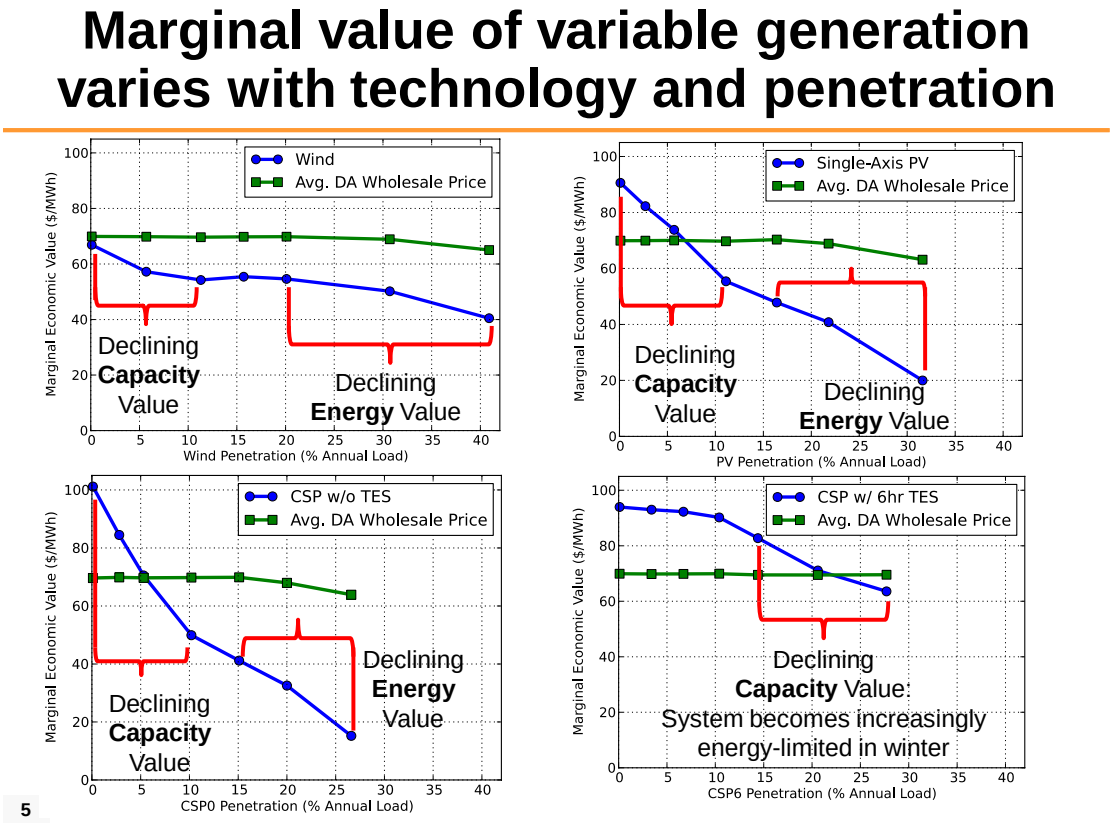
[1] Credible natural gas price forecasts do not support an assumption that such low prices are sustainable. The long term average price will continue a gradual upward trend. Cf. EIA and other forecasts that account for expansion of US supply to include shale gas basins.

[2] This is a DOE sponsored study looking at high wind and solar penetration of the grid. (NOTE: The four Phase 2 study scenarios include *high solar* which has 25% solar and 8% wind, *high wind* which has 25% wind and 8% solar, *intermediate* which has 16.5% solar and 16.5% wind, and *reference* which has 8% wind and 3% solar. In each case PV is 60% of solar and CSP with 6 hrs storage is 40%)

component of economic value remains fairly constant, but the capacity component starts to decline at about 10% penetration due to the electric system becoming energy limited in winter months (see charts below).

For single axis PV, consistent with NREL's example result, the capacity component of economic value decreases sharply up to about 10% penetration and the decline at higher penetration is due to decline in the energy component of economic value as penetration increases.



Andrew's conclusions:

- Solar has high economic value at low penetration levels
- There is little apparent economic value to thermal storage for CSP plants at low penetration levels
- The economic value of PV and CSP without thermal storage drop considerably with increasing penetration levels
- At medium to high penetration CSP with thermal storage is considerably more valuable relative to PV and CSP without thermal storage[3]
- The value of wind is largely driven by energy value and is lower than solar at low penetration

[3] According to PAC member John Balance, the first four bullets confirm conclusions drawn from similar analysis conducted in the 1970s by Southern California Edison.

- At high penetration, the value of wind can exceed the value of PV and CSP without thermal storage

These results are qualitatively consistent with NREL's example results. It is likely that more detailed models will produce more accurate quantitative results at low penetration levels. However, high penetration levels where TES has the greatest planning and operational benefits are the scenarios having greatest interest in determining the best long term mix of resources in the California electric system.

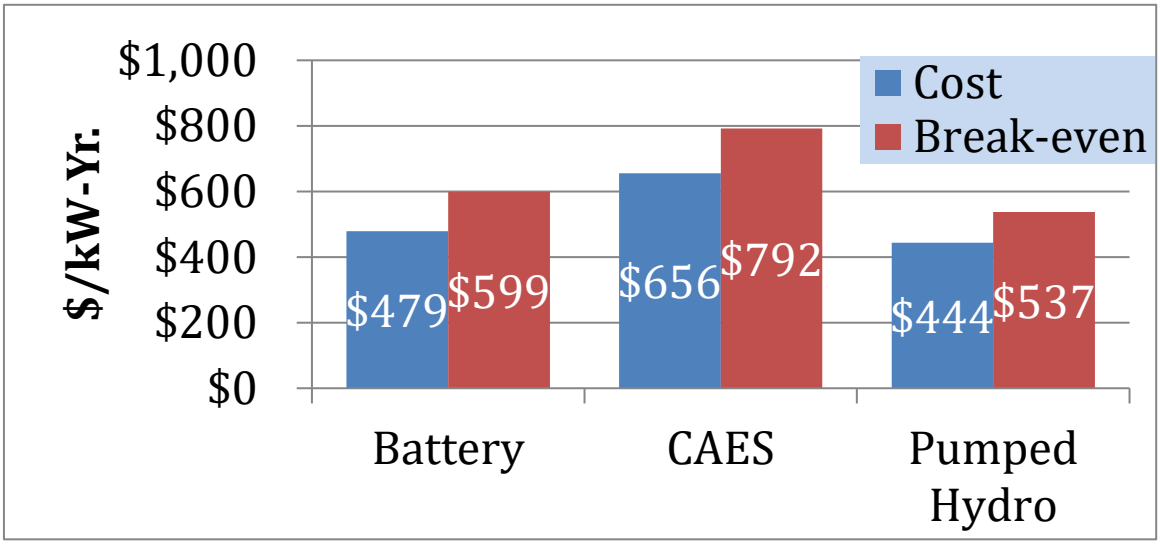
Shucheng Liu, CAISO: CAISO is expanding its PLEXOS modeling in support of the CPUC long term procurement planning process. It is developing a stochastic dispatch model and is looking at higher load cases. More attention will be given to dynamic scheduling, the need for flexible resources and implications of the 3,500 MW storage mandate. The study will be completed in 2013. One feature of the study is to look at increased sharing of energy and ancillary services throughout the region. E3 is working on the study for CAISO. There was a workshop in San Francisco on May 3 where methodology and preliminary results were to be presented.[4]

John Warmerdam, KEMA: KEMA is 6 months into a two year study. The study's objective is to determine the benefits to ratepayers of adding utility scale CSP with storage. Unlike NREL's study, KEMA's runs are very quick. They are using KERMIT to model the dynamic impact of "worst days", not doing annual simulations. This analysis could complement NREL's by identifying charging and dispatch strategies that maximize storage coupled CSP's value to the grid, thus helping NREL to determine which scenarios and sensitivities should be addressed. KEMA is using a "generic" CSP technology and 2-tank storage as their base configuration. They will look at sensible and latent heat storage options. Their grid economics task is complete and their plant level thermodynamic modeling is underway. They are expecting the study to be completed in mid 2013.

Aiden Tuohy, EPRI: Aiden's presentation was entitled "Storage and high variable generation: Introduction to EPRI studies". EPRI has done several storage studies for independent system operators looking at wind integration issues. A study is underway for California addressing hydro and pumped hydro services managed by CAISO. The focus of EPRI's studies has been/is in determining the value, benefits and value proposition of energy storage under specific applications. EPRI is modeling the western grid doing annual simulations. In the context of wind deployment, they have found ancillary services are very important, accounting for up to 50% of the economic value of storage. They conclude that flexibility is key to managing variability. They also cited a CEC study "*Research of Wind Generation, Solar Generation, and Storage Impact in the California Grid"* that concluded **"**energy storage is 2 to 3 times more effective in providing regulation, MW for MW, compared to combustion turbines."

[4] No reference to the workshop could be found based on an internet search.

Some of the benefits of storage supporting wind deployment include increased capacity factors of thermal units, less turndown or minimum part load operation units, less starts/stops, reduced cycling and maintenance costs, and congestion relief. Storage, however, has to be cost effective. EPRI has estimated the cost and break-even price points for several storage modes (see below). EPRI observes that CSP plants with storage will start to look like conventional power plants as the number of hours of storage increase.



Response to the Studies/Planning Panel Session

This panel session was meant to discuss what should be included in the studies to enable policy makers to better understand how best to optimize the mix of resources on feeding into the California grid as the penetration of variable renewable energy resources (wind, solar) increases.

- Multiple studies add credibility, but follow-up is needed. Are they answering the same question or different questions? How will differing results be explained and resolved?
- The studies should clarify whether their primary metric is relative value to the ratepayer, developer, or operator.
- The studies should determine the importance of grid flexibility in general and the role of storage in enhancing it. They should recognize regional balancing/exchange as a way of adding flexibility to the grid. Thermal storage isn't the only option. Pumped hydro and compressed air storage could also provide grid flexibility, and comparisons must be conducted in an overall system context. Will the studies as currently plan provide an adequate answer to the basic question of whether CSP/TES has a key role in opening the window for higher penetration of variable renewable generation?

- The studies should address a scenario of renewable energy penetration that goes beyond the current 33% California renewable portfolio standard. It was mentioned that Karen Douglas, Commissioner at the CEC, stated at the previous week's CSP conference in San Diego that the 33% RPS was a base and that California will eventually go above it.
- All agreed that storage will become more important as the penetration of wind, PV, and CSP without storage is increased. In that context, the question was asked why any CSP plant would be built without storage. An answer offered was that utilities (particularly the California utilities) don't seem interested in storage at this time.[5] It was mentioned that Solana has storage because it stays hot in Arizona after sundown, and APS required a solar project that had storage. Similarly, NV Energy wanted storage in a solar project because the power was going to Las Vegas, which uses a lot of power during the evening. The best mix of wind, PV, and CSP with storage is likely to differ from balancing area to balancing area. What will it be overall for California at high levels of renewable energy penetration?
- There was near consensus that storage was very important. However, it must be proven that storage is cost-effective, and thermal storage coupled CSP has to compete with other storage options (e.g. batteries, CAES, pumped hydro) that may indirectly couple to other variable renewable sources. Under what conditions will CSP/TES be cost effective and under what scenario will this occur? How much storage will be optimal at different penetration levels? Optimal storage capacity from a value perspective may be 6 hours, though ramping requirements shift with penetration, and their impact is not yet fully understood. Optimal storage capacity from a cost/benefit perspective is still an open question. It depends on both cost and value based pricing. This year's RPS review will look at ancillary services.
- Combustion turbines (CT) are currently the primary alternative to TES. CTs provide cheap capacity.
- The studies are not looking broadly enough at plant configuration options. The best relative sizing of collector field, storage and thermal plant may change with penetration and pricing to minimize delivered electricity cost.
- Demand patterns shift over time, e.g. for some utilities the shift has been from winter to summer peaking. Electric systems are designed to accommodate this. What will be the demand profiles of the future when fundamentally new demand patterns emerge, e.g. related to the uptake of plug in vehicles?
- The one dissenting comment on the value of detailed analysis to determine the economic value of CSP/TES reflected a philosophy of "there hasn't been a problem (with variable renewable grid impacts) yet and may never be. Let's build more wind and PV and see what happens." The accompanying question was whether storage could be retrofitted on existing CSP plants if it turns out there is a problem with a lot of variable energy sources on the grid. Could there be a plan for building CSP without storage but with the ability to add

[5] This is consistent with study results suggesting a CSP's plant's storage has limited value at current low levels of variable renewable penetration.

storage at a later date? What are the incremental costs of storage and when will the incremental value off-set incremental cost? The preliminary answer of course was that "it depends"….primarily on the specific collector technology, heat transfer loop operating temperatures, etc. Each basic CSP plant has its preferred storage solution, and the solution may or may not be ready when the economic need arises.

- A simple, understandable story describing CSP and specifically how it enables higher overall renewable penetration is needed for policy makers (e.g. a better description of the solar multiplier effect is needed…..why does the LCOE[6] go down as projects get bigger…what is the impact of storage on LCOE).
- LBNL's study showed that the capacity value of CSP drops off because it relies on a lesser resource in the winter. The capacity value would remain high, however, if the CSP plants could augment solar with natural gas, similar to the way the SEGS[7] plants operate. However, existing regulations do not allow solar plants to augment solar with gas. There was discussion on changing the regulation to enable gas augmentation, but with no resolution.
- NREL's model uses troughs as the representative CSP technology even though towers might provide a more favorable result. Mark Mehos said troughs were assumed because they could be modeled more accurately based on actual deployment experience, and it was deemed important to get answers to the value of storage as soon as possible. The SAM model for towers is being improved and NREL will eventually use towers in its study.

Operational Panel Session

This panel session was meant to give analysts the chance to discuss their approach to modeling different processes and cost avoidance strategies related to the dispatch of storage.

- Paul Denholm offered to send a list of the basic parameters he is using to the other analysts. A range of parameters, sensitivities, validation standards for data and assumptions should be agreed on by all.
- Need to get all ancillary services (A/S) values and income correct, e.g. CAISO spinning reserve requirements have changed. CAISO pays for standby A/S. No bid for A/S, only opportunity cost. Ditto for load following. No resource specific bid. Bid price capped.
- CAISO sometimes does minute by minute load following. KEMA is using hourly data. Plant operators in Spain sometimes dispatch power in 5 minute intervals.
- The following were all mentioned as important operational concerns: integration costs, reserve requirement differences, trade-off between exports and capacity credit, how to factor in state goals/policies regarding imports,

[6] Levelized cost of energy
[7] Solar Electric Generating Station, i.e. the plants deployed in the late 80s by LUZ in southern California

WECC wide model limitations, potential need to export energy at high RE penetration, and implications of export/curtailment for capacity value
- Paul thinks the studies covered by the workshop are complementary. The LBNL study looks like it is closest to NREL's in terms of purpose and assumptions.
- Discussion among the analysis leaders in attendance was thoughtful and lively.

Overall Assessment

Among the organizations that will ultimately use the results of the analyses, there was good representation from the CPUC and CAISO. Unfortunately, those invited from PG&E, SCE, and SDG&E did not attend. Thanks to John Ballance's facilitation, the afternoon planning panel session provided insights into the kind of information the analysts need to provide.

All of the invited organizations studying the impact of renewable energy on the grid showed up and contributed. Each provided an understandable summary of their plans and analytical methods. Thanks to Udi Helman's facilitation, the afternoon operational panel discussion among the analysts was very interactive, which suggests the workshop had value to the modeling efforts.

Next Steps

1. Complete a meeting summary. Send summary and copies of meeting presentations to meeting attendees.
2. In his new role as Executive Director of the CSP Alliance, Tex Wilkins will take over responsibility for supporting the PAC process. Gerry Braun will continue to serve on the PAC as its Chairman.
3. Write a short white paper summarizing CSP
4. Send white paper to the PAC for their edits/comments.
5. Establish a forum for the analysts to keep them in contact with one another to reconcile any differences in basic assumptions.
6. Set timetable for next PAC meeting, possibly in conjunction with the next NREL report.

Acknowledgements

This summary relied on notes taken by Gerry Braun, Ronnie Holland and Tex Wilkins. Tex provided editorial consolidation of his and Gerry's notes, and Gerry provided final review and editing. Gerry takes responsibility for any errors or omissions. The summary of course reflects the excellent contributions of workshop participants. Special thanks are due to the Sacramento Municipal Utilities District for hosting the workshop and arranging for meeting communications and refreshments and to the CSP Alliance for covering the cost of meeting refreshments.

CSP Thermal Storage/Grid Integration Workshop

April 23, 2012: 9:00 am - 4:45 pm

SMUD's Customer Service Center (Rubicon Room)
6301 S Street, Sacramento, CA. 95817
http://www.smud.org/en/about/Pages/maps-etc.aspx

AGENDA

Time	Topic	Presenters
8:30-9:00	Coffee, etc., Sign In and Set-up	Informal Meet and Greet
	Morning Session – PAC Review of NREL Study Progress (Starts promptly @ 9:00 with tea and coffee available but no formal breaks until lunch)	
9–9:15	Preliminaries	
	• Welcome	Mike DeAngelis, SMUD
	• PAC Purpose/Agenda Review *	Gerry Braun, PAC Chair
	• Sponsor Perspectives	Joe Stekli, USDOE Frank Wilkins, CSP Alliance
	• PAC mission and purpose	Mark Mehos, NREL
9:20-10:20	NREL Study Progress Report	Paul Denholm, NREL
10:20-11:00	Introductory Overviews of Related Studies	Ralph Masiello, KEMA Shucheng Liu, CAISO Aidan Tuohy, EPRI Andrew Mills, LBNL
11:00-12:00	PAC response to the 4 studies	Gerry Braun, Moderator
12:00-1:00	**Lunch Break** (Light lunch provided for pre-registered attendees)	
	Afternoon Session - CSP/TES Integration Workshop (Each panelist will speak to all listed issues plus others)	
1:00-2:00	CSP/TES Integration Planning Panel	John Ballance, Moderator
	• Plant Options	Mark Mehos, NREL
	• Storage Configuration Options	Hank Price, Abengoa Solar
	• Variable Renewable Penetration Sensitivities	Udi Helman, BrightSource
	• Storage Capacity Drivers	Bradley Allen, APS Karin Corfee, Navigant
2:00-2:30	PAC Member Reflections on CSP/TES Integration Planning	

2:30-3:00	**Break**	
3:00-4:30	CSP/TES Operational Value Panel	Udi Helman, Moderator
	• Modeling energy dispatch	Paul Denholm, NREL
	• Ancillary service needs	Shucheng Liu, CAISO
	• Avoiding integration costs	Ralph Masiello, KEMA
	• Assessing capacity value	Aidan Tuohy, EPRI
4:30-4:45	Workshop Wrap-up	Frank Wilkins, CSP Alliance

*PAC – Project Advisory Committee

Storage Value Workshop

Apr 23, 2012

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