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EPC15-049 Tech Memo No. 2 –
Statewide Benefits of Pumped Storage at Groundwater Banks

ABSTRACT

This Technical Memo No 2's purpose is to report on the benefits associated with adding pumped storage to existing aquifer (groundwater) storage facilities. Pumped storage additions to groundwater banks may be able to provide electrical system benefits from: 1) generation of electricity during period of high system demand, 2) increasing pumping demand (load) during renewable over generation periods to reduce the risks of overgeneration, 3) reducing load during high system ramping requirements and system demand, and 4) provide a plethora of ancillary services, depending upon the configuration of the generation and groundwater storage bank.

There are a multitude of ancillary services that could be possible from new pumped storage facilities at groundwater banks – if they were configured properly and if the water bank was willing to turn over operational control of the facilities to the Independent System Operation. Willow Springs Water Bank's (WSWB) primary purpose is as a water storage facility and it is reluctant to invest in the additional facilities necessary to perform many of the ancillary services nor turn over operation of the water bank to the ISO in order to participate in many of these markets, so the types of ancillary services that could be provided were limited from their facilities.

The WSWB operates in three different modes, depending upon the hydrologic year and the operation of any energy facilities has to be subservient to the water bank operation. During a wet year the water bank is continuously recharging water into the water bank. During dry years the water bank is continuously extracting water from the water bank. During neutral or idle years the water bank is neither recharging nor extracting water.

This project[1] shows that there is a 44 MW potential statewide for adding Peak Hour Pumped Storage (PHPS), adding upper and lower surface storage reservoirs with hydroelectric generators and associated components, and 220 MW potential statewide for using existing extraction well load for demand response. Using WSWB PHPS as a typical example, then the 44 MW of generation would have an annual net benefit of $5.9M and the 220 MW of load used as demand response would have an annual net benefit of $6.3M.

This analysis, using Willow Springs Water Bank as a specific example, found that Aquifer Pumped Hydro (APH) project (using the existing underground aquifer as a lower storage reservoir and adding a surface storage reservoir and reversible pump turbines to pump water out of the ground or generate power when water is injected into underground storage) was too expensive, the round trip efficiencies were too low, and the operational characteristics too restricting to be cost effective but that Peak Hour Pumped Storage (adding onsite hydropower and surface storage reservoirs and using pumps and piping of the existing water bank) would be a cost effective

[1] Antelope Valley Water Storage, LLC. *Assess Report Part II: Groundwater Bank Energy Storage Systems – A Feasibility Study,* 2017

investment if demand response ability is added to the pumped storage project. APH was limited to participation in the Day Ahead Market as a pumped storage facility, but PHPS could provide generation during wet (recharge) years, pumped storage operation during a neutral year in the Day Ahead Market and Flexible Ramping and Demand Response markets as pumped storage, and if configured properly, both could provide Demand Response during dry (extraction) years.

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SUMMARY AND CONCLUSIONS

This Technical Memo No 2's purpose is to report on the benefits associated with adding pumped storage to existing aquifer (groundwater) storage facilities. Pumped storage additions may be able to provide electrical system benefits from: 1) generation of electricity during period of high system demand, 2) increasing pumping demand (load) during renewable over generation periods to reduce the risks of overgeneration 3) reducing load during high system ramping requirements and system demand and, and 4) provide a plethora of ancillary services, depending upon the configuration of the generation and groundwater storage bank.

This memo reports on the markets and services potential of adding pumped storage to existing groundwater storage facilities using Willow Springs Water Bank (WSWB) as a specific example: 1) using the existing underground aquifer as a lower storage reservoir and adding reversible pump turbines to pump water out of the ground and generate power when water is injected into storage (Aquifer Pumped Hydro - APH), and 2) adding onsite hydropower using pipe, pump, and reservoir facilities that are part of the existing water bank (Peak Hour Pumped Storage - PHPS). Table 1 provides a summary of the characteristics and analysis of these two options for WSWB.

As Table 1 shows, there are a multitude of ancillary services that could be possible using these technologies – if they were configured properly and if the water bank was willing to turn over operational control of the facilities to the Independent System Operation (Frequency Regulation, Spinning Reserve, Non-Spinning Reserve, Regulation Energy Management [REM], Reactive Power/Voltage Support, and Black Start require the generation facilities to be under ISO control). WSWB's primary purpose is as a water storage facility and is reluctant to invest in the additional facilities necessary to perform these services nor turn over operation of the water bank the ISO in order to participate in many of these markets, so the ancillary services options were limited.

The operation of the water bank varies significantly depending upon the type of water year, so operation had to be assessed for three water year types (wet - 32% probability, neutral - 33% probability, and dry - 35% probability).

In wet (recharge) years, WSWB will recharge water into the bank's percolation ponds. During this year type the PHPS was evaluated as a generator (5.2 MW generated constantly over the year). The APH can't operate as a generator during this year type because the recharge process would have to be by injection instead of percolation and the project may need to meet additional water quality requirements of the Regional Water Quality Control Board, which would increase the capital cost of the APH project.

During an idle year in which the WSWB is neither recharging nor extracting, the PHSP and APH were evaluated in pumped storage mode, generating when electricity prices were high, and refilling storage when prices were low based upon Day Ahead Market prices. PHPS can provide generation during the morning and evening ramp periods, and increased demand (load) during the afternoon periods to refill storage reservoirs, so it was evaluated for Flexible Ramping and Demand Response also. The APH response time, round-trip efficiencies, and operational constraints so limited that it was not evaluated for Flexible Ramping nor Demand Response.

In a dry year WSWB will extract water and pump it to the California Aqueduct. This year was evaluated for both PHPS and APH for demand response (curtailing electricity use in response to system needs). Two additional extraction wells would be necessary to recover from curtailing the wellfield for up to 320 hours per year..

There is additional flexibility possible with this technology. During a wet hydrologic year, when the PHPS can operate as a hydroelectric generator, it could be configured to curtail generation for 5 hours per day per year, ideally during the afternoon renewable generation over production period.

This project[2] shows that there is a 44 MW potential statewide for adding Pumped Storage (adding upper and lower surface storage reservoirs with hydroelectric generators and associated components) and 220 MW potential statewide for using existing extraction well load for demand response.   If these projects had similar characteristic to the WSWB PHPS then the 44 MW of generation would have an annual net benefit of $5.9 million and the 220 MW of load used as demand response would have an annual benefit of 6.3 million.

[2] Antelope Valley Water Storage, LLC. *Assess Report Part II: Groundwater Bank Energy Storage Systems – A Feasibility Study,* 2017

Table 1. Comparison of WSWB APH and PHPS Characteristics and Analysis

	WSWB Aquifer Pumped Hydro (APH)	WSWB Peak Hour Pumped Storage (PHPS)	Demand Response
Components needed	Reversible pump-turbines, surface storage reservoir, aquifer is lower reservoir	Hydroelectric generator, upper and lower surface reservoirs	2 additional groundwater wells for 320 hours curtailment
Pumping Capacity	17.2 MW	10.1 MW	27.3 MW
Generating Capacity	3.7 MW	5.2 MW	
Energy Storage (5 hours of generation)	18.5 MWH	26.0 MWH	Curtailable up to 320 hours per year
Pumping Efficiency	41.5%	83.4%	
Generating Efficiency	51.7%	87.4%	
Round Trip Efficiency	21.6%	72.9%	
Capital Cost	$18.6M	$7.9M	$2.1M
Net Present Value (@6%, 20 years)	-$18.2M (generator operating in neutral years)	-$0.9M (generator operating during wet and neutral year)	$9.1M (dry year)
Capital Cost with Dry Year Demand Response	$20.3M	$10M	
Net Present Value (@6%, 20 years) with dry year demand response	-$9.1M	$8.1M	
Markets/Services:			
Day Ahead Hourly Market	Yes	Yes	
Flexible Ramping	No, response time too slow, operational parameters preclude	Yes	
Demand Response	Yes	Yes	
Real Time Energy Time Shift	No	No	
Retail Energy Time Shift	No, lack of load on site	No, lack of load on site	
Frequency Regulation	No, not configured for, wish to maintain local control of operations	No, not configured for, wish to maintain local control of operations	
Spinning Reserve	No, not configured for, wish to maintain local control of operations	No, not configured for, wish to maintain local control of operations	
Non-Spinning Reserve	No, not configured for, wish to maintain local control of operations	No, not configured for, wish to maintain local control of operations	
Regulation Energy Management (REM)	No, not configured for, wish to maintain local control of operations	No, not configured for, wish to maintain local control of operations	
Investment Deferral	No. Area of WSWB is an unconstrained SCE area	No. Area of WSWB is an unconstrained SCE area	
Reactive Power/Voltage Support	No, not configured for, wish to maintain local control of operations	No, not configured for, wish to maintain local control of operations	
Resource Adequacy Capacity (RA)	No, expected operations preclude	No, expected operations preclude	
Black Start	No, not configured for	No, not configured for	

PURPOSE

This Technical Memo No 2's purpose is to report on the potential benefits associated with adding pumped storage to existing aquifer (groundwater) storage facilities. Pumped storage additions may be able to provide electrical system benefits from: 1) generation of electricity, 2) increasing demand (load) during renewable over generation periods and reducing load during ramping periods and 3) ancillary services, depending upon the configuration of the groundwater storage bank and the ability of the water bank to cede operational control to the ISO. This memo is a summary of the potential benefits that could be associated with pumped storage additions to aquifer storage projects.– a Peak Hour Pumped Storage project where two surface reservoirs are constructed and hydroelectric generators installed and of Aquifer Pumped Hydro project where reversible pump turbines are installed on extraction wells.

BACKGROUND

There are a multitude of water banks existing in California today[4]. These are known variously as aquifer storage, groundwater storage, and conjunctive use projects. Their purpose is to store water underground. They all take surface water and store it underground for usage later.

These storage projects come in a variety of configurations, depending upon sources of water, the configuration of the underground storage basin, method of getting water underground (either passive via recharge basins that let the water percolate into the ground or, less frequently, actively injecting water into the ground). While they all may not have enough topographical variation to support hydroelectric generation, they all have one thing in common, an electricity demand when they are extracting the water from underground for delivery to customers. And, depending upon their delivery requirements, they may have the ability to vary that pumping load to accommodate electrical system needs.

POTENTIAL BENEFITS ASSOCIATED WITH PUMPED STORAGE ADDITIONS TO GROUNDWATER STORAGE PROJECTS

A summary of the various market/service characteristics and their applicability to groundwater energy storage banks, and WSWB in particular, are provided in Table 2.

[4] Antelope Valley Water Storage, LLC. *Assess Report Part II: Groundwater Bank Energy Storage Systems – A Feasibility Study,* 2017

Table 2. Potential Markets and Services for Groundwater Pumped Storage Projects

Market/Service	Definition	Time Period	Applicable to Groundwater Energy Bank Storage System	Willow Springs Water Bank APH Simulation	Willow Springs Water Bank PHPS Simulation
Day Ahead Energy Time Shift	Hourly market energy prices established for the next day. Based upon unit commitment on the day prior to the actual operating day.	Hour	In both generating and pumping mode.	Yes	Yes
Real Time Energy Time Shift	The real-time market is a spot market in which utilities can buy power to meet the last few increments of demand not covered in their day ahead schedules.	15-minute procurement, 1-hour continuous requirement	In both generating and pumping mode.	No	Yes
Retail Energy Time Shift	Hourly energy and demand prices based upon utility retail tariffs.	Hour	If significant on-site electricity use	No	No
Frequency Regulation	Maintaining the grid frequency within the given margins by continuous modulation of active power. Capacity that follows (in both the positive and negative direction) a 4-second ISO power signal.	Seconds	Have to be operating and have special generation configuration for rapid response.	No	No
Spinning Reserve	Spinning reserve is standby capacity from generation units already connected or synchronized to the grid and that can deliver their energy in 10 minutes when dispatched. Dispatched within 10 minutes in response to system contingency events. Must be frequency responsive and be able to run for 2 hours.	10 minutes	If generation configured properly, and operating, could be provided in generating mode.	No	No
Non-Spinning Reserve	Non-spinning reserve is Off-line Generation Resource capacity that can be synchronized to	10 minutes	If generation configured properly, and operating,	No	No

Market/Service	Definition	Time Period	Applicable to Groundwater Energy Bank Storage System	Willow Springs Water Bank APH Simulation	Willow Springs Water Bank PHPS Simulation
	the grid and ramped to a specified load within 10 minutes and run for at least 2 hours.		could be provided in generating mode		
Regulation Energy Management (REM)	Regulation energy is used to control system frequency, which must be maintained very narrowly around 60 hertz. Composed of regulation up (increased generation) and regulation down (decreased generation). Capacity that follows (in both the positive and negative direction) a 4-second ISO power signal. It requires 1 -hour of continuous response. Capacity is limited by the resource's 5-minute ramp.	5-10 minute, must be available for 60 minutes	Have to be operating and include equipment necessary to follow regulation signal.	No	No
Flexible Ramping	The ability to change generation (ramp) in response to system needs. Requires participation in market with bids and 3-hour continuance response capability.	5 minutes	Depends upon pump and generator characteristics	No, response time too slow	Yes
Investment Deferral	The ability to defer additional investment in distribution system, substations, or transmission lines. Resource capable of reliably and consistently reducing net loading on desired infrastructure.	Year	Depends upon location of groundwater bank	No. Area of WSWB is an unconstrained SCE area	No. Area of WSWB is an unconstrained SCE area
Reactive Power/Voltage Support	The injection or absorption of reactive power to maintain transmission system voltages within required ranges. Resource	Seconds	If generation configured properly	No	No

Market/Service	Definition	Time Period	Applicable to Groundwater Energy Bank Storage System	Willow Springs Water Bank APH Simulation	Willow Springs Water Bank PHPS Simulation
	capable of dynamically correcting excursions outside voltage limits as well as supporting conservation voltage reduction strategies in coordination with utility voltage/reactive power control systems.				
Resource Adequacy Capacity (RA)	Assurance that there is adequate physical capacity in existence to serve likely peak load and the ability of the ISO to call on it to perform when needed for system reliability. Must provide net qualifying capacity (NQC) for 4 hours over 3 consecutive days up to a total of 24 hours per month. The resource must bid into the ISO day-ahead and real-time markets.	Hour	For flexible capacity, and be 2 hours charging and 2 hours discharging.	No	No
Demand Response	Demand response is a change in the power consumption of an electric utility customer in response to utility system needs (typically a reduction in customer demand)	Hour	In both generating and pumping mode project could	Yes, if additional extraction wells added.	Yes, if additional extraction wells added.
Black Start	Generation able to start itself without support from the grid and with sufficient real and reactive capability and control to be useful in system restoration.	Minutes	If water stored at elevation, and generation configured appropriately.	No	No

PATICIPATION IN ISO MARKETS

The California Independent System Operator (ISO) provides markets for various services and access to the transmission grid. Groundwater bank pumped storage could participate as either a generator or as a demand (load), but not all markets/services are available to both operations. The ISO currently runs three primary wholesale energy markets: Day-Ahead, Real-Time, and Ancillary Services.

Day-ahead market. The day-ahead market is made up of three market processes that run sequentially. First, the ISO runs a market power mitigation test. Bids that fail the test are revised to predetermined limits. Then the integrated forward market establishes the generation needed to meet forecast demand. And last, the residual unit commitment process designates additional power plants that will be needed for the next day and must be ready to generate electricity. Market prices set are based on bids. The day-ahead market opens for bids and schedules seven days before and closes the day prior to the trade date. Results are published at 1:00 p.m.

Real-time market. The real-lime market is a spot market in which load serving entities can buy power to meet the last few increments of demand not covered in their day ahead schedules. It is also the market that secures energy reserves, held ready and available for ISO use if needed, and the energy needed to regulate transmission line stability. The market opens at 1:00 p.m. prior to the trading day and closes 75 minutes before the start of the trading hour. The results are published about 45 minutes prior to the start of the trading hour. The real-time market system dispatches power plants every 15 and 5 minutes, although under certain grid conditions the ISO can dispatch for a single 1-minute interval.

Ancillary service market. Ancillary services are energy products used to help maintain grid stability and reliability. There are four types of ancillary services products currently procured: regulation up, regulation down, spinning reserve and non-spinning reserve. Regulation energy is used to control system frequency, which must be maintained very narrowly around 60 hertz, and varies as generators change their energy output. Resources providing regulation are certified by the ISO and must respond to automatic control signals to increase or decrease their operating levels depending upon the need. Spinning reserve is standby capacity from generation units already connected or synchronized to the grid and that can deliver their energy in 10 minutes when dispatched. Non-spinning reserve is capacity that can be synchronized to the grid and ramped to a specified load within 10 minutes.

Generators participating in the ISO markets are limited to one megawatt or more. Their ability to participate in the various markets is limited by their configuration (various ancillary service markets have response/performance requirements) and their operation (many of the ancillary services markets require direct ISO control of the generator).

Load can also participate in ISO markets. ISO rules allow load and aggregation of loads capable of reducing their electric demand to participate as price responsive demand in the ancillary services market and as curtailable demand in real-time markets. Load can participate in some ISO markets via a Proxy Demand Resource (PDR) or via a Reliability Demand Response Resource (RDRR). PDR and RDRR only allow for load curtailment, not load consumption or the export of energy to the grid.

Proxy Demand Resource (PDR) is a participation model for load curtail introduced in 2010 to increase demand response participation in the ISO's wholesale Energy and Ancillary Services markets. PDR helps in facilitating the participation of existing retail demand response into these markets: Day-ahead, Real-time, Spinning and Non-

Spinning Reserves like a generator resource, but it cannot ever inject energy into the grid. PDR can only be dispatched in one direction – to reduce load.

Reliability Demand Response Resource (RDRR) is a product created to further increase demand response participation in the ISO markets by facilitating the integration of existing emergency-triggered retail demand response programs and newly configured demand response resources that have reliability triggers and desire to be dispatched only under certain system conditions. RDRR may participate in the Day-Ahead and Real- Time markets like a generator resource, but may not submit Energy Self-Schedules, may not Self-Provide Ancillary Services, and may not submit RUC Availability or Ancillary Service bids.

Electricity storage can participate in the ISO markets also. A storage device could participate using the ISO's non-generating resource (NGR) participation model. The main difference of NGR compared to a generator is that the NGR can have negative output (absorbing electricity from the grid). Additionally, NGRs are ISO metered entities requiring them to comply with ISO metering and telemetry requirements. All utility interconnection requirements would need to be met which may include the need to obtain a WDAT interconnection, similar to any other generator connected at the distribution level that participates in the wholesale market.

OTHER MARKETS/SERVICES

There is a CPUC proceeding (R.15-03-011) and an ISO stakeholder initiative on Energy Storage and Distributed Energy Resources that is investigating additional markets/service for energy storage and distributed energy resources. Table 3 provides a summary of the reliability and non-reliability services that are being investigated in these proceedings. It should be emphasized that there are a number of services listed in this table for which there is currently no existing market (back-tie services, inertia, primary frequency response, resiliency). For reliability services, there can be reliability impacts to the system if the resource does not follow instructions from the ISO or utility distribution company (UDC).

Table 3. Storage Reliability Services and Non-Reliability Services[5]

Domain	Reliability Services	Non-Reliability Services
Customer	None	TOU bill management; Demand charge management; Increased PV self-consumption; Back-up power
Distribution	Distribution capacity deferral; Reliability (back-tie) services[2]	Voltage support; Resiliency/microgrid/islanding
Transmission	Transmission deferral; Inertia; Primary frequency response; Voltage support; Black start	None
Wholesale Market	Frequency regulation; Spinning reserves; Non-spinning reserves	Imbalance energy
Resource Adequacy	Local capacity; Flexible capacity	System capacity

5 California Public Utilities Commission, R.15-03-011, Joint Workshop Report and Framework Multiple-Use Applications for Energy Storage CPUC Rulemaking 15-03-011 and CAISO ESDER 2 Stakeholder Initiative, May 15, 2017, gg. 7.

A summary of the available and potential markets and services as applicable to groundwater pumped storage projects is found in Table 4.

Table 4. Groundwater Bank Operation Potential Markets and Services

Market or Service	Groundwater Bank Operation	Comments
Bulk Energy Supply (day ahead, real time, retail energy shift)	Generation Load	If there is water available at elevation to run through hydroelectric generators If operating via PDR or RDRR
Frequency Regulation	Generation (currently) Load (theoretically as dedicated Demand Response)	If generation configured properly, is operating and under ISO (AGC) control If configured properly, load operating and dedicated to ISO control
Spinning Reserves	Generation Load	If generation configured properly, is operating and under ISO control If operating via PDR
Non-Spinning Reserves	Generation Load	If generation configured properly If operating via PDR
Regulation Energy Management	Generation Load (theoretically)	If configured properly and participating in ISO regulation up/down markets If configured properly and participating in ISO regulation up/down markets
Flexible Ramping	Generation Load (theoretically)	If configured properly. If configured properly and allowed to provide service
Investment Deferral	Generation Load	Generators or reduction in load that is capable of reliably and consistently reducing net loading on desired distribution infrastructure.
Reactive Power/Voltage Support	Generation Load	If configured properly and operated under ISO control Not applicable.
Resource Adequacy	Generation Load	If configured and operated properly and participates in ISO markets
Demand Response	Generation Load	Not applicable Depends upon ability to curtail/shift load
Black Start	Generation Load	Only if there is water available at elevation to run through hydroelectric generators and configured for black start. Not applicable.

A key point to remember from this table is that all these markets/service have specific performance requirements which may not be compatible with groundwater bank operations. The primary purpose of groundwater storage banks is to store water and the operation of a pumped storage project cannot interfere with that water storage priority, and a pumped storage addition will need to be carefully configured to provide some of these services without compromising the water bank operation. Water bank operator may be reluctant to turn operation of their facility over to the ISO in order to participate in some ancillary markets.

For example, Resource Adequacy (RA) capacity is classified as system, local, or flexible. The rules for system and local RA define the qualifying capacity (QC) of a storage resource to be the maximum discharge rate the resource can sustain for four hours[6]. If a storage resource is counted toward a load serving entity's resource adequacy obligation, then it must participate in the wholesale market and be subject to a must-offer obligation. A must-offer obligation requires the resource to participate in the market during specific time periods and with specific rules, it is a requirement to bid or schedule the capacity into the ISO's day-ahead and real-time markets in accordance with specific ISO tariff provisions, and to be able to perform to fulfill its ISO schedule or dispatch instructions. A groundwater pumped storage facility would have to maintain sufficient water in elevated storage for 4 hours of operation at all times to qualify for Resource Adequacy.

In the WSWB example of this investigation, there are years (extraction years) in which the Peak Hour Pumped Storage Project operates as a load year-round (extraction years), as a pumped storage project (neutral years), and as a generator year-round (wet years) . While there is some flexibility in operations (Figures 4, 5, and 6) there are years in which participation in the markets/services in Table 4 will be impractical.

CASE STUDY: WSWB AQUIFER PUMPED HYDRO (APH) AND PEAK HOUR PUMPED STORAGE (PHPS) BENEFITS ANALYSIS[7]

ANALYSIS OF WSWB APH AND PHPS ECONOMIC BENEFITS

As Technical Memo No. 1 discussed, the WSWB Aquifer Pumped Hydro and Peak Hour Pumped Storage project was assessed based upon groundwater bank operation during various hydrologic years[8]. In wet (recharge) years, WSWB will recharge water into the bank's percolation ponds for storage. During this year type the PHPS project was evaluated as a generator (5.2 MW generated constantly over the year). ACH cannot generate during this type year. During an idle year, the projects were evaluated in pumped storage mode, generating when electricity prices were high, and refilling storage when prices were low (5.2 MW generation, 10.2 MW demand for pump station use). In a dry year WSWB will extract water and pump it to the California Aqueduct. This year was evaluated for demand response (curtailing electricity se in response to system needs). The electricity demand is continuous from groundwater pumping (17.2 MW) plus power for the pump station (10.2 MW). The addition of two additional extraction wells would allow 27 3 MW of potential demand response for 5 hours daily for up to 320 hours per year.

The projects electrical operation parameters are summarized in Table 5.

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[6] A storage resource that can store 4 MWh of energy would typically be able to sustain a 1 MW discharge rate for 4 hours and would therefore qualify to provide 1 MW of system or local RA capacity.

[7] Details in Technical Memo No. 1.

[8] The Aquifer Pumped Storage Project was too expensive, the efficiencies too low, and operational constraints too limiting to operate during wet (generation) years.

Table 5. Willow Springs Water Bank Aquifer Pumped Hydro and Peak Hour Pumped Storage Operation Scenarios

Hydrologic Year Type	Probability of Occurrence	WSWB Operation Type	Electricity Demand Potential	Electricity Generation Potential	Evaluated As
APH					
Wet	32%	Recharge	0	0	
Neutral	33%	Idle	17.2 MW	3.7 MW for 5 hour daily	Pumped Storage
Dry	35%	Extraction	17.2 MW groundwater pumping + 10.1 MW pump station use	0	Demand response
PHPS					
Wet	32%	Recharge	0	5.2 MW 24 hours daily	Generator
Neutral	33%	Idle	10.1 MW pump station use	5.2 MW for 5 hours daily	Pumped storage
Dry	35%	Extraction	17.2 MW groundwater pumping + 10.1 MW pump station use	0	Demand Response (demand reduction)

Table 6 provides a summary of the annual benefit from WSWB operating as pumped storage (both APH and PHPS) during a neutral year[9]. It is of interest to note that the traditional way for evaluating pumped storage - using day ahead energy market prices and generating when prices are high and extracting water when prices are low, is the least valuable of the services evaluated.

[9] Using the StorageVet simulation model.

Table 6. WSWB Operated as Pumped Storage (Neutral Year – 33% Probability)

Market	APH Annual Value	PHPS Annual Value
Day Ahead Energy	$4,044	$94,852
Flexible Ramping	0	$384,637
Demand Response	0	$311,590
Total	**$4,044**	**$791,079**

Source: StorageVet Simulation using 2015 SCE DLAP prices (Default Load Aggregation Point prices - reflects the costs SCE avoids in procuring power during the time period).

During wet years, the water bank is storing water, and can operate as a hydroelectric generator year-round. For this case, PHPS was evaluated as a 5.2 MW hydroelectric generator operating 24 hours a day. The electricity was evaluated using the 2015 SCE DLAP hourly prices. APH is not able to operate as a generator during this type year due to water quality requirements. Table 7 shows the annual benefit during wet years of WSWB operating as a hydroelectric generator[10].

Table 7. WSWB Operated as a Hydroelectric Generator (Wet Year – 32% Probability)

Market	APH Annual Value	PHPS Annual Value
Day Ahead Energy	N/A	$**1,386,330**

During dry years, the water bank is extracting water (using pumps), and will operate as a continuous load year-round. For this case, the project was evaluated as a 27.3 MW load operating 24 hours a day, with the ability to be curtailed up to 5 hours per day for up to 320 hours during the year[11].

The project was evaluated for demand response using values from 2025 California Demand Response Potential Study[12]. This study recognizes three primary types of demand response: Shift, Shed, and Shimmy.

> The Shift service type is demand response that moves load to desired times during the day, increasing energy consumption during periods of the day when there is surplus generation, and reducing consumption during periods of the day when there is excess load.
>
> The Shed service type describes loads that can occasionally be curtailed to reduce customer demand during peak net load hours.

[10] 5.2 MW operating 24/7, priced at 2015 SCE DLAP prices, assuming no curtailment or load following.

[11] Additional curtailment would require the addition of additional extraction wells. Two additional wells would be necessary to accommodate curtailments up to 320 hours per year.

[12] 2025 California Demand Response Potential Study, Final Report on Phase 2 Results, Lawrence Berkeley National Laboratory, March 1, 2017.

The Shimmy service type involves using loads to dynamically adjust demand on the system to alleviate ramps and disturbances at timescales ranging from seconds up to an hour.

Figure 1. Types of Demand Response[13]

Service Type	Description	Grid Service Products/Related Terms
Shift	Demand timing shift (day-to-day)	Flexible ramping DR (avoid/reduce ramps), Energy market price smoothing
Shed	Peak load curtailment (occasional)	CAISO Proxy Demand Resources/Reliability DR Resources; Conventional DR, Local Capacity DR, Distribution System DR, RA Capacity, Operating Reserves
Shimmy	Fast demand response	Regulation, load following, ancillary services

Table 8 shows the annual benefit during a dry year of WSWB providing demand response services.

Table 8. WSWB Operated as a Continuous Load (Dry Year – 35% Probability)

Demand Response Service	Market Value (low)	Market Value (high)	Unit	WSWB Annual Value (low)	WSWB Annual Value (high)
Shed	$4	$4	$/kW-yr	$109,200	$109,200
Shift (1)	$20	$52	$/MWh	$174,720	$454,272
Shimmy – load following	$35	$45	$/kW-yr	$955,500	$1,228,500
Shimmy - regulation	$57	$98	$/kW-yr	$1,556,100	$2,675,400
			Total	$2,795,520	$4,467,372
(1) Assuming up to 5 hours of daily curtailment available, 27.3 MW curtailable up to 320 hours per year.					

[13] Ibid, pg. 3-16.

DISCUSSION OF WSWB PUMPED STORAGE PROJECT BENEFITS

California is experiencing a plethora of abundance in renewable generation, and this is causing system operating issues. As the following Figure 2 illustrates, there is a huge amount of solar generation occurring during the afternoon hours.

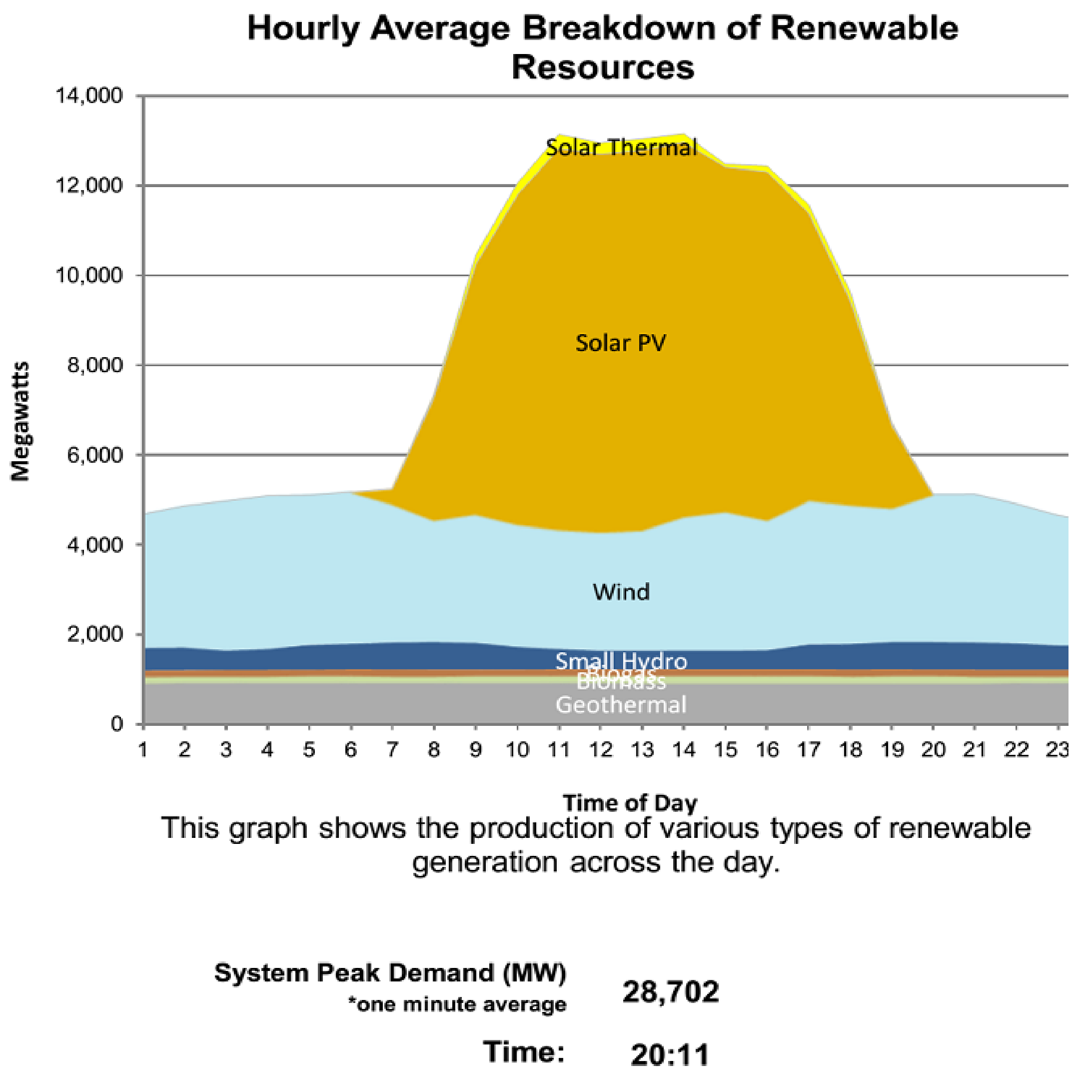

Figure 2. Renewable Energy Generation, April 27, 2017
Source: California ISO data for April 27, 2017

This overabundance of solar generation during afternoon hours has resulting in an operating phenomenon known as the "duck curve", so named by ISO staff due to its resemblance to the bird profile.

The ISO "duck curve" is shown in Figure 3. The "duck curve" is the net generation load – generation requirements after renewable generation has been subtracted out. This figure illustrates the operational issues facing California: specifically, an overabundance of renewable generation during the afternoon hours, a very steep ramping requirement during the late afternoon, and a peak generation requirement during the evening. The "duck curve" is forecasted to only get worse as California installs more and more renewable generation.

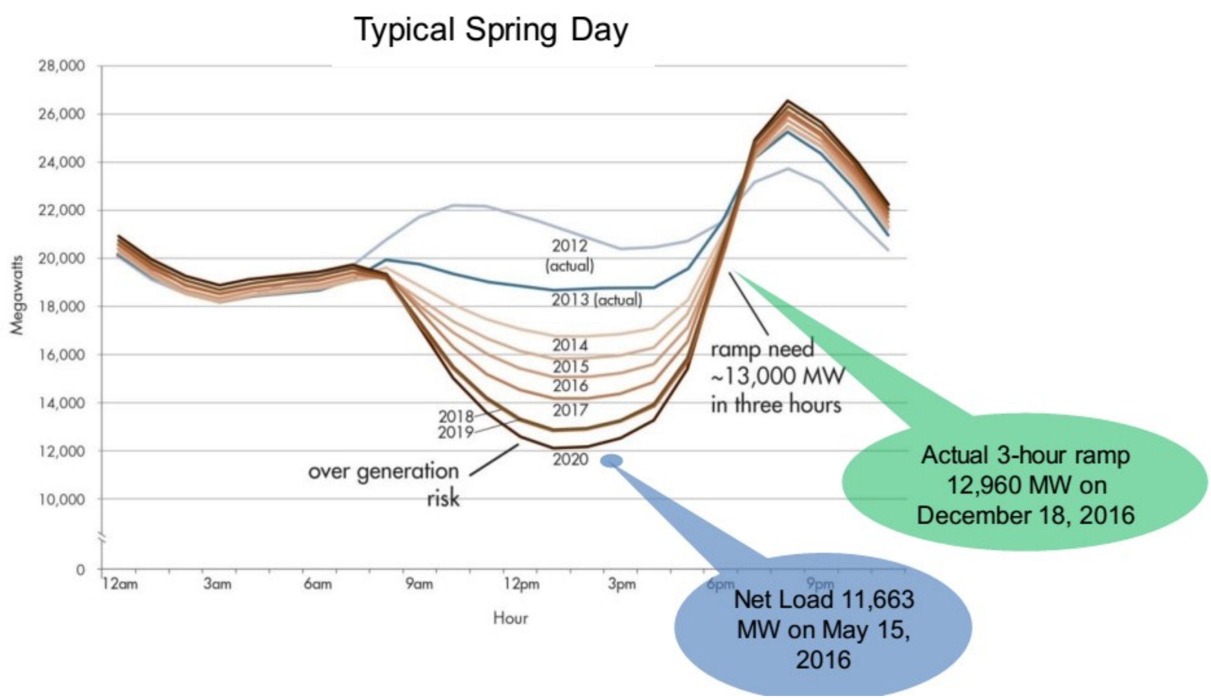

Figure 3. California ISO "Duck Curve"
Source: California ISO[14]

There have been a number of methods proposed for coping with an increasing "duck curve", including:

- Exploiting regional diversity in generation resources and demand
- Installing more dispatchable generation
- Adding more energy storage
- Increased demand management:
    - Time-of-use pricing (TOU) and real-time pricing
    - Increased demand response
    - Smart grid technology.

The WSWB PHPS could assist in addressing "duck curve" operation issues in all hydrologic years.

[14] Using Renewables to Operate a Low-Carbon Grid, California ISO, pg. 11, http://www.caiso.com/Documents/UsingRenewablesToOperateLow-CarbonGrid.pdf

Wet Hydrologic Year

During a wet hydrologic year, the WSWB PHPS can operate as a hydroelectric generator. As Figure 4 shows, the PHPS can be configured to curtail generation for 5 hours per day, ideally during the afternoon renewable generation over production. This would assist with the "belly" of the "duck curve" the period of renewable energy overgeneration.

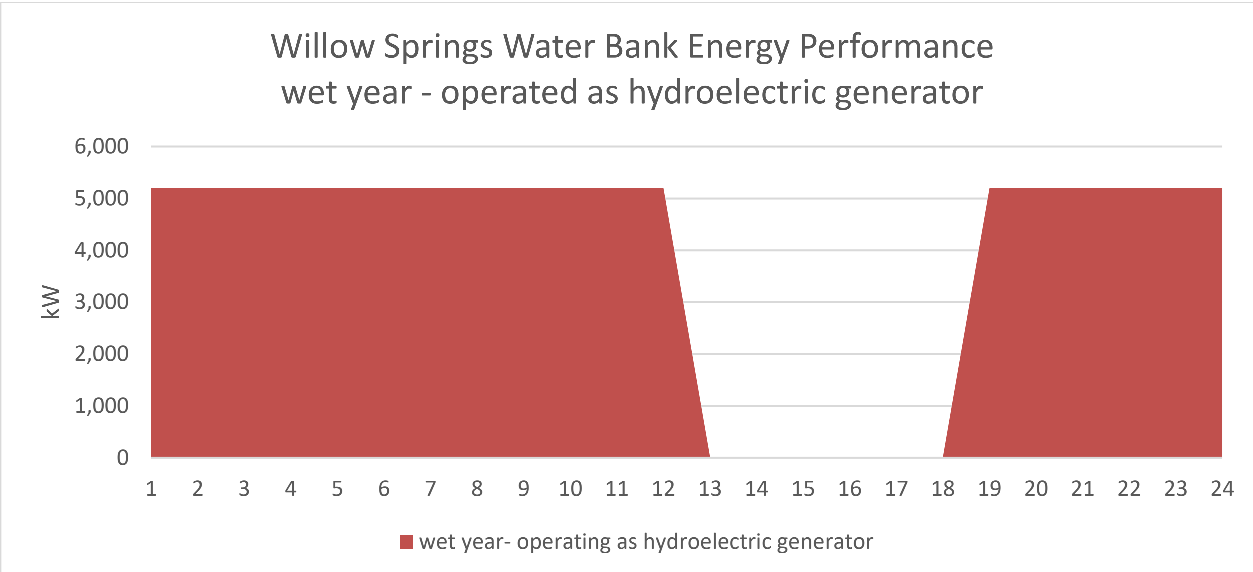

Figure 4. WSWB PHPS Hypothetical Operation During Wet Year – Operating as Generator

Neutral Hydrologic Year

During a neutral hydrologic year, the WSWB PHPS can operate as a pumped storage facility. Figure 5 show the PHPS operation, from the StorageVet simulation for the day of April 15th based upon Day Ahead Market Prices PHPS provides generation during the morning and evening ramp periods, and increased demand (load) during the afternoon periods to refill storage reservoirs.

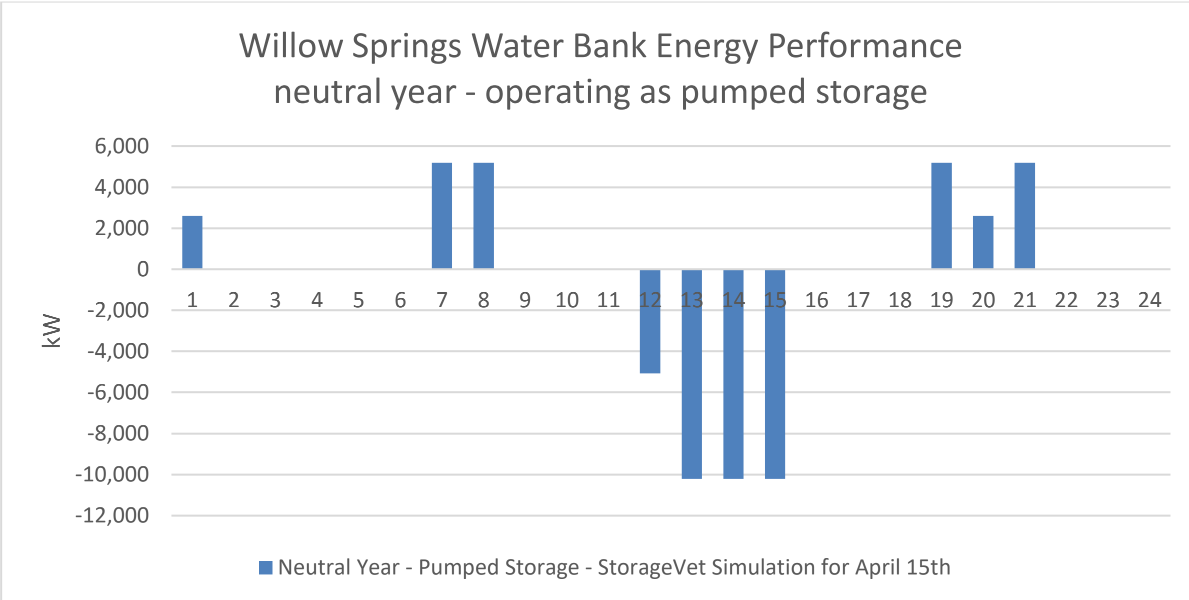

Figure 5. WSWB PHPS Hypothetical Operation During Neutral Year – Operating as Pumped Storage
Source: StorageVet simulation for April 15th, using SCE DLP prices

Dry Hydrologic Year

During a dry hydrologic year, the WSWB operates as a load (pumping water out of the ground and delivering it to Aqueduct) and could be configured to accommodate 5 hours of curtailment if necessary. Figure 6 show hypothetical WSWB operation during this period, using the surface reservoirs. WSWB can be configured to reduce load during the late afternoon ramping period and evening peak.

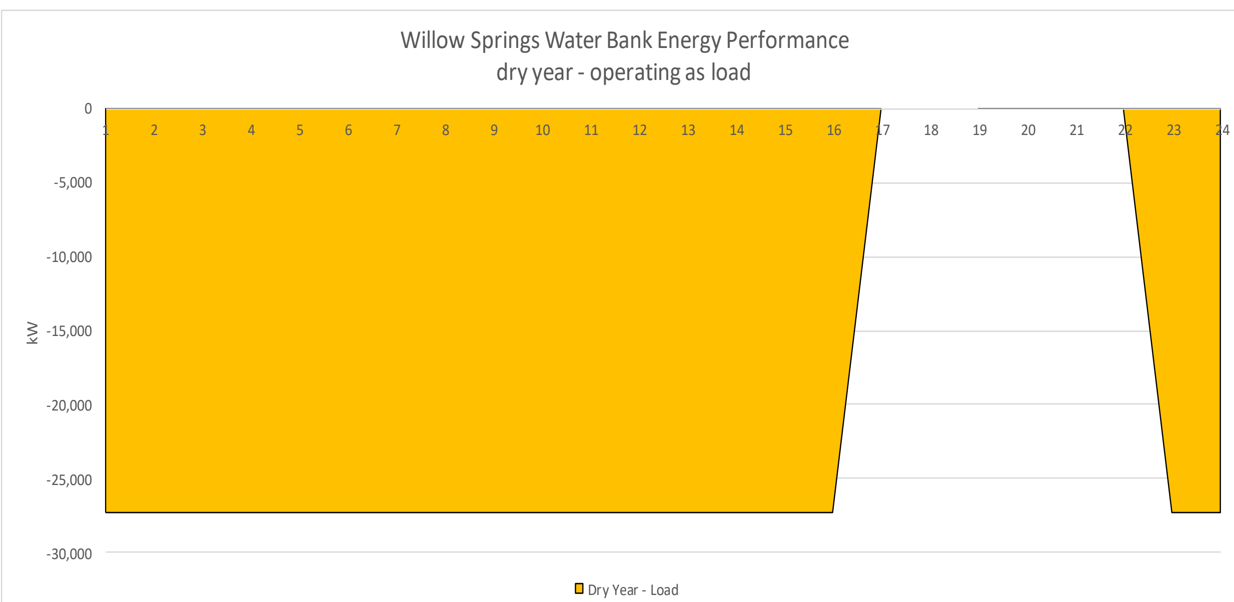

Figure 6. WSWB Hypothetical Operation During Dry Year – Operating as a Load

STATEWIDE POTENTIAL FROM ADDING PUMPED STORAGE TO GROUNDWATER BANKS

A part of this investigation the statewide potential of using groundwater storage banks as energy storage facilities was prepared. Table 9 provides an estimate of the statewide potential for these facilities, the annual benefit, and the expected capital cost associated with these type of projects using WSWB as a specific example. Demand Response is very cost effective investment. Aquifer Pumped Hydro (APH) never pays for itself, due to high capital cost, low round trip efficiencies, and limited operating flexibilities. PHPS is cost effective, if demand response is added to its operation.

Table 9. Statewide Potential, Benefits, and Costs From Energy Storage at Groundwater Banks.

Type	MW potential	Annual Net Benefit	Facilities Needed	Capital Cost	NPV per kW[15]
Peak Hour Pumped Storage – PHPS Generation	44 MW	-44K[16]	Upper and lower surface storage reservoirs, connecting piping, hydroelectric generators and controls, utility interconnection	$66.8M ($1,518/W)[17]	-$190/kW
Aquifer Pumped Hydro - APH		[-$431/kW]	Surface storage reservoir, reversible pump turbines and controls, connecting piping, utility interconnection	[$5,000/kW][18]	-$4,945/kW
Flexible Load (Demand Response)	220 MW	$6.3M[19]	Surface storage reservoir and additional extraction wells	$18M ($82/kW)[20]	$332/kW

15 Assuming a 20-year life and a 6% interest rate. Based upon generating capacity for pumped storage, and curtail capacity for demand response.
16 The probability weighted annual net benefit for WSWB PHPS generation was -17/kW.
17 The capital cost of WSWB PHPS was $1,518/kW.
18 The capital cost of WSWB APH was $5,000/kW.
19 The annual net benefit for demand response was $29/kW.
20 The capital cost of adding a 5 hours surface storage reservoir (320 hours) and additional extraction wells was $82/kW.

APPENDIX A: List of Required Permits and Registrations

Note- not all of these may be applicable to all groundwater energy storage projects.

Agency	Permit / Registration	Criteria	Comments
FERC – Federal Energy Regulatory Commission	Hydro exemption or license	Will need either a conduit exemption, a 10-MW exemption, or a license, depending upon characteristics of hydro generator	Consult FERC small hydro website: https://www.ferc.gov/industries/hydropower/gen-info/licensing/small-low-impact.asp
	Qualifying Facility	80 MW or less using renewable generation	Form 556
EIA - Energy Information Administration	Generator Registration	1 MW or larger	EIA Form 860
CaISO – California Independent System Operator	FNM – Full Network Model	1 MW or larger	GRDT – Generation Resource Data Template
	Interconnection	If connected to transmission system	FERC wholesale interconnection application http://www.caiso.com/planning/Pages/GeneratorInterconnection/InterconnectionRequest/Default.aspx
	NRI – New Resource Integration	1 MW or larger (occasionally 500 KW or larger)	http://www.caiso.com/Documents/NewResourceImplementationGuide.doc
CEC – California Energy Commission	Small Hydro Certification	Required for RPS (Renewable Portfolio Standard)	CEC RPS-1
	Generating Unit ID	1 MW or larger	CEC-1304

WREGIS – Western Renewable Energy Generation Information System	QRE (Qualified Reporting Entity) Generating Unit ID		Credit for RECs (Renewable Energy Certificates)
SWRCB – State Water Resources Control Board	Nonconsumptive Water Use Right		
	401 permit	Water Quality Certification	
Electric Utility	Interconnection	If connected to Distribution System	
	PPA (Power Purchase Agreement)	If selling output to utility	
Environmental Documents	CEQA (California Environmental Quality Act)	EIR (Environmental Impact Report)	
	USACE (US Army Corps of Engineers) 404 permit	Discharge permit	
	CDFW (California Department Fish and Wildlife) 1602 permit	Streambed alteration permit	

CEP: In 2014, the California Public Utilities Commission established a Consistent Evaluation Protocol (CEP) for jurisdictional utilities to provide offer results confidentially for regulatory review in a common data format, for “benchmarking and general reporting purposes”.

Descriptive Information Included in the CEP Spreadsheet. The following shows the descriptive information about offers required in the CEP spreadsheet:

Descriptive information included in the CEP Spreadsheet

IOU (PGE / SCE / SDGE)	**Commercial Operation Date**	**Self-discharge** in Stand-by (MW/hour)
Name of Shortlisted Project	**Term** (Years)	**Ramp rate** – charge/discharge, up/down (MW/hour)
Interconnection Voltage (kV)	**Max Capacity** – Charge/Discharge at grid connection point (MW)	**AGC** (yes/no)
Interconnection Level (Transmission / Distribution)	**Min Capacity** – Charge/Discharge at grid connection point (MW)	**Regulation at zero** -- up/down (yes/no)
Local Capacity Area	**Qualifying RA Capacity** (MW)	**Contract Cost** ($)
Zone (NP / ZP / SP)	**Duration** of max sustainable discharge rate (Hours)	**Variable O&M** for discharging ($/MWh)
Status (New / Existing)	**Efficiency** at max capacity (%)	**Fixed O&M** ($/kW-year)
Product (Dispatchable / RA)	**Max daily switches** – charge/discharge (# charges per day)	
Energy Storage Technology	**Max cycles** per lifetime (# cycles)	