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FPLE - Beacon Solar Energy Project Dry Cooling Evaluation

FPLS-0-LI-450-0001 Rev B

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FPL Energy

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Any questions concerning the information or its interpretation should be directed to Geoff Baxter, Project Manager.

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1. INTRODUCTION

FPL Energy (FPLE) has hired Worley Parsons to provide conceptual design and permitting support for the Beacon Solar Energy Project (Beacon), a 250 MW parabolic trough solar facility. The base design of the facility includes a surface condenser and wet cooling tower for condensing the steam turbine exhaust. Groundwater is proposed as the source of makeup water to the cooling tower and all other plant needs. At the request of FPLE, WorleyParsons has evaluated alternatives to the base cooling design. This report serves to document the gathered information, analysis and conclusions regarding the base and alternate cooling methods. In addition, information from this report will be incorporated into the Beacon Solar Energy Project California Energy Commission (CEC) Application For Certification (AFC).

Two alternate cooling technologies have been considered - dry cooling with an air cooled condenser (ACC), and wet/dry hybrid cooling systems. (Note: The wet/dry hybrid is sometimes called a parallel condensing system and is different than a wet/dry cooling tower that is designed specifically for plume abatement). For each of the dry and hybrid technologies, three options reflecting different pricing, sizing, performance and water use (hybrid only) have been considered. The inclusion of multiple options in each cooling technology provides a feel for the sensitivity of the different options on key parameters.

The base and two alternate technologies have been evaluated and are described below in the following categories: Design Assumptions, Capital Costs, Thermal Performance, and Water Treatment and Consumption.

2. DESIGN ASSUMPTIONS AND METHOD

2.1 Base Design - Wet Cooling

The base design cooling system consists of a steam surface condenser, circulating water pumps, and an induced draft counter-flow cooling tower. The induced draft tower is understood to have the lowest life cycle cost for this 250 MW size facility compared to other cooling tower types.

The design assumptions for the wet cooling design are as follows:

Dry Bulb	103.5 deg F
Wet Bulb	68 deg F
Cooling tower approach temp	9 deg F
Cooling tower range	20 deg F
Circulating water flow rate	149,000 gpm
Condenser Terminal Temperature Difference (TTD)	5 deg F

The base design achieves a steam turbine back pressure of 2.1 inches HgA at the rated 250 MW and the stated design conditions.

2.2 Dry Cooling

The dry cooling alternative utilizes an air cooled condenser to cool the exhaust steam using a large array of fans that force air over finned tube heat exchangers. The heat is rejected directly to the atmosphere, and no external water supply is needed. Three different options having inlet temperature differences (ITD) of 35 °F, 40 °F, and 45 °F, were considered for the dry cooling alternative. The ITD is defined as the difference between the ambient air temperature at the design point and the steam condensation temperature within ACC. The smaller the ITD, the more aggressive the design resulting in better STG backpressure but at a higher cost. An ITD of around 40 °F is considered typical in the industry. For purposes of this evaluation a more aggressive option of 35 °F ITD, and a more conservative option of 45 °F ITD, were also considered.

The sizing criteria in the following table were used to obtain budgetary quotes from a vendor:

Table 1 – ACC Design Criteria

			Option 1	**Option 2**	**Option 3**
			35 ITD	**40 ITD**	**45 ITD**
Parameter		Units	**Value**	**Value**	**Value**
Ambient Conditions					
	Elevation	ft	2,314	2,314	2,314
	Temperature (DB)	°F	103.5	103.5	103.5
	Temperature (WB)	°F	68.0	68.0	68.0
ITD		°F	35	40	45
Steam Turbine Exhaust Enthalpy		Btu/lb	1,045.8	1,054.6	1,063.6
Steam Turbine Exhaust Flow		lb/hr	1,848,207	1,884,259	1,919,791
Steam Turbine Exhaust Back Pressure		Inches HgA	6.24	7.06	8.00

The three options shown here provide a range of pricing and performance of dry cooling systems. However, if it is determined that dry cooling will be used, further items must be considered in the ACC sizing in conjunction with the STG supplier including maximum exhaust pressure alarm and trip pressure. Option 2 and Option 3 ACC designs shown here may not meet the STG back pressure requirements at the high ambient temperature conditions for one or more STG supplier designs.

2.3 Wet-Dry Hybrid Cooling

The hybrid cooling system is a combination of wet and dry cooling, utilizing both a wet cooling tower/surface condenser and an ACC in a parallel configuration. In this way the air cooled portion can be used as the primary heat sink and the water cooled portion supplements the cooling load at higher ambient conditions as needed. Utilizing the air cooled portion for the majority of operation, the hybrid system reduces plant water consumption and wastewater generation significantly. However, a hybrid cooling system has the additional complexity of redundant cooling systems, which tends to drive costs higher.

The hybrid system splits the cooling duty between wet and dry systems, and the split between wet and dry cooling can be adjusted to almost any ratio. For this evaluation, three separate ratio split options were assumed and used to analyze the hybrid cooling system performance. The ACC was sized for a desired steam turbine exhaust pressure at a specific net output at the annual average ambient conditions, and the wet cooling tower was then sized to accommodate additional cooling duty as needed to achieve a desired steam turbine exhaust pressure at the hot day design point ambient conditions while having a net plant output of 250 MW.

The sizing criteria in the following table were used to obtain budgetary quotes from a vendor:

Table 2 – Wet/Dry Hybrid Design Cases

Parameter		Units	Option 1 Value	Option 2 Value	Option 3 Value
Ambient Conditions					
	Elevation	ft	2,314	2,314	2,314
	Temperature (DB)	°F	71.0	71.0	71.0
	Temperature (WB)	°F	52.0	52.0	52.0
Dry Cooling Design Point			**250 MW NET**	**200 MW NET**	**150 MW NET**
Steam Turbine Exhaust Enthalpy		Btu/lb	1,010.0	1,010.0	1,010.0
Steam Turbine Exhaust Flow		lb/hr	1,672,843	1,272,761	1,084,459
Steam Turbine Exhaust Back Pressure		Inches HgA	2.97	2.97	2.97
Combined Hybrid System Requirements			**250 MW NET**	**250 MW NET**	**250 MW NET**
Ambient Conditions					
	Temperature (DB)	°F	103.5	103.5	103.5
	Temperature (WB)	°F	68.0	68.0	68.0
Steam Turbine Exhaust Enthalpy		Btu/lb	1,033.1	1,033.1	1,033.1
Steam Turbine Exhaust Flow		lb/hr	1,779,347	1,779,347	1,779,347
Steam Turbine Exhaust Back Pressure		Inches HgA	5.10	5.10	5.10
Maximum Duty		MMBtu/hr	1663	1663	1663

Of these hybrid cooling options, Option 1 has a comparatively larger ACC with smaller surface condenser and wet tower, while Option 3 is the reverse. Note that the largest hybrid option ACC is smaller (by surface area) than the smallest pure ACC Option 3. A key advantage of the hybrid system is the benefit of having the wet cooling tower (which works off the wet bulb temperature) to achieve better steam turbine back pressure on hot days.

2.4 Method

Using the criteria given above, budgetary quotes for ACC and hybrid systems were requested in order to determine impact on performance, cost and water consumption.

Performance models of the steam cycle were created in Gatecycle version 5.61.0.r to evaluate the impact of the different cooling systems on cycle output and efficiency.

Vendor cost data was combined with estimates for installation to arrive at installed costs for the different alternatives. Care was taken to account for the changes in scope, such as removal of the circulating water pumps and the addition of an auxiliary cooling source for a stand alone ACC system.

Impacts of the cooling system on water consumption and water treatment equipment were done by calculating the operating point and annual water consumption, and evaluating the changes in the water treatment equipment for the different alternatives.

For the Life Cycle Cost Analysis discussed in section 6 two scenarios were evaluated. One scenario assumes that the solar field size is held constant and the annual net output of the plant decreases due to the efficiency impact for each cooling technology alternative. The second scenario assumes that the solar field size will increase to offset the efficiency impact for each cooling technology alternative. In both cases boiler feed water pumps, HTF Pumps, and the Steam Generator Heat Exchanger sizes were changed to accommodate increase in steam and HTF flow

The results of the evaluation are presented in the following sections.

3. CAPITAL COSTS

Capital costs have been determined using a combination of vendor budgetary proposals, in house equipment cost estimates, and in house installation cost estimates. The capital costs should be considered as +/- 30% range of accuracy. However, the relative accuracy between the various options (e.g. option A compared to option B) is considered +/-10%.

As expected, there is a wide range in capital cost among the three alternatives, as well as among the different options considered for the dry and hybrid cooling systems. Differences in operating costs and plant performance are covered in later sections of this document.

3.1 Base Design Cooling System

Worley Parsons obtained a budgetary quote for an 11-cell wet cooling tower for $4,275,000. An earlier budgetary quote for the condenser has been adjusted for the current performance requirements. The quotes and data sheets are included in Appendix A. Other internal estimates were used for the circulating water piping, circulating water pumps, and installation costs.

3.2 Air Cooled Condenser

Worley Parsons obtained a budgetary quote covering three different ACC designs as specified in the design assumptions. The full quote and data sheet is included in Appendix B. Installation costs were estimated internally. For the ACC only alternative, costs were also included for an air cooled auxiliary cooling water system.

3.3 Wet/Dry Hybrid System

WorleyParsons obtained a budgetary quote covering the ACC and wet tower equipment for the three hybrid options as specified in the design assumptions. A full quote with base material scope and specifications is included in Appendix C. It was not possible to obtain budgetary quotes for the surface condensers, which have been estimated using in house information.

The following table is a summary of the complete cost analysis showing the line items that build up the overall total installed capital cost for the seven different options (one base option, three ACC options and three hybrid options). Installed costs are summed with and without consideration of the water treatment equipment, which is discussed further within this report.

Table 3 – Capital Cost Summary

Case	Base	ACC 1	ACC 2	ACC 3	Hybrid 1	Hybrid 2	Hybrid 3
Description	Cooling tower	35 ITD	40 ITD	45 ITD	250 MW ACC	200 MW ACC	150 MW ACC
Number of cooling tower cells	11				3	4	4
Number of ACC cells		42	40	35	35	25	20
HTF Pumps Estimated Capital Cost	$3,000,000	$3,300,000	$3,300,000	$3,300,000	$3,150,000	$3,150,000	$3,150,000
Boiler Feed Water Pumps Estimated Capital	$2,300,000	$2,400,000	$2,400,000	$2,400,000	$2,320,000	$2,320,000	$2,320,000
Steam Generator Heat Exchanger Estimated Capital Cost	$12,500,000	$14,100,000	$14,100,000	$14,100,000	$13,400,000	$13,400,000	$13,400,000
Solar Field Sizing [1]	$410,000,000	$463,000,000	$463,000,000	$463,000,000	$441,000,000	$441,000,000	$441,000,000
Cooling tower Estimated Cost	$4,275,000				$1,025,000	$1,475,000	$1,675,000
Cooling tower basin + installation Estimated Cost	$1,500,000				$350,000	$450,000	$500,000
Circulating Water pumps + installation Estimated Cost	$600,000				$265,000	$350,000	$375,000
Surface Condenser + installation Estimated Cost	$3,500,000				$700,000	$875,000	$975,000
Circulating Water piping Estimated Cost	$1,300,000				$750,000	$950,000	$1,050,000
Circulating Water piping installation Estimated Cost	$520,000				$400,000	$450,000	$500,000
ACC Equipment Only		$42,500,000	$36,900,000	$33,300,000	$28,260,000	$21,860,000	$19,620,000
ACC Installation		$12,075,000	$11,500,000	$10,062,500	$10,062,500	$7,187,500	$5,750,000
Closed cycle aux cooler (installed)		$450,000	$450,000	$450,000			
Water Treatment Capital Cost-Installed	$21,158,000	$2,500,000	$2,500,000	$2,500,000	$11,116,000	$11,116,000	$11,116,000
TOTAL CAPITAL COST with Solar Field Size Consideration	**$460,653,000**	**$540,325,000**	**$534,150,000**	**$529,112,500**	**$512,798,500**	**$504,583,500**	**$501,431,000**
TOTAL CAPITAL COST without Solar Field Size Consideration	**$50,653,000**	**$77,325,000**	**$71,150,000**	**$66,112,500**	**$71,798,500**	**$63,583,500**	**$60,431,000**

1. Solar field capital cost applies to the case where the solar field size is increased to offset lower cycle efficiency.

4. PERFORMANCE

ASHRAE climate data has previously been used to establish the summer design point, annual average and winter ambient conditions for the facility. These ambient conditions were used in the Beacon project heat and mass balances for the base design, which have been issued to FPLE. Appendix D shows a complete summary of the ambient conditions that were used for the cycle design.

The issued heat balances have been used as the baseline for performing the alternative cooling performance calculations. The heat balances established an assumption for the solar energy available at the annual average and winter operating points. The performance modeling used to generate these results for the alternative cooling methods has used those assumptions for the annual average and winter operating conditions.

One area where this analysis differs from the issued heat balances is at the hot day design point. In light of the FPLE requirement that the facility should have 250 net MW regardless of heat rejection system, and because air cooling requires greater solar thermal energy input to achieve the desired electrical generation, it has been assumed that there is sufficient solar thermal energy available from the field to generate the necessary steam flow for the alternate cooling system cycles to meet 250 net MW. In reality, this means that the cycles other than the base are encroaching upon the established solar multiple of the base design having wet cooling.

Because of the requirement to meet 250 net MW at the design point, the performance table below shows equal plant output for all the cooling options at this operating condition. The performance item that then distinguishes the cooling options is the steam cycle efficiency, so that a lower efficiency translates to increased solar thermal energy needed for the steam cycle.

Various Gatecycle models were created to model the different cooling configurations. They were created at the model design point using vendor information, and then run at "off design" conditions to determine plant performance for the annual average and winter ambient.

There has been some effort within Gatecycle to optimize the steam turbine for the different types of cycles, recognizing that the operating back pressure heavily influences the size of the steam turbine last row blade. Different last row blade lengths were modeled for the ACC and hybrid options as compared to the base design options. This modeling was done based on generic information, not tied to specific vendor information.

The calculation of steam cycle efficiency has been done on a net power basis, after subtraction of the auxiliary loads from the gross generation.

4.1 Base Design Cooling System

The performance shown for the base cooling system is taken directly from the issued heat balances.

4.2 Air Cooled Condenser

Three different design cases using an ITD of 35°F, 40°F, and 45°F were used to model the ACC performance.

4.3 Wet/Dry Hybrid System

Plant performance was modeled for the three different hybrid cooling cases using Gatecycle software. The wet cooling tower was sized according to the size of the ACC for each case in order to maintain the base case output of 250 MW. Table 4 shows the wet cooling tower sizing used for the hybrid performance analysis.

Table 4– Wet Cooling Tower Sizing for Hybrid Design

Case		Hybrid 1	Hybrid 2	Hybrid 3
Wet Cooling	**Units**	**3-Cell Tower**	**4-Cell Tower**	**4-Cell Tower**
Flow	gpm	41,768	63,811	74,039
Evaporation	gpm	1003	1530	1775
Footprint	ft^2	6336	9504	11988

4.4 Performance Results

Table 5 is a summary of the complete performance analysis showing the net output and the steam cycle efficiency for the seven different options across the specified ambient conditions.

Table 5 – Performance Summary

Performance Summary						
Cooling Option	Design Point		Annual Average		Winter Conditions	
	Net Output(MW)	Steam Cycle Efficiency(%)	Net Output(MW)	Steam cycle Efficiency(%)	Net Output(MW)	Steam cycle Efficiency(%)
Base Design	250.0	34.7	151.6	33.7	54.3	37.5
ACC (35 ITD)	250.0	31.4	141.4	31.4	49.2	25.0
ACC (40 ITD)	250.0	31.1	142.8	31.7	49.2	24.9
ACC (45 ITD)	250.0	30.6	143.0	31.7	49.4	25.1
Hybrid 1	250.0	32.6	145.0	32.2	*49.2	*25.0
Hybrid 2	250.0	32.6	143.8	31.9	*49.2	*25.0
Hybrid 3	250.0	32.6	141.4	31.4	*49.2	*25.0

*Note: Hybrid performance was not evaluated for winter ambient conditions. Values are based on ACC performance.

4.5 Performance Discussion

As noted previously, at the design point all cooling scenarios were run to achieve the desired 250 net MW. The steam cycle efficiency is the differentiator, showing the inefficiencies of the dry and hybrid cooling options compared to the base design. There is a significant decrease in cycle efficiency moving to the ACC options. Within those options, the level of aggressiveness in sizing the ACC is reflected in the efficiency results. For the hybrid alternative, the design point results are considered identical. Per the design criteria for the hybrid systems, the design point steam turbine back pressure is the same for the three hybrid options, therefore it is expected that the cycle performance is the same for the three.

At the annual average operating point there are differences in power output and cycle efficiency. This is also expected since all the cases at the annual average point were run with the same solar thermal energy input as was defined in the issued heat balances using the wet cooling option. The significant decrease in both power output and cycle efficiency for all options other than base shows the ability of the wet tower to achieve better back pressure at the annual average conditions.

The pure ACC options show very similar performance. From modeling it was determined that all three ACC's, despite having notable performance differences on the hot day, were able to reach the assumed minimum ACC operating pressure of 2.0 Inches HgA. (If not limited by user, the different designs achieved predictable different pressures, but the 2.0" limit was applied based on real world experience.) Because the steam turbine back pressure is the same for the three ACC options, the gross steam turbine output was essentially the same, and the only difference in performance being subtle changes in auxiliary loads. The three ACC options can be considered equal in performance at the annual average condition.

At the annual average condition it was determined that the hybrid options could all be run with only the ACC in service, the wet tower and condenser being out of service. Because of the smaller ACC's used in the hybrid options compared to the pure ACC options, none of them achieved the 2.0" HgA lower pressure limit. There were subtle differences in back pressure across the three options that are reflected in the performance. As a whole the hybrid options show about equal performance as the pure ACC's despite having slightly higher back pressure, a difference that is probably due to steam turbine optimization. In practical terms, the pure ACC and hybrid options have comparable performance at the annual average point.

At the winter operating conditions, all the ACC and hybrid designs were limited to the 2.0" HgA lower operating limit, and have essentially the same performance. The base design is clearly better, being able to operate at a lower back pressure.

5. WATER TREATMENT AND CONSUMPTION

Wells 63, 48 and 43 for the Beacon Project were sampled and analyzed for key chemistry parameters important for identifying the required water treatment and chemical feed systems. Silica was measured in concentrations between 30 and 35.9 ppm, thus providing constraints on the cycles of concentration for the cooling tower without treatment. Silica saturation limit at cooling water chemistry conditions is approximately 150 ppm, thus limiting the cycles of concentration (COC) to approximately 4 without a silica inhibitor. In addition, the alkalinity of Well 48 was elevated (290 ppm) compared to Well 63 (160 ppm) and Well 43 (170 ppm), thus potentially requiring more sulfuric acid and possibly limiting the COC also to approximately 4 to maintain 800 ppm sulfate as $CaCO_3$. The presence of calcium can cause scale when cooling tower water is cycled up, and scale inhibitor should be used as a preventative measure. With the makeup water chemistry, plant conditions and cycles of concentration modeled, the WaterCycle program indicated that scale could be prevented with a scale inhibitor, and thus calcium is not considered a limiting parameter.

5.1 Wet Cooling Vs. Dry Cooling

Parallel work on the water treatment systems has resulted in three categories or options; minimal makeup treatment and no blowdown treatment (Option 1), makeup pre-treatment only (Option 2), and blowdown post-treatment only (Option 3). Based on the makeup water chemistry and limited cycles of concentration (COC) that can be achieved without makeup water treatment using a wet condenser design, the pre-treatment option (Option 2) is considered the base for this evaluation, and the costs for this design are aligned with the wet tower base design. For the alternative cooling technologies, additional options are being considered for the different water treatment design conditions that the cooling systems present. Therefore, the pre-treatment Option 2 will be compared with water systems needed to support air cooled condenser operation (Option 4). (Note that number of Options for water treatment is different than the numbering of the ACC or hybrid cooling options).

The pre-treatment option for the Beacon project takes into account the silica concentration in the makeup water that limits the COC that can be achieved in the cooling tower to approximately 4 without treatment. The pre-treatment components would consist of an ion exchange system containing strong acid cation exchange vessels, a degasifier, and strong base anion exchange vessels. The system would be regenerated on site, and therefore would require sulfuric acid and sodium hydroxide chemical storage tanks. Water upstream of the ion exchange system would be contained within large Service Water Storage Tanks and downstream of the demin would be contained in a Treated Water Storage Tank (e.g., with a combined storage of ~5,190,000 gallons). A small storage tank for Demin Water and Neutralized Water Storage Tanks would also be required. With some raw water feed to the cooling tower (e.g., 5-20%), the cooling tower would require commonly used chemicals including sulfuric acid, sodium hypochlorite and scale inhibitor (with usage volumes being reduced compared to cooling water without pre-treatment). The steam cycle would also require makeup water treatment, which could be accomplished with a mixed bed demineralizer system to provide final polishing.

Using pre-treatment ion exchange provides the benefit of reducing the potential for silica scale, calcium scale, and sulfuric acid corrosion, eliminates the need for reverse osmosis for steam cycle makeup, and allow the cooling tower COC to increase (e.g., ~15), thereby reducing wastewater. This option for wet cooling will result in an annual makeup of approximately 3353 gpm with summer makeup increasing to 4054 gpm. Blowdown to the evaporation ponds will be approximately 462 gpm annually with blowdown increasing in the summer to approximately 563 gpm due to increased evaporation.

In comparison, the makeup water required to support an ACC would be reduced and would consist primarily of the volumes necessary for reverse osmosis feed (creating demin water for steam cycle makeup and mirror washing), and quench water. Makeup for these systems would be approximately 178 gpm with wastewater flow of approximately 82 gpm annually. These flows would increase by approximately 10% in the summer.

The water system required with an ACC would consist of components designed to provide high-purity water to the steam cycle and for mirror washing. This system would consist primarily of a pre-filter (for iron and manganese removal), a reverse osmosis system and an ion exchange system (e.g., mixed bed polishing vessel). Smaller tanks would be required for the Service Water Storage Tank and Demin Water Storage Tank. Reverse osmosis reject and steam generator blowdown would be diverted to evaporation ponds. With blowdown flow using the ACC approximately 20% of the wet cooling option, the acreage of evaporation ponds would also be reduced proportionately from approximately 25 acres of evaporation ponds for wet cooling to 5 acres of evaporation ponds for an ACC.

Capital costs for the pre-treatment option (Option 2) for wet cooling include an ion exchange system for makeup, chemical feed for demin regeneration, chemical feed for circulating water, chemical and water storage tanks, a mixed bed demin for steam cycle makeup, and 25 acres of evaporation ponds. An estimate for the Capital Cost for these items is $21,158,000. O&M costs for the water treatment system are $1,420,000 per year, excluding labor. The volume required for makeup is approximately 1599 acre-feet per year.

Capital costs for the water treatment components to support an air cooled condenser (Option 4) include an inlet filter, reverse osmosis, Service Water and Demin Water tanks, and approximately 5 acres of evaporation ponds. An estimate for the Capital Cost for these items is $2,500,000. O&M costs for the water treatment system are $132,000 per year, excluding labor. The volume required for makeup is approximately 79 acre-feet per year. See Appendix E for a full cost comparison of capital and O&M costs between the wet cooling tower and the ACC water treatment systems. (Note: These values are rough estimate based on a conceptual design, and are not based on quoted prices from suppliers. O&M costs are based on chemicals and power, and do not include labor).

5.2 Wet Cooling Vs. Hybrid Wet/Dry Cooling

Hybrid cooling (Water Treatment Option 5) uses water from the circulating water system during the hottest days when air cooling is insufficient to maximize electrical power output and supplemental wet cooling is necessary. In order to support hybrid cooling, a circulating water system will be needed to enable evaporation rates ranging from approximately 1400 gpm to 2300 gpm. To support the circulating water system, chemical feed including sulfuric acid, sodium hypochlorite and scale inhibitor will be needed. Since silica is present in makeup water, pre-treatment is suggested to increase the cycles of concentration (COC) in the circulating water.

Ion exchange pre-treatment provides the benefit of reducing the potential for silica scale, calcium scale, and sulfuric acid usage and potential acid corrosion, eliminates the need for reverse osmosis for cycle makeup, and allows the cycles of concentration in the cooling tower to increase (e.g., ~15). The option for a water pre-treatment system used for wet cooling will result in a summer makeup of approximately 2502 gpm. Blowdown to the evaporation ponds will be approximately 144 gpm in the summer months and discharge to the evaporation ponds will be approximately 349 gpm.

A high-purity water system is also required for a hybrid plant's steam cycle and would consist of an ion exchange system for steam cycle makeup and mirror washing, consisting of a mixed bed vessel (possibly to be regenerated off-site) along with a Demin Water Storage Tank. These components would be used regardless of whether the condenser is using wet or dry cooling.

The circulating water system required for a hybrid cooling system would consist of components designed to reduce silica, calcium and alkalinity to the cooling water to enable cycling up of the water (e.g., ~15). The system would consist of a cation exchange vessel, a degasifier, and anion exchange vessel. The system would be regenerated on site, and therefore would require sulfuric acid and sodium hydroxide chemical storage tanks. Water upstream of the ion exchange system would be contained within large Service Water Storage Tanks and downstream of the demin would be contained in a Treated Water Storage Tank. A small storage tank for Demin Water and Neutralized Water Storage Tanks would also be required. With some raw water feed to the cooling tower (e.g., 5-20%), the cooling tower would require sulfuric acid, sodium hypochlorite and scale inhibitor (with usage volumes reduced compared to wet cooling options).

This circulating water system will not be required during the winter and perhaps some shoulder months with the plant's power output decreasing significantly (e.g., to 15% or less of maximum power) during the months of November, December and January. The transition from full power operation with hybrid wet cooling to dry cooling would decrease the makeup water required for operation from 2502 to 157 gpm, and would decrease the blowdown from 144 to 0 gpm during this period, although wastewater from ion exchange regeneration would still need to be processed and waste flows would decrease from 349 gpm in the summer to 36 gpm in the winter. As a result, the need for evaporation ponds would decrease, although 10 acres will still need needed to contain the blowdown during the summer months. Chemical feed costs in the winter would also decrease compared to wet cooling.

Capital costs for the water treatment components to support a hybrid system (Option 5) include an ion exchange system for makeup, chemical feed for demin regeneration, chemical feed for circulating water, chemical and water storage tanks, and 10 acres of evaporation ponds. An estimate for the Capital Cost for these items is $11,116,000. O&M costs for the water treatment system are $815,000 per year, excluding labor. The volume required for makeup is approximately 625 acre-feet per year. See Appendix E for a full cost comparison of capital and O&M costs between the wet cooling tower and the hybrid wet/dry system. (Note: These values are rough estimate based on a conceptual design, and are not based on quoted prices from suppliers. O&M costs are based on chemicals and power, and do not include labor).

5.3 Water Consumption

This analysis compares the water consumption between the different cooling options. In order to be able to compare and contrast how the plant's cooling system affects water consumption, water balances were generated for average ambient conditions.

5.3.1 Cooling Tower

The wet cooling tower will consume a large amount of water, which is lost through evaporative cooling and also through blowdown. Water consumption varies depending on fluctuating ambient temperatures, therefore two cases for water treatment options were generated for average summer conditions and average annual conditions. The complete water balances can be found in Appendix F.

5.3.2 Air Cooled Condenser

Utilizing a dry cooling system will consume a minimum amount of water. The ACC is a closed loop system that does not utilize evaporative cooling, and therefore blowdown is not necessary to maintain water chemistry (There will be a minimal loss of about 1% of the steam flow for the HRSG blowdown, which is negligible for this comparison).

5.3.3 Wet/Dry Hybrid System

The hybrid cooling system can be used to reduce water consumption in a flexible manner. The hybrid design allows for variation in the cooling load between the wet and the dry system. This evaluation has considered three hybrid options that require differing amounts of wet cooling and makeup water. When conditions are ideal, the plant will utilize the full capacity of the ACC and achieve no water loss from the ACC due to evaporation or blowdown. When necessary, a fraction of the cooling load can be pushed over to the wet cooling tower at the discretion of the operator. This creates a wide range of water reduction capability for the hybrid system. The size of the ACC is the limiting factor for percentage of water reduction in a hybrid system. For the hybrid system, the cooling tower will dictate the water consumption of the complete cooling system. For purposes of water consumption estimation, wet cooling (Option 2) was compared with the dry ACC cooling (Option 4) and hybrid cooling (Option 5).

Table 6 – Estimated Water Consumption and Water Treatment Costs at Annual and Summer Conditions

	OPTION 2: Pre-treatment	OPTION 4: Air Cooled Condenser	OPTION 5: Hybrid Wet/Dry Cooling
Annual/Summer Makeup (gpm)	3353/4054	178 / 192	157 / 2502
Annual/Summer Blowdown (gpm)	197 / 240	0 / 0	0 / 144
Annual/Summer Flow to Evap Ponds (gpm)	462 / 563	82 / 92	36 / 349
Annual Makeup (AFY)	1599	79	625
Annual Makeup Savings (AFY) compared to Opt. 2	0 (compared to Option 2)	1520	974
O&M Costs ($1000) per year (excluding labor)	$1,420	$132	$815
Capital Costs ($1000)	$21,158	$2,500	$11,116

6 LIFE CYCLE COST ANALYSIS

To understand the impact each cooling technology will have during the entire life cycle of the Beacon Solar Energy Project, a Life Cycle Cost Analysis was performed. The purpose of the Life Cycle Cost Analysis (LCCA) is to compare the expected differences in net present value among the three cooling technologies relative to each other. The net present value (NPV) accounts for initial capital costs, ongoing operating costs, and ongoing revenue from generation. The reduction in NPV for the alternative cooling technologies compared to the base is a measure of the economic disadvantage they cause to the project.

The Solar Advisor Model (SAM) software was used to determine the net annual generation for each technology. SAM is limited in modeling dry cooling systems and is currently not designed to model hybrid systems. However, the different cooling technologies result in different steam cycle efficiencies. These cycle efficiencies result in different annual generation as determined using SAM and included in Appendix I. A separate calculation method, which accounts for dry cooling was also performed as a check of the SAM results. For the second method, steady-state heat balance cases were used to create performance curves of the solar energy required for a given output. A simplified integration of solar energy available resulted in the relative difference in net generation between the wet and dry technologies. The results of this method are included as Appendix G and H. Though there were differences in the absolute annual generation between the results of the two methods, the relative difference in generation among the wet and dry cooling technologies was consistent using the two methods. Table 7 summarizes the difference between the net annual output for each technology as calculated by SAM.

Table 7 – Net Annual Output for Different Cooling Technologies Using Same Solar Field Size (all rated for 250 MW under design conditions).

SAM OUTPUT	Base Design (Wet Cooling)	ACC (40 ITD)	Hybrid 2
Estimated Annual Energy Output (MWhr)	**602,527**	**557,365**	**574,771**
% Difference to Base Design	**0.0%**	**-7.5%**	**-4.6%**

The three designs studied for Table 7 have the same size solar field and are each rated for 250 net MW. Since the alternative cooling technologies are less efficient in the steam cycle, it follows that a solar multiple for the alternatives would be less than the a solar multiple for the base design. Table 7 shows the result of the solar multiple in lower annual generation.

In order to maintain the same solar multiple for the different designs, it is necessary to increase the size of the solar field for the dry and hybrid cooling technologies in order to offset the lower steam cycle efficiency. Doing so results in the same net annual generation for the base and alternatives. The LCCA was prepared using both approaches, one keeping the same solar field size and suffering a loss in annual power generation, and the other increasing the size of the solar field to maintain a constant annual net generation.

Net Present Values were determined based on the difference between each alternate technology as compared with the Base Design. Using the capital costs provided by vendors or estimated by WorleyParsons, along with operating and maintenance (O&M) cost estimates, a Life Cycle Cost Analysis was performed for the three different technologies. The results are summarized in Table 8. See Appendix J for the full Life Cycle Cost Analysis.

To develop an estimate for equipment O&M costs for the Wet, Dry, and Hybrid Cooling options a desktop study was performed and a consensus was determined based on the results of the different sources. Considering the wide range of conclusions made in published reports WorleyParsons has estimated $100,000 for an annual O&M cost for the base design and $200,000 for the ACC option. The hybrid option was split between the base design and ACC option. Forty percent of the base design would be used in the hybrid O&M estimate and sixty percent of the ACC option for an estimated annual O&M cost of $160,000

Table 8 – Net Present Value For Alternative Cooling Technologies relative to Base Design (Wet Cooling).

	Dry Cooling Technology		**Hybrid Cooling Technology**	
	Solar Field Size Held Constant	**Solar Field Size Increased**	**Solar Field Size Held Constant**	**Solar Field Size Increased**
Annual Net Generation Impact relative to Wet Cooling (MWhr)	-45,162	0	-27,756	0
Annual Revenue Impact from Net Generation Impact Relative to Wet Cooling	($6,774,350)	$0	($4,163,410)	$0
Capital Expenses for Dry Cooling Relative to Wet Cooing[1]	($20,497,000)	($73,497,000)	($12,930,500)	($43,930,500)
Total Net Present Value of O&M Expenses relative to Wet Cooling[2]	$12,980,000	$12,980,000	$5,870,000	$5,870,000
Total Net Present Value of Generation Revenue Relative to Wet Cooling	($63,860,000	$0	($39,250,000)	$0
Total Net Present Value Impact relative to Wet Cooling	($71,100,000)	($60,100,000)	($46,300,000)	($38,000,000)

1. The capital costs show in the table include cooling equipment, boiler feed water pumps, HTF pumps, and solar field addition for the case where the solar field size is increased.

2. O&M Expenses include water treatment, operating, and water pumping costs

3. Standard accounting format used for tables. ($) denotes a negative number.

As shown in Table 8 for the case where the solar field is held constant, implementing the dry cooling technology would impact net annual generation by 45,000 MWhr relative to the base design. The total net present value impact for the decrease in generation revenue would be $64 Million. The total net present value difference to implement dry cooling would be $71 Million. For hybrid cooling the net annual generation impact would be nearly 28,000 MWhr relative to the base design. The total net present value impact for the decrease in revenue would be $39 Million. The total net present value difference to implement hybrid cooling would be $46 Million.

If the solar field is increased to offset the reduced steam cycle efficiency, the resulting NPV impact is less than if the solar field is unchanged.

7. CONCLUSION

The wet cooling tower base configuration has the lowest capital cost and far better thermal performance than the alternative cooling technologies. When combined into an overall Life Cycle Cost Analysis, the benefit of the wet cooling base configuration is even more apparent. While it does require a significant amount of makeup water, which is factored into the Life Cycle Cost Analysis of the plant, the advantages in capital cost, performance, and revenue outweigh this concern.

As a solar facility with a relatively fixed amount of insolation, every effort should be taken to maximize the conversion of the sunlight's energy into electricity. Dry cooling performs least efficiently during the summer months when solar energy is most abundant, and the plant should have the greatest output.

BEFORE THE ENERGY RESOURCES CONSERVATION AND DEVELOPMENT COMMISSION OF THE STATE OF CALIFORNIA
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APPLICATION FOR CERTIFICATION For the *BEACON SOLAR ENERGY PROJECT*	**Docket No. 08-AFC-2**
	PROOF OF SERVICE *(Revised 11/10/08)*

INSTRUCTIONS: All parties shall either (1) send an original signed document plus 12 copies or (2) mail one original signed copy AND e-mail the document to the address for the Docket as shown below, AND (3) all parties shall also send a printed or electronic copy of the document, which includes a proof of service declaration to each of the individuals on the proof of service list shown below:

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DECLARATION OF SERVICE

I, April Albright, declare that on January 6, 2009, I deposited copies of the attached Dry Cooling Evaluation and Notice of Proposed Preliminary Determination of Compliance in the United States mail at Sacramento, CA with first-class postage thereon fully prepaid and addressed to those identified on the Proof of Service list above.

Transmission via electronic mail was consistent with the requirements of California Code of Regulations, title 20, sections 1209, 1209.5, and 1210. All electronic copies were sent to all those identified on the Proof of Service list above.

I declare under penalty of perjury that the foregoing is true and correct.

Original signature in Dockets
April Albright

Attachments