CPUC Energy Storage Use Case Analysis

[Bulk Storage]

[DRAFT - Concentrating Solar Power with Thermal Energy Storage]

Version 0.1

NOT FOR PUBLIC CIRCULATION – THIS USE CASE NEEDS FURTHER REVIEW FROM CSP COMPANIES

Contents

1. Overview Section

Wind and solar resources have characteristics of variability and sometimes high production forecast errors; moreover, most solar and wind technologies lack the capability to exert any control over the dispatch of the energy – whether in timing or amount – from the renewable facility.

Concentrating solar power (CSP) plants with thermal energy storage provide a technological solution to the forecast errors and variability of solar production by coupling a solar thermal plant with an on-site thermal energy storage system. As discussed below, there are several designs for such plants. Under all designs, the addition of thermal energy storage allows for an increase in plant capacity factor, some smoothing of plant production including during morning and evening ramps, and possibly, depending on the design, provision of dispatchable energy and ancillary services that can be used to address integration requirements of other, more variable wind and solar plants or general system needs.

There is a large and growing body of research literature discussing the economic value of CSP with thermal energy storage on different power systems, including California; several references are cited in this Use Case and listed in Section 5.3. Some of these studies model individual (simulated) plants in some detail (e.g., Madaeni et al., 2011), while others model entire power systems with larger aggregations of CSP with bulk storage (e.g., Denholm and Mehos, 2011; Mills and Wiser, 2012). With respect to operational and reliability attributes, CSP with thermal energy storage is not a full substitute for all other types of storage technologies – for example, it is not necessarily suited to provide quick response reserves (e.g., "fast" regulation) in a sustained fashion – but it has other benefits that most electrical storage systems do not, including the capability to provide bulk energy storage using a completely emissions-free energy source (the solar field). Over 2,000 MW of CSP plants are now operating internationally, with over 1,000 MW expected to come on-line in California, Arizona, and Nevada in 2013. With respect to CSP with thermal energy storage, pilot plants have operated in the United States, and more than 200 MW utility-scale plants of different designs (parabolic trough, power tower) are now operating commercially in Spain. The primary challenges in California at present are (1) large-scale technology demonstration of a utility or system operator with dispatch control over a CSP plant, and (2) quantification of benefits and demonstration of long-term cost-effectiveness.

2. Use Case Description

This Use Case describes the attributes of thermal energy storage associated with a utility-scale, 100-300 MW-energy CSP plant that connects to the grid primarily to deliver energy under a long-term power contract but then also offers some degree of dispatchability associated with the operation of its thermal energy storage system.

There are two ways that a thermal energy storage system is integrated into CSP plant operations. In a "direct" storage system, the storage medium is heated directly by sunlight inside the solar receiver. In an "indirect" storage system, the sun is used to heat a primary fluid (either water/steam or a mineral oil) and that heat from that fluid is transferred to the storage medium be means of a heat exchanger. In either case, the attributes of the integrated CSP plant with thermal energy storage can be described using its operational parameters: start-up time, min and max operating limits, ramp rates, Regulation capability and regulating ranges, thermal losses from storage, thermal storage capacity, capability to shift between production and storage, and so on. In all cases, a CSP plant is dependent on the availability of sufficient DNI (direct normal irradiance – sunlight, basically) to charge the storage medium, such that lower DNI conditions (i.e., a cloudy day) may substantially reduce the plant's availability for flexible operations. Of course, differences among plant designs result in relative advantages and disadvantages as well.

2.1 Objectives

CSP with thermal energy storage can be designed to achieve a number of market, operational and reliability objectives:

- Shift renewable energy to the highest value hours in the operating day across seasons
- Provide ancillary services, primarily regulation and spinning reserve
- Reduce curtailment during periods of over-generation
- Improve the Net Qualifying Capacity (NQC) of the plant
- Provide more flexibility to meet future NQC production requirements
- Reduce integration requirements, compared to solar plants without thermal energy storage
- Provide power quality associated with a synchronous generator, backed also by a flexible fuel source

2.2 Actors

In this Use Case, the storage facility is completely integrated with the operations of the CSP plant, and hence ownership of the CSP plant, whether utility or non-utility, would typically confer rights to operations of the thermal storage capabilities. However, other ownership and contractual structures could be possible, such that a non-utility owner of the plant could sell plant attributes separately to different parties on a forward basis or offer them into the wholesale markets.

Name	*Role description*
CSP Plant Owner/Developer	For this technology, the CSP plant owner/operator will also have full operational rights over the thermal energy storage system. Other arrangements are possible, but not currently commercially viable.
Storage Provider	
Utility	May procure all or some services offered by the CSP plant with thermal energy storage
Grid Operator	Could accommodate self-scheduling or market bids from the CSP plant

2.3 Regulatory Proceedings and Rules that Govern Procurement Policies and Markets for This Use

Agency	*Description*	*Applies to*
CPUC	Renewable Portfolio Standard Bidding	Utility/Third Party
CPUC	Long-term Procurement Proceeding	Utility
CPUC	Resource Adequacy	Utility

CPUC	Rule 21 Interconnection	Third-party Owner
FERC	Order No. 785 Pay for Performance	ISO/RTO, Third-party Owner
CAISO	Renewable Interconnection Study	Utility/Third Party
Other		

Unlike other types of storage, CSP with thermal energy storage has been procured to date under renewable energy procurement mechanisms, such as the Spanish Feed-In Tariff (FIT) or the California RPS, with all energy being sold as solar energy. More recently, in California, the attributes of the CSP energy storage system – e.g., provision of ancillary services – are being factored into the market valuation of the solar plant under the prevailing CPUC RPS "least-cost, best-fit" rules. As the LTPP and RA program evolve to define operational needs, it may provide further support for procurement of CSP with thermal energy storage, by aligning its attributes not just with RPS market valuation but also with identified system operational needs.

2.4 Location

The thermal energy storage component of a CSP plant is always co-located with the CSP plant and fully integrated into its operations. The plants currently under construction in California and southwestern states are in locations with the highest direct normal irradiance (DNI), and somewhat distant from major California load centers. It is possible that smaller scale plants could be constructed closer to load centers, but these areas typically have lower DNI. Moreover, typical CSP facilities, because of their footprint and visual impact, may not be feasible to site or permit near major urban areas. Because of the reduced insolation as well as foregone economies of scale, the levelized cost of energy may be higher. On the other hand, wholesale price divergence based on transmission congestion and losses may be reduced.

2.5 Operational Requirements

2.6 Applicable Storage Technologies

CSP with thermal energy storage refers to a class of technologies, which will not be reviewed extensively here. In general, a thermal energy storage system includes a collection method, a reservoir, and a storage medium. Depending on CSP plant configuration and design, the storage medium may also be the working fluid of the CSP cycle (e.g., oil or molten salt) or it can be a separate loop that communicates with the working fluid through a heat exchanger. This medium is heated (directly or indirectly) by sunlight and held in reserve until some later time, when it is used to generate steam to drive a turbine for electricity production. The choice of medium is very important, since the mechanical, bulk and thermal properties of the medium determine the physical and operational characteristics, and therefore the overall cycle efficiencies. The ideal medium is inexpensive, extremely stable through a large temperature range, environmentally benign, has a high specific heat (ability to store heat per unit of mass), has a high heat density (heat per unit of volume), and is easy to handle and pump. Additionally, it is convenient if the material does not experience a phase change over a large temperature range.

While research continues into thermal storage media compatible with CSP, molten salts (combinations of KNO_3, $NaNO_3$, and others) is the current commercially-viable heat storage medium, due to several decades of experience in different applications. The salts are typically a mixture of nitrate salts designed to be close to eutectic point (lowest melting point). The salts are stable up to extremely high temperatures and remain molten down to relatively low temperatures, and therefore can support relatively efficient steam cycles. A critical requirement of molten salt operation is that the temperature must be maintained to prevent solidification. This requires sufficient insulation on the piping and tanks, and potentially supplemental heating at night or during startup.

Both direct and indirect storage systems utilizing molten salt as a storage medium make use of heat exchangers for steam production to drive the steam turbine. (Indirect systems also utilize heat exchangers when extracting heat for storage from the medium used in the solar receiver.) The use of heat exchangers for steam generation from molten salt provides additional operational flexibility to the overall CSP system. Depending on system configuration, the amount of either heat being stored or of steam being generated can be adjusted to meet load conditions. Generally, those technologies operating at a higher peak temperature store more energy per unit of salt, and thus storage comes at a lower cost to them; operating temperature will depend on plant configuration (i.e., tower versus trough) and whether salt, steam or mineral oil is the working fluid. Depending on system configuration, indirect systems producing steam in the solar receiver loop have the added benefit of generating additional steam from storage for an additional boost during daylight operation hours. Direct storage systems can provide a similar "boost" by utilizing a larger steam turbine generator such that the system collects energy for more hours than it produces electricity.

Storage Type	*Storage capacity*	*Discharge Characteristics*
Molten salt	Limited by amount of solar collection and capacity of the turbine.	

2.7 Non-Storage Options for Addressing this Objective

To date, CSP with thermal energy storage has competed with other renewable technologies to provide RPS energy; until recently, the operational attributes of the thermal storage systems were considered incidental to the RPS energy transaction. With improved coordination of the RPS, LTPP, and RA programs, CSP with thermal energy storage will be able to be compared more comprehensively to other renewable technologies coupled with alternative integration solutions.

Although highly complex, the key analytical step is to rank all renewable technologies by their *net system cost* – that is, their benefits minus their costs – including energy, ancillary services, long-term RA value within a defined renewable technology portfolio, and integration costs (Mills and Wiser, 2012).

3. Cost/Benefit Analysis

3.1 Direct Benefits

End Use	*Primary/ Secondary*	*Benefits/Comments*
1. Frequency regulation	P	In all CSP designs, the availability of ancillary services will be a function of the DNI available to charge the thermal storage system and the amount of storage. Otherwise, the generator could in principle be certified to provide Regulation and Spinning Reserve.
2. Spin	P	
3. Ramp	P	
4. Black start		Black start capability of CSP has not been evaluated, but would be in part of a function of the availability of DNI, storage capacity, and operational strategy, to ensure a charge on the thermal energy storage system
5. Real-time energy balancing	P	Real-time energy balancing is operationally feasible but requires further assessment
6. Energy arbitrage	N/A	CSP plants with thermal energy storage are currently not designed to heat the tanks using electric power. Hence, while the plant may be dispatched optimally to utilize its available stock of stored thermal energy, it is not engaging in arbitrage (i.e., charging at a low price, discharging at a higher price).
7. Resource Adequacy	P	
8. VER[1] / voltage support,	P	
9. VER/ PV shifting, Voltage sag, rapid demand support	P	
10. Supply firming	P	
11. Peak shaving: load shift	P	CSP with thermal energy storage not only shaves afternoon peaks, but also can shift energy to shave evening peaks. It could address winter morning peaks as well, as applicable.
12. Transmission peak capacity support (deferral)		
13. Transmission operation (short duration performance, inertia, system reliability)	S	Dispatchable CSP with thermal energy storage will support transmission operations
14. Transmission congestion		Since CSP plants will typically be located in remote locations, they are unlikely to participate in congestion management on a regular basis unless California resource and transmission planning leads to sub-optimal use of the

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[1] VER = Variable Energy Resource

relief		grid.
15. Distribution peak capacity support (deferral)		
16. Distribution operation (volt/VAR support)	N/A	
17. Outage mitigation	N/A	Depending on outage and load characteristics and the nature of the CSP system, and on the ramping requirements involved, a fully dispatchable CSP plant could support islanded operations in the event of an outage
18. TOU energy mgt	N/A	
19. Power quality	P	
20. Back-up power	N/A	

3.2 Other Beneficial Attributes

Benefit Stream	*Y/N*	*Assumptions*
Flexibility (Dynamic Operations)	Y	
Reduced Fossil Fuel Use	Y	CSP with thermal energy storage provides further capability to be dispatched to minimize fossil fuel use. CSP is a renewable source of energy.
Reduced Emissions	Y	CSP with thermal energy storage provides further capability to be dispatched to minimize emissions over time, not only from energy generation but also from the provision of ancillary services by conventional generators.
Increased T&D Utilization	Y	For any transmission investment, the addition of thermal energy storage at a CSP plant will increase capacity factor and hence is likely to increase transmission utilization
Reduced T&D Investment Risk		
Power Factor Correction		
Optionality	Y	At least some CSP plant designs may provide options to add further storage capacity. CSP with storage may be able to alter its operational schedule (e.g., use stored energy in the morning instead of in the evening) if future market conditions warrant.
Other		
Other		

3.2 Analysis of Costs

[THIS SECTION WILL REVIEW PUBLICLY AVAILABLE COST ESTIMATES, BUT OBVIOUSLY NOT THE BID COSTS OF THE PARTICIPATING COMPANIES]

Cost Type	*Description*
Installation	
O&M	

3.3 Cost-effectiveness Considerations

The cost-effectiveness of CSP with thermal energy storage is typically calculated differently from other types of storage, because the CSP plant is being compared other renewable technologies, not to other storage solutions. Hence, the studies done to date on costs and benefits, or only on benefits, of CSP with thermal energy storage, typically calculate a baseline of a solar plant without thermal energy storage, whether CSP or PV, to determine the added value of thermal energy storage. Analysis has been done of the value in four primary areas:

- Energy (including shifted energy)
- Ancillary services
- Capacity
- Avoided integration costs
- Power quality

The literature on the U.S. markets typically shows that the opportunity to shift energy into peak hours that occur after sunset along with the additional sales of ancillary services, improve average value (usually calculated as $ per MWh of energy sales) by $5-10/MWh using historical market prices or utility production costs (Madaeni et al., 2011). As additional solar generation is added to the power system, the progressive displacement of gas-fired generation actually leads to lower energy value for incremental solar additions. However, CSP with thermal storage can continue to shift energy to the highest value hours. In simulations of the California power system conducted by Mills and Wiser (2012), the difference in marginal value of a parabolic trough plant with 6 hours of thermal storage when compared to solar plants without storage is $9/MWh by 10% solar energy penetration, $17/MWh by 15%, $20/MWh by 20% and $36/MWh by 30%.

CSP plants in California typically obtain NQC ratings of 75-83% of nameplate, and the additional of thermal energy storage increases that rating as a function of storage capacity, solar field, etc (e.g. Madaeni et al., 2011) up to levels comparable to conventional generation. More recently, attention has shifted to the long-term capacity value of incremental solar resources as solar penetration increases. Mills and Wiser (2012) have calculated capacity value by renewable technology type at progressively higher penetrations. Of the alternative wind and solar resources, the dispatchable solar resources retain more of their capacity revenues as solar penetration increases. The value of capacity for the plants with 6 hours of thermal storage ranges from $37/MWh at low penetration to $15/MWh at high penetration (30% energy). In contrast, the capacity value for non-dispatchable solar resources may diminish to almost $0/MWh at such high penetrations, due to the shifting net load peaks.

CSP with thermal energy storage provides the capability to reduce variability and possibly also provide services to integrate other renewable resources. Hence, the avoided integration costs should be considered when an investment in CSP is compared to an investment in an alternative renewable resource. When existing power systems are modeled at penetrations of 20-33%, wind and solar PV integration costs based on variable commitment and dispatch costs, are often calculated in the range of $3-10/MWh, including the cost of curtailing some energy that cannot be absorbed by demand (e.g., U.S. DOE 2009; Milligan et al., 2009; Mills and Wiser, 2012; Navigant et al., 2011). If further investment to improve operational flexibility is needed – whether retrofits of existing plants, construction of new generation or storage – then the associated fixed costs could increase substantially over these estimates. Some of these fixed costs would be avoided by including dispatchable solar plants in the solar portfolio.

With (or without) thermal energy storage, large-scale CSP plants are fully visible to the system operator and always controllable to support reliability (although with some production loss for plants without storage). Hence, if these plants are removed from the solar portfolio and substituted for by distributed PV plants, there will some added cost of obtaining visibility and control (CAISO/KEMA 2012).

4. Barriers Analysis and Policy Options

4.1 Barrier Resolution

Barriers Identified	*Y/N*	*Venue for Resolution*
System Need	Y	LTPP, RA
Cohesive Regulatory Framework	Y	CPUC, CAISO, CEC
Evolving Markets	Y/N	As thermal power plants with bulk storage, CSP plants can offer into the existing wholesale markets without any significant rule changes. However, because they are variable resources, the CAISO would need to forecast their availability each operating day.
Resource Adequacy Value	Y/N	The RA value of CSP with thermal energy storage is currently measured using existing NQC rules for solar technologies.
Cost Effectiveness Analysis	N	
Cost Recovery Policies	N	
Cost Transparency & Price Signals	N	
Commercial Operating Experience	Y	
Interconnection Processes	N	

We summarize the key regulatory reforms that could assist in appropriate valuation of CSP with thermal energy storage:

- Long-term procurement planning – to include evaluation of CSP with thermal energy storage in subsequent phases of the 33% RPS integration studies;
- Resource Adequacy counting rules -- to adapt existing counting rules for dispatchable but energy limited solar plants, and consider long-term RA value of alternative solar technologies;
- RPS market valuation under least-cost, best-fit – to include value of dispatchable energy and ancillary services, capacity value of a dispatchable solar plant, and avoided integration costs when compared to other wind and solar resources.

4.1 Other Considerations

5. Real World Examples

Similarly to other storage technologies, CSP with thermal energy storage has a variety of technology developers and designs. The pilot project for CSP with molten salt storage was Solar 2, which was operated by the US Department of Energy (DoE) from 1996 to 1999. At present, the commercially operating plants with molten salt storage are located in Spain, and are in range of 1.4 - 150 MW. There are several larger plants under construction or development in the United States, each utilizing different technology designs. Table 1 shows the major U.S. CSP projects under construction, with and without thermal storage, all of which are scheduled for commercial operations in 2013. The remainder of the section then reviews the designs for three alternative CSP technologies with thermal storage.

Project name, location and on-line date	*CSP type*	*MW*	*Developer and Current Owners*	*Off-takers*
Ivanpah California, (2013)	Power tower with steam boiler and *de minimis* auxiliary gas, no storage	392 MW (3 power towers)	BrightSource (developer and minority owner), NRG (majority owner) and Google (minority owner)	Southern California Edison, Pacific Gas & Electric
Mojave Solar, California (2013)	Parabolic trough, no storage	250MW	Abengoa Solar	Pacific Gas & Electric
Genesis, California (2013)	Parabolic trough, no storage	250 MW	NextEra (owner)	Pacific Gas & Electric
Solana, Arizona (2013)	Parabolic trough with 6 hours of thermal storage	250MW	Abengoa Solar	Arizona Public Service
Crescent Dunes, Nevada (2013)	Power tower with molten salt receiver and 10 hours of thermal storage	110 MW	SolarReserve (developer and owner), Banco Santander and ACS Cobra (owners)	NV Energy

5.1 (a) Project Description – Parabolic Trough with Indirect Heating of Molten Salts

[Description of Abengoa Solana plant]
250 megawatt (MW) parabolic trough plant with six hours of thermal storage.

Location	*Near Gila Bend, Arizona*
Operational Status	Under construction, commercial operations in 2013
Ownership	Abengoa Solar
Primary Benefit Streams	
Secondary Benefits	
Available Cost Information	

(b) Project Description – Power Tower with Indirect Heating of Molten Salts

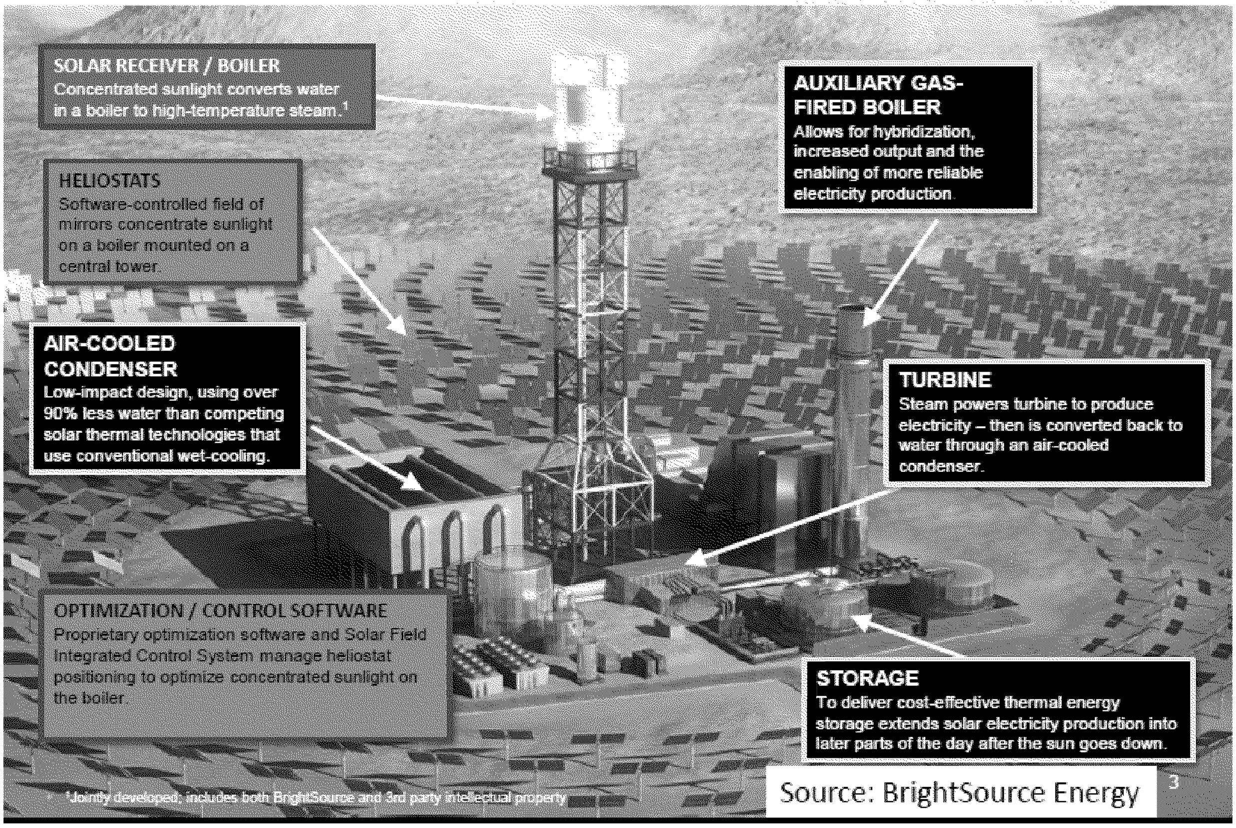
This section provides a brief description of a power tower with indirect heating of thermal energy storage utilizing molten salts. The design is based on a 200 MW BrightSource Energy project with 2 hours of thermal energy storage under contract to Southern California Edison. With this technology, a solar field consisting of thousands of flat mirrors on dual-axis tracking mounts are arranged around a tower, on which is mounted a solar receiver steam generator. The mirrors track the motion of the sun, reflecting sunlight onto the solar receiver. As in a traditional boiler, water is pumped through channels within the solar receiver, where it absorbs the heat of the reflected sunlight and becomes steam. Steam temperatures are typically in excess of 565°C.

During daylight, most steam produced in the tower is directed to a steam turbine, where it is converted into mechanical energy to turn a generator and thus make electric power. Simultaneously, the excess steam is used to heat the energy storage fluid, molten salt, by passing it through a heat exchanger. Hot steam and relatively cold molten salt enter the heat exchanger and cooler steam and hotter molten salt exit. The steam output from both the heat exchanger and the turbine, which has now given up most of its energy, is sent to an air-cooled condenser (ACC) where it is condensed back to water and ultimately pumped back up the tower to repeat the cycle. The hot molten salt exiting the heat exchanger is pumped into the hot molten salt storage tank and stored there for later use. The system is fully charged once all the salt has been pumped from the cold molten salt storage tank, heated in the heat exchanger, and pumped into the hot storage tank.

During night or other periods of no sun when electric output is desired, hot molten salt from the hot molten salt storage tank can be pumped through the same heat exchanger used for charging, but in the reverse direction. Water is similarly pumped through the heat exchanger in the reverse direction. In this process, the heat from the salt is transferred to the water, turning the water to steam and cooling the salt. The steam thus generated is sent to the turbine to generate electricity, and the cooled molten salt is sent to the cold molten salt storage tank. The storage system is depleted when all hot molten salt from the hot tank has been used to generate steam and pumped into the cold tank. The system is capable of operating at full capacity from a fully-charged thermal storage system for two hours. It can also be operated at lower capacities for longer periods of time, and can also operate in discharge mode in tandem with direct generation during periods of partially reduced sun in order to maintain full electric production.

Location	
Operational Status	In development
Ownership	
Primary Benefit Streams	
Secondary Benefits	
Available Cost Information	

Representation of BrightSource plant design with thermal energy storage



SOLAR RECEIVER / BOILER
Concentrated sunlight converts water in a boiler to high-temperature steam.[1]

HELIOSTATS
Software-controlled field of mirrors concentrate sunlight on a boiler mounted on a central tower.

AIR-COOLED CONDENSER
Low-impact design, using over 90% less water than competing solar thermal technologies that use conventional wet-cooling.

OPTIMIZATION / CONTROL SOFTWARE
Proprietary optimization software and Solar Field Integrated Control System manage heliostat positioning to optimize concentrated sunlight on the boiler.

AUXILIARY GAS-FIRED BOILER
Allows for hybridization, increased output and the enabling of more reliable electricity production

TURBINE
Steam powers turbine to produce electricity – then is converted back to water through an air-cooled condenser.

STORAGE
To deliver cost-effective thermal energy storage extends solar electricity production into later parts of the day after the sun goes down.

[1] Jointly developed; includes both BrightSource and 3rd party intellectual property

Source: BrightSource Energy

3

(c) Project Description – Power Tower with Direct Heating of Molten Salts

This section provides a brief description of a power tower with direct heating of thermal energy storage utilizing molten salts, based on SolarReserve's Crescent Dunes project. Crescent Dunes is currently under construction in Nevada and will be the largest molten salt power tower in the world when completed in 2013. Under its PPA with NV Energy, the project will deliver 500,000 MWh annually with a 110 MW steam turbine and 10 hours of molten salt storage, resulting in an annual capacity factor of 52%. Construction is well underway and plant commissioning will commence in early 2013. In California, SolarReserve is developing the Rice Solar Energy Project under a PPA with PG&E; with 150 MW, 8 hours of storage, and 500,000 MWh annually, it employs essentially the same technology as the Crescent Dunes project but with a more "peaking" configuration.

SolarReserve's technology uses an optimized circular field of mirrors which track throughout the day to focus sunlight on a central receiver atop a tall tower. Molten salt flows through the receiver and is heated directly by the sunlight. Hot salt is stored at over 560°C and used to generate superheated steam on demand at a consistent temperature and pressure. The steam powers a conventional steam turbine generator. Because the salt is both the receiver working fluid and the storage medium, this is commonly considered "integrated" molten salt storage.

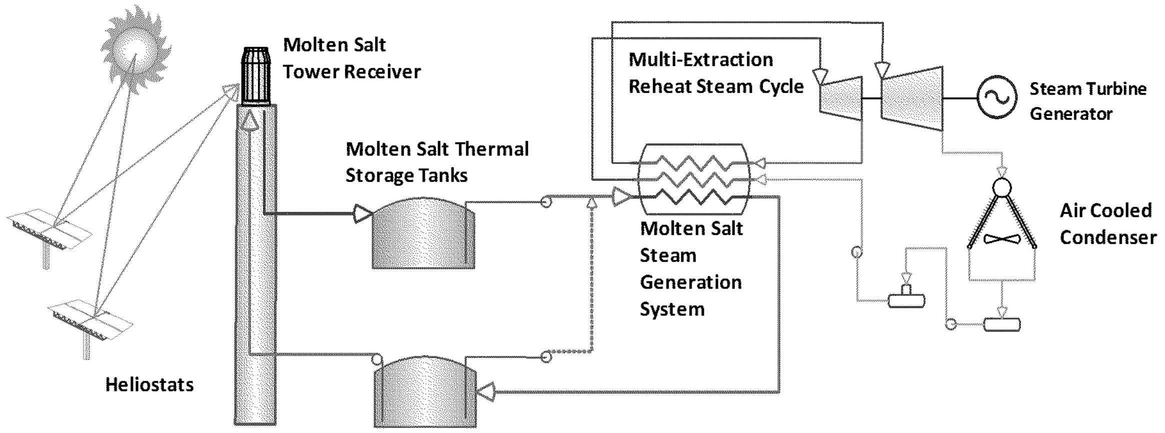


Figure 1 - Integrated Molten Salt Storage Process Flow Diagram

Direct heating of the molten salt, rather than heating salt with solar steam, allows energy to be stored and dispatched without multiple heat exchange steps. This integrated storage approach enables a project like Crescent Dunes to deploy a large amount of storage (e.g., 10 hours) efficiently and cost-effectively. Higher storage efficiency enables more flexible dispatch and multiple configuration options of the CSP plant (i.e., baseload or peaking). Integrated storage also allows the system to ride through intermittent cloud cover by simply slowing the flow of salt through the receiver, while direct steam systems may experience problems with steam condensing in the receiver during cloud cover. Riding through cloud cover and more efficient bulk storage were the primary motivations behind the DOE's advancement from direct steam tower at Solar 1 to an integrated molten salt receiver at Solar 2.

Figure 2 - Crescent Dunes project under construction near Tonopah, NV

Location	*Near Tonopah, Nevada*
Operational Status	Under construction, commercial operations in 2013
Ownership	SolarReserve, Banco Santander, and ACS Cobra
Primary Benefit Streams	
Secondary Benefits	
Available Cost Information	$135/MWh PPA price, $737M DOE loan guarantee, $260M equity investment.

5.2 Outstanding Issues

Description	*Source*

5.3 Contact/Reference Materials

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[MAY ADD OTHER CSP COMPANIES AND CONTACTS]

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6. Conclusion and Recommendations

Energy storage (ES) can be used on all relevant time-frames – seconds, minutes, hours – to meet aspects of the power system's operational and reliability needs under scenarios of high renewable penetration. CSP with thermal energy storage has primary use as a means to shift energy to modify the morning and evening solar ramps, as dispatchable energy that can be used at other times of the operating day, and as a means of providing regulation and spinning reserves. In turn, dispatchability improves RA capacity value and reduces integration costs, when compared to other solar resources, and enables the more cost-effective deployment of other intermittent renewable resources.

Is ES commercially ready to meet this use?

Yes, utility-scale CSP plants with thermal energy storage systems using molten salts were demonstrated on a pilot basis at Solar 2, from 1996-1999, are in commercial operations in Spain, and are under construction in the southwestern U.S., with commercial on-line dates of the first projects expected in 2013, with additional plants coming on-line between 2013-16.

Is ES operationally viable for this use?

The first generation of utility-scale CSP plants with thermal energy storage were designed for production of firm blocks of power and not to provide operational flexibility. The CSP sector needs to design subsequent plants for greater operational flexibility, which is technologically feasible.

What are the non-conventional benefits of storage in this use?

One non-conventional benefit is that all the stored thermal energy is solar energy and does not require charging from the grid, hence the storage facilities do not affect the power system when charging and also provide all services using renewable energy. This benefit is captured, indirectly, in the sale of RPS energy.

Can these benefits be monetized through existing mechanisms?

Since CSP plants currently enter the California market (for this purpose, specifically the CPUC-jurisdictional RPS market) through long-term PPAs, the monetization of benefits comes largely through the valuation of long-term benefits to the utility buyers. Because these plants are the first (partially) dispatchable renewable plants, CSP plant developers have had some difficulty in fully monetizing all long-term benefits through existing RPS LCBF rules. Of note, the valuation of competing wind and solar technologies has not yet considered factors such as integration costs and long-term Resource Adequacy capacity value. These factors have to be accounted for in an economic benefits analysis of CSP with thermal energy storage.

If not, how should they be valued?

Mills and Wiser (2012) is the one study to offer a reasonably complete framework for an economic valuation analysis of CSP with thermal energy storage compared to other renewable resources, for purposes of RPS procurement. However, further work needs to be done on aspects of valuation. For example, additional comparative analysis of simulation results is needed to resolve some inconsistencies among different national lab studies. The net costs of other storage technologies must be considered as well. Ideally, the valuation frameworks then have to be adopted in a transparent fashion by the CPUC jurisdictional utilities with appropriate regulatory oversight.

Is ES cost-effective for this use?

The cost-effectiveness of CSP with thermal energy storage is a complex question, since the attributes of the storage system are bundled with the RPS energy. Generally, most analysts recognize that while thermal energy storage using molten salts is possibly the cheapest utility scale storage solution at present (cite), the higher cost of the associated solar energy from CSP needs to be reduced over time to remain competitive with solar PV or wind coupled with other integration solutions. In addition, successful deployment of U.S. CSP plants with thermal energy storage over 2013-15 will provide further evidence of technology viability and the potential for cost reductions.

What are the most important barriers preventing or slowing deployment of ES in this use?

The primary barriers to deployment of CSP with thermal energy storage are commercial and regulatory. The existing deployments at Solar 2 and in Spain have demonstrated large-scale applications, and the much larger scale next U.S. generation projects will provide commercial applications beginning in 2013. With greater confidence in the technology and its cost-effectiveness, the remaining regulatory barriers include appropriate valuation under RPS of the benefits of dispatchable solar power. With respect to system operations and wholesale markets, the primary barriers will be the optimization of a variable energy resource that can provide dispatchable energy and ancillary services.

What policy options should be pursued to address the identified barriers?

See discussion below.

Should procurement target or other policies to encourage ES deployment be considered for this use?

[THIS QUESTION IS STILL BEING DISCUSSED BY CSP COMPANIES]

Since CSP with thermal energy storage is first and foremost a supplier of RPS energy, and the thermal energy storage component cannot be de-coupled from the solar plant, it would not be a clear fit for a storage procurement target. If a storage procurement target is adopted, however, this technology should receive credit as an eligible storage system, and the procurement process for storage should go alongside the procurement process for renewable energy.

Perhaps more importantly, adoption of this technology should be encouraged through further modifications of existing resource procurement mechanisms, including:

- Long-term procurement planning – to include evaluation of CSP with thermal energy storage in subsequent phases of the 33% RPS integration studies;
- Resource Adequacy counting rules -- to adapt existing counting rules for dispatchable but energy limited solar plants, and consider long-term RA value of alternative solar technologies;
- RPS market valuation under least-cost, best-fit – to include value of dispatchable energy and ancillary services, capacity value of a dispatchable solar plant, and avoided integration costs when compared to other wind and solar resources.

This recommendation benefits from the analysis of economic value conducted by the national labs, particularly Mills and Wiser (2012) and the work of NREL associated researchers (e.g., Denholm and Mehos, 2011; Madaeni et al., 2011).