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BEFORE THE ARIZONA CORPORATION COMMISSION

COMMISSIONERS
KRISTIN K. MAYES, CHAIRMAN
GARY PIERCE
SANDRA D. KENNEDY
PAUL NEWMAN
BOB STUMP

IN THE MATTER OF THE APPLICATION OF HUALAPAI VALLEY SOLAR LLC, IN CONFORMANCE WITH THE REQUIREMENTS OF ARIZONA REVISED STATUTES §§ 40-360.03 AND 40-360.06, FOR A CERTIFICATE OF ENVIRONMENTAL COMPATIBILITY AUTHORIZING CONSTRUCTION OF THE HVS PROJECT, A 340 MW PARABOLIC TROUGH CONCENTRATING SOLAR THERMAL GENERATING FACILITY AND AN ASSOCIATED GEN-TIE LINE INTERCONNECTING THE GENERATING FACILITY TO THE EXISTING MEAD-PHOENIX 500kV TRANSMISSION LINE, THE MEAD-LIBERTY 345kV TRANSMISSION LINE OR THE MOENKOPI-EL DORADO 500kV TRANSMISSION LINE.	**CASE NO. 151** **Docket No. L-00000NN-09-0541-00151** **NOTICE OF FILING STAFF'S DIRECT TESTIMONY (CORRECTED VERSION)**

Staff of the Arizona Corporation Commission ("Staff") hereby refiles the Direct Testimony of Laura A. Furrey of the Utilities' Division. The filing on June 7, 2010 inadvertently omitted several pages of testimony and the attachment.

RESPECTFULLY SUBMITTED this 15th day of June, 2010.

Charles Hains by [signature]

Charles H. Hains
Arizona Corporation Commission
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Arizona Corporation Commission
DOCKETED
JUN 15 2010
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Original and twenty (20) copies of the foregoing filed this 15th day of June, 2010 with:

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Phoenix, Arizona 85007

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By Roseann Osorio

BEFORE THE ARIZONA CORPORATION COMMISSION

KRISTIN K. MAYES
Chairman
GARY PIERCE
Commissioner
PAUL NEWMAN
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Commissioner

IN THE MATTER OF THE APPLICATION OF HUALAPAI VALLEY SOLAR LLC, IN CONFORMANCE WITH THE REQUIREMENTS OF ARIZONA REVISED STATUTES §§ 40-360.03 AND 40-360.06, FOR A CERTIFICATE OF ENVIRONMENTAL COMPATIBILITY AUTHORIZING CONSTRUCTION OF THE HVS PROJECT, A 340 MW PARABOLIC TROUGH CONCENTRATION SOLAR THERMAL GENERATING FACILITY AND AN ASSOCIATED GEN-TIE LINE INTERCONNECTING THE GENERATING FACILITY TO THE EXISTING MEAD-PHOENIX 500kV TRANSMISSION LINE, THE MEAD-LIBERTY 345kV TRANSMISSION LINE OR THE MOENKOPE-EL DORADO 500 kV TRANSMISSION LINE.

DOCKET NO. L-00000NN-09-0541-0151

DIRECT TESTIMONY

OF

LAURA FURREY

ELECTRICITY SPECIALIST

UTILITIES DIVISION

ARIZONA CORPORATION COMMISSION

JUNE 07, 2010

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ATTACHMENT

EXECUTIVE SUMMARY
HUALAPAI VALLEY SOLAR LLC
DOCKET NO. L-00000NN-09-0541-00151

Staff conducted a literature review on the use of wet, dry, and hybrid cooling systems in new power plants. Although general conclusions may be drawn from the literature, Staff is not making any recommendations regarding the method of cooling to be used in this application. This review is provided for informational purposes.

INTRODUCTION

Q. Please state your name, occupation, and business address.

A. My name is Laura Furrey. I am an Electricity Specialist employed by the Arizona Corporation Commission ("ACC" or "Commission") in the Utilities Division ("Staff"). My business address is 1200 West Washington Street, Phoenix, Arizona 85007.

Q. Briefly describe your responsibilities as an Electricity Specialist.

A. In my capacity as an Electricity Specialist, I provide recommendations to the Commission in a variety of electricity-related cases, including renewable energy projects and demand side management programs. I also perform research on energy-related topics as needed.

Q. Please describe your educational background and professional experience.

A. In 2002, I graduated from California Polytechnic State University – San Luis Obispo, receiving a Bachelor of Science degree in Environmental Engineering. In 2003, I joined Stanley Consultants, Inc. in Phoenix, Arizona as a civil designer. In 2005 I became a certified professional engineer in the State of California. In 2008, I graduated cum laude from Vermont Law School with a Juris Doctor degree, focusing on energy and environmental law. In 2008, I became a member of the State Bar of Arizona and began working with the American Council for an Energy-Efficient Economy in Washington, DC. In 2010, I became employed with the Staff of the Commission as an Electricity Specialist in the Telecom and Energy Unit. Since that time, I have attended various seminars and classes on general regulatory and energy issues.

Q. What is the scope of your testimony in this case?

A. My testimony is limited to providing Staff's attached literature review regarding wet cooling, dry cooling, and hybrid cooling systems and the associated economic and environmental impacts. Staff does not make any recommendations in the attached review and did not perform any separate analysis. Attachment A summarizes the information available related to various power plant cooling methods and draws general conclusions from that information.

Q. Please describe the information contained in Staff's literature review.

A. The literature review first describes each cooling system in general terms, then examines the various cooling systems currently available for use in new power plants, describing the amounts of water consumed by the various cooling systems used in different types of power plants, the comparative costs of such systems, and potential performance penalties. Available literature suggests that each system has advantages and disadvantages such that some systems may be better suited to certain locations based on site characteristics.

Q. What are Staff's conclusions based on the literature review you performed?

A. Based on the documents that were reviewed, it appears that, in general, power plants operating at high thermal efficiencies require less cooling water and cost less to operate. High thermal efficiencies are not as easily achieved with dry cooling systems because ambient dry bulb temperatures are always higher than ambient wet bulb temperatures. There is a tradeoff between stream flow, water use and availability, and energy output under the various cooling systems which should be evaluated on a site-specific basis, taking into consideration the value of water, fuel, emissions, and subsequent effects on electric rates.

However, as stated earlier, the scope of my assignment in this application was to prepare a review of available research and analyses on the topic of wet, dry, and hybrid cooling systems and the associated impacts. To the extent that I provide conclusions as part of the review, these are general conclusions and are not intended to provide the basis of a Staff recommendation with regard to this application.

Q. Does this conclude your Direct Testimony?

A. Yes, it does.

ATTACHMENT A

USE AND ASSOCIATED COSTS OF WET, DRY, AND HYBRID COOLING SYSTEMS IN NEW POWER PLANTS

UTILITIES DIVISION STAFF

ARIZONA CORPORATION COMMISSION

APRIL 14, 2010

Use and Associated Costs of Wet, Dry, and Hybrid Cooling Systems in New Power Plants
(April 14, 2010)

Introduction

In all thermal (Rankine-cycle) power plants, whether fossil-, nuclear-, or solar-fueled, heat is used to boil water into steam to run a steam turbine to generate electricity. The exhaust steam from the generator must be cooled prior to being heated again and turned back into steam.

Cooling System Options[1]

Cooling can be done with water (wet cooling) or air (dry cooling), or a combination of both (hybrid cooling). Thermal power plants (fossil, nuclear and solar[2]) must use some form of cooling to condense the steam which spins the turbine. From a cost and efficiency perspective, the preferred method, thus far, has been the use of large quantities of cooling water.[3] In 2000, thermoelectric power accounted for 3.3 percent of total freshwater consumption (3.3 billion gallons per day) and represented over 20 percent of nonagricultural water consumption.[4]

Once-Through Cooling Systems (Wet)

In a once-through cooling system, water from an external water source passes through the steam cycle condenser and is then returned to the source at a higher temperature with some level of contaminants. This system withdraws a significant amount of water, but consumes little at the plant site (with some evaporation occurring after the water is returned to its source).[5]

Recirculating Cooling Systems (Wet)

In recirculating (or closed-loop) wet systems, smaller amounts (typically 2 to 3% of the amount withdrawn for once-through cooling) are taken into the plant, but the majority is evaporated in the cooling equipment (in mechanical or natural draft cooling towers or a cooling pond), with very little water returned to the source. Water withdrawn from a local source is circulated continuously through the cooling system. The cooling system must be replenished with "make-up water" to replace water lost to evaporation and blowdown.[6,7]

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[1] See Appendix A for illustrative representations of all cooling system types.
[2] Concentrating solar power (CSP) plants using parabolic trough, linear Fresnel, and power tower technologies must use some form of cooling. Photovoltaic (PV), concentrating PV, and dish-engine solar plants are not thermal cycle plants and do not require water for cooling. See Solar Energy Industries Association, Utility-Scale Solar Power, Responsible Water Resource Management (October 2, 2009) at 1. Available at www.seia.org.
[3] U.S. Department of Energy, Energy Demands on Water Resources, Report to Congress on the Interdependency of Energy and Water, at 63 (December 2006), hereinafter DOE 2006.
[4] DOE 2006 at 9.
[5] Water Requirements for Existing and Emerging Thermoelectric Plant Technologies, DOE/NETL-402/080108, August 2008 (April 2009 Revision), at 3-4. Available at http://www.netl.doe.gov/energy-analyses/pubs/WaterRequirements.pdf, hereinafter D0E 2009.
[6] Blowdown refers to water that must be removed from the system with removal rates set to control scaling, fouling, and corrosion by limiting the buildup of impurities in the circulating water.
[7] California Energy Commission, Comparison of Alternate Cooling Technologies for California Power Plants Economic, Environmental and Other Tradeoffs, at 1-6 (February 2002), hereinafter CEC Report.

Advantages of recirculating cooling systems are reduced withdrawal rates, and reduced entrainment/impingement (of fish), in comparison to once-through systems. Disadvantages of this system include decreased plant efficiency, higher capital cost, higher water consumption/evaporation, visible plume/drift emissions, wastewater treatment requirements, chemical treatment programs, emissions of controlled air pollutants or pathogens, and site space.[8] About 85% of U.S. electricity is produced via steam cycles with recirculating wet cooling.[9]

Dry Cooling

In direct dry cooling systems (also referred to as air-cooled condensers or ACC), the turbine exhaust steam enters condenser tubes and is cooled by ambient air through either mechanical or natural draft units.[10] In an indirect system, cooling water is used to condense the steam, as in a wet recirculating system. Then the cooling water flows through tube bundles that are cooled in a mechanical or natural draft cooling tower.[11] Cooling water make-up requirements can be nearly eliminated by use of dry cooling systems, but process and steam make-up water requirements are unaffected.[12]

Advantages of dry cooling systems include the least water consumption of all cooling system types and no entrainment/impingement losses. Disadvantages include high installation and operating costs, high efficiency penalties, increased air emissions, load limitations on hottest days, and larger site space than wet cooling systems.[13]

A 2002 report by the Electric Power Research Institute for the California Energy Commission ("CEC report"), based on a review of a number of dry cooling systems in California, noted some "rules of thumb" when considering a dry cooling system:

- "Lost capacity for dry cooling equals 16 MW on an average day and 28 MW on a hot day, equivalent to 4 to 8% of the plant's steam-side output.
- Cooling systems are designed and compared at the design back pressure at the 1% temperature (temperature exceeded for 1% [88 hours] of the year).
- Dry cooling saves approximately 80% of makeup water and 85% of wastewater discharge over a typical year.
- The loss of 1 kW is approximately worth $1500 over the life of a project.
- The capital cost of the dry cooling system is approximately three times that of a wet cooling system."[14]

Hybrid Wet-Dry

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[8] CEC Report at 2-4.

[9] Water & Sustainability (Volume 3): U.S. Water Consumption for Power Production—The Next Half Century, EPRI, Palo Alto, CA: 2002. 1006786. at 1-1, hereinafter EPRI Volume 3.

[10] DOE 2009 at 5.

[11] For new power plants in the U.S., indirect dry cooling has been dismissed by utilities and architect-engineers as impractical because of the extremely poor thermal performance relative to direct dry cooling. See Micheletti and Burns, Emerging Issues and Needs in Power Plant Cooling Systems. Available at http://www.netl.doe.gov/publications/proceedings/02/EUW/Micheletti_JMB.PDF

[12] DOE 2009 at 5.

[13] CEC Report at 2-9.

[14] CEC Report at 3-12.

In hybrid wet-dry systems, both wet and dry components are included and can be used separately or simultaneously for either water conservation or plume abatement[15] purposes. Depending on system configuration (of which there are many options), water consumption can approach that of recirculating wet systems or be much lower. Design studies have ranged from 30 to 98% reduction in water use compared to all-wet recirculating systems.[16]

Impacts of cooling system use at power plants in the US

The amount of cooling required by any thermal power plant is determined by its thermal efficiency. The bigger the temperature difference between the internal heat source and the external environment where the surplus heat is discarded, the more efficient the process in achieving mechanical work, such as turning a steam turbine.[17] This is because the cooling water (or air) temperature affects the level of vacuum at the discharge of the steam turbine. As the cooling medium temperature decreases, a higher vacuum can be produced and additional energy can be extracted.[18] It is, therefore, desirable for a power plant to have a high internal temperature and a low external or environmental temperature.[19]

The amount of cooling water required depends on the generating and cooling technologies, as well as the ambient meteorological conditions at the plant.[20] A range of water withdrawal and consumption (including downstream evaporation of once-through or open-loop systems) for typical thermal power plants and cooling systems is presented below. The lower end of the flow rate range corresponds to higher temperature differentials, and vice versa.[21]

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[15] Plume abatement is achieved by passing the saturated exhaust from a conventional wet cooling tower is through an indirect dry cooling system located above the cooling tower to prevent the atmospheric release of a visible plume. Depending upon the temperature and humidity of the surrounding air, the saturated exhaust can form a visible plume which may be unaesthetic, might impair visibility, or may cause icing on nearby roadways.

[16] CEC Report at 1-7 (citing Mitchell, R. D. Survey of Water-Conserving Heat Rejection Systems. 1989. Palo Alto, CA, Electric Power Research Institute).

[17] World Nuclear Association, Cooling Power Plants, updated February 2010. Available at http://www.world-nuclear.org/info/cooling_power_plants_inf121.html, hereinafter World Nuclear Association.

[18] U.S. Department of Energy, Energy Penalty Analysis of Possible Cooling Water Intake Structure Requirements on Existing Coal-Fired Power Plants at 2 (October 2002), hereinafter DOE 2002.

[19] World Nuclear Association.

[20] DOE 2006 at 63.

[21] EPRI Volume 3 at 3-1.

Plant and Cooling System Type	Water Withdrawal (gal/MWh)[22]	Typical Water Consumption (gal/MWh)[23]	Typical Water Consumption (gal/MWh)[24]
Fossil/biomass/waste-fueled steam, once-through cooling	20,000 - 50,000	~300	
Fossil/biomass/waste-fueled steam, pond cooling	300 - 600	300 - 480	
Fossil/biomass/waste-fueled steam, cooling towers	500 - 600	~480	450 – 520
Nuclear steam, once-through cooling	25,000 - 60,000	~400	
Nuclear steam, pond cooling	500 - 1100	400 - 720	720
Nuclear steam, cooling towers	800 - 1100	~720	720
Natural gas/oil combined-cycle[25], once-through cooling	7500 - 20,000	~100	
Natural gas/oil combined-cycle, cooling towers	~230	~180	190
Natural gas/oil combined-cycle, dry cooling	~0	~0	
Coal/petroleum residuum–fueled combined-cycle, cooling towers	~380*	~200	310 (IGCC)
Concentrating Solar Plant, Parabolic Trough, water-cooling		800[26]	
Concentrating Solar Plant, Power Tower, water-cooled		500[27]	
Concentrating Solar Plant, dry cooling		~0	

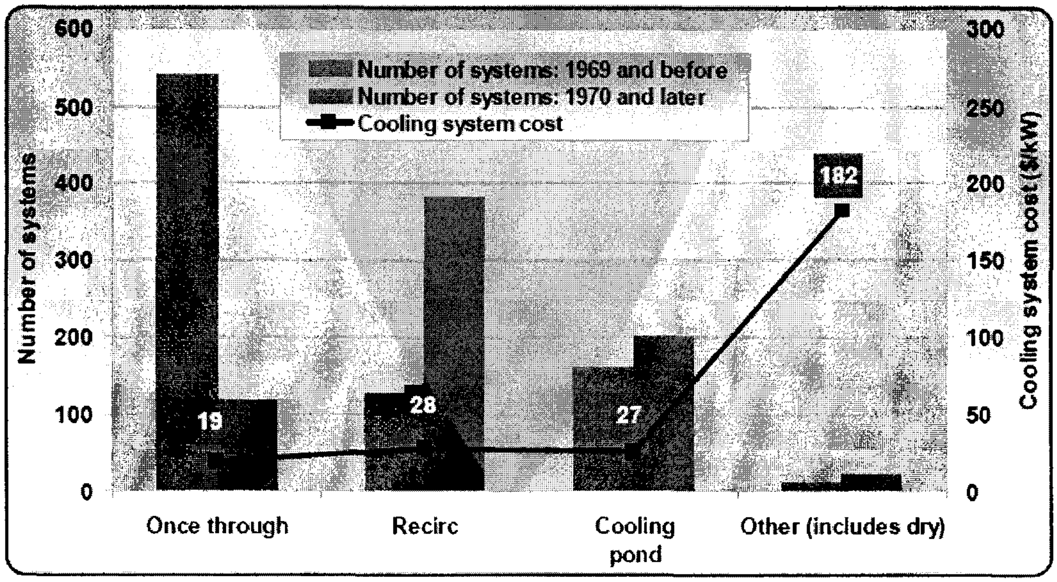
* includes gasification process water.

Comparative Costs of Cooling System Use[28]

[22] EPRI Volume 3 at viii.
[23] EPRI Volume 3 at viii.
[24] DOE 2009 at 1 (not including CO2 capture).
[25] Combined-cycle plants derive 2/3 of their power from gas turbine (Brayton) cycles, which extract energy from hot, pressurized gases, not steam; just 1/3 of the total power output comes from a conventional steam cycle.
[26] U.S. Department of Energy, Concentrating Solar Power Commercial Application Study: Reducing Water Consumption of Concentrating Solar Power Electricity Generation, Report to Congress, at 4. Available at http://www1.eere.energy.gov/solar/pdfs/csp_water_study.pdf, hereinafter DOE CSP.
[27] DOE CSP at 3.
[28] For a graphical economic comparison of cooling systems for a 250 MW CSP plant see Appendix B.

Generally, wet recirculating systems are roughly 40% more expensive than once-through systems, while dry cooling systems are 3 to 4 times more expensive than a wet recirculating system.[29] For all thermal systems, water cooling has, thus far, been more economical than air cooling because water cooling has a low capital cost and higher thermal efficiency.[30] Because water temperatures tend to be lower than ambient air temperatures, condensers in wet cooling systems can be smaller in size while once-through systems do not require the cooling towers associated with wet and dry recirculating systems.

Average total cost and number of cooling systems for fossil/biomass-fueled steam plants in the U.S. (as of 2005)[31]



Wet Cooling System Costs[32]

The two major elements of a recirculating wet cooling system are the cooling tower (which is not needed in a once-through system) and the surface condenser (which is likely smaller in a once-through cooling system due to lower cooling water temperatures). The equipment included in the cost estimate evaluated in the CEC report consisted of everything downstream of the turbine flange and includes the costs of engineering, site preparation, erection, installation, and testing. The base system chosen to represent recirculating wet cooling is the mechanical draft, cross-flow wet cooling tower in the traditional in-line arrangement of cells to form a rectangular tower.[33]

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[29] DOE 2009 at 5 (citing R.Tawney, Z. Khan, J. Zachary (Bechtel Power Corporation), "Economic and Performance Evaluation of Heat Sink Options in Combined Cycle Applications", Journal of Engineering for Gas Turbines and Power, April 2005, Vol. 127). It is unclear whether this refers to capital costs or lifetime costs.

[30] DOE CSP at 4.

[31] DOE 2009 at 5 (adapted from U.S. Department of Energy, Energy Information Administration (EIA). Form EIA-767: Annual Steam-Electric Plant Operation and Design Data. 2005 data).

[32] For engineering assumptions, see CEC Report at 5-9 – 5-11.

[33] CEC Report at 5-17.

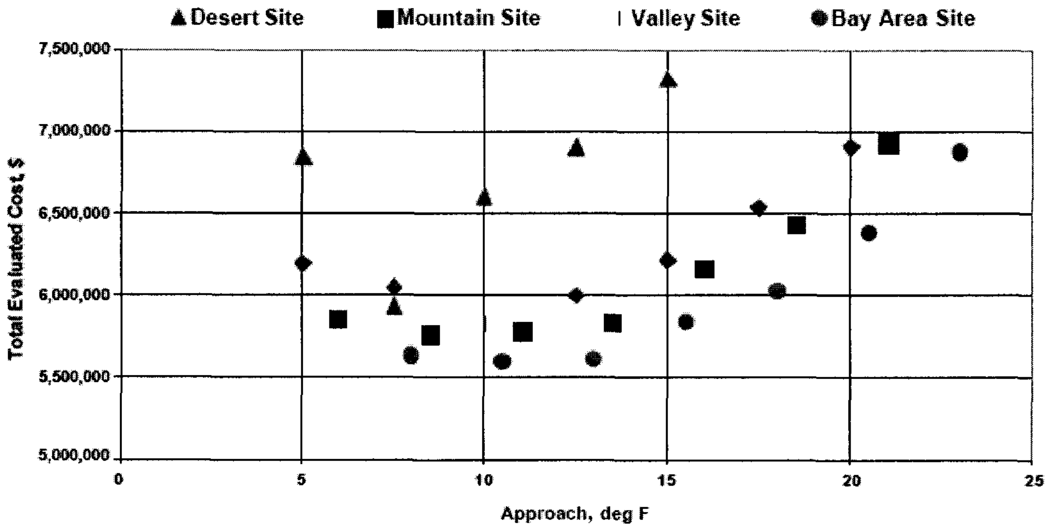
The cost of the power required to operate cooling system pumps and fans, which is borne continuously for the life of the plant, should also be taken into consideration. The CEC report converted future power costs into an evaluated power cost of $3625/kW. This was based on an energy cost of $60/MWh, a 6.7% discount rate, a 3% escalation, a 50% tax rate, and a 30-year plant life.[34] The total evaluated cost for a wet recirculating cooling system, under the minimum evaluated cost scenario, evaluated at the four sites is detailed in the chart below.

Site-to-Site[35] Cost Estimates—Wet Cooling Tower[36] and Surface Condenser for New 500-MW Combined-Cycle Plants with 170-MW Steam Cycle[37]

	Desert Site	Mountain Site	Valley Site	Bay Area Site
Low First Cost Design[38]				
Total Cost	$2,924,000	$2,710,000	$2,820,000	$2,680,000
Minimum Evaluated Cost Design[39]				
Total Cost	$3,331,000	$3,118,000	$3,405,000	$2,960,000

[34] CEC Report at 5-21 (parameters selected in discussions with vendors, users, and the CEC as reasonable values for the power industry situation in California at time of report).
[35] High desert site characterized by conditions at Blythe, California; Northern mountain site characterized by conditions at Burney, California (near Redding); Central Valley site characterized by conditions at McKittrick, California (near Bakersfield); Bay Area/Delta Region site characterized by conditions at Pittsburg, California.
[36] The budget price for the tower included the erected/installed cost of the tower itself, the basin costs, and the fan/motor costs.
[37] CEC Report at 5-17.
[38] A "low first cost" case in which the capital cost of the tower was minimized at the expense of additional fan power (see CEC Report at 5-16).
[39] A "minimum evaluated cost" case in which the sum of the capital cost and the cost of power evaluated over the assumed 30-year life of the tower was minimized (see CEC Report at 5-16). This method results in a more expensive tower but lower lifetime cost.

Wet Cooling System Total Evaluated Cost vs. Approach[40] for Minimum Evaluated Cost Design (for New 500-MW Facilities with 170-MW Steam Cycle)[41]



Capital costs for wet systems generally tend to decrease as the approach temperature increases (because the tower and condenser may be smaller due to the higher temperature differential). However, higher approach temperatures can lead to higher circulating water flows and inlet temperatures, resulting in higher condenser costs. Additionally, the higher wet bulb temperatures at the Desert site lead to higher condenser inlet temperatures (more so than for the other sites) substantially increasing condenser costs.

Dry Cooling System Costs

The capital costs included in a new dry cooling system include the base system for dry cooling. The CEC report evaluated a direct system with a mechanical draft air-cooled condenser (ACC). Additional costs include installation and erection costs (which vary depending on the design temperature, size and site), electrical wiring and hookup (which range from about 3.5 to 7.5% of cooling system costs), auxiliary cooling (about 7.5% of cooling system costs), and additional items, such as sensors, controls, fire and lighting protection, finned surface cleaning equipment, and finish painting.[42]

Dry cooling systems, as well as hybrid cooling systems, are larger and mechanically more complex than corresponding wet cooling systems. They require a larger heat transfer surface area and more fans (which means more electrical motors, gearboxes and drive shafts) increasing capital and operating costs.[43]

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[40] "Approach" is the temperature differential between the cold water entering the condenser and the inlet wet bulb temperature, which is typically in the range of 8-15°F. See CEC report at 2-7.
[41] CEC Report at 5-22.
[42] CEC Report at 5-24 – 5-26.
[43] Micheletti and Burns, Emerging Issues and Needs in Power Plant Cooling Systems at 5. Available at http://www.netl.doe.gov/publications/proceedings/02/EUW/Micheletti_JMB.PDF

Site-to-Site Cost Estimates—Air-Cooled Condenser (for New 500-MW Facilities with 170-MW Steam Cycle)[44]

	Desert Site ITD[45] = 37	Mountain Site ITD = 44	Valley Site ITD = 44	Bay Area Site ITD = 55
Capital Cost	$30,300,000	$25,500,000	$25,500,000	$20,400,000
Total Evaluated Cost[46]	$44,700,000	$38,400,000	$37,900,000	$30,000,000

Hybrid System Costs
Limited information is available regarding economic impacts of hybrid cooling systems. An evaluation of alternative cooling systems for a 250 MW CSP plant (see Appendix B) provides one of the most comprehensive evaluations as far as cost estimates are concerned but there is limited discussion on operating conditions and associated tradeoffs. This analysis does suggest, however, that hybrid system efficiency is similar to that of an ACC and may have lower capital costs.[47] Long-term operating costs and associated energy penalties are unclear.

Performance Penalties
Economic consequences associated with cooling technologies vary with location and climate which impacts the cooling system performance, water conditions which affects the cost of water and water treatment, and depend on the value of delivered electricity during peak demand which coincide with high ambient temperatures.

Wet cooling systems face performance limits during periods of high humidity while dry cooling systems face performance limits at times of high dry bulb temperature. Both situations tend to occur during the summer months during peak loads (air conditioning).[48] The CEC report noted that high humidity is not an issue that significantly affects plant operations at any of the four sites reviewed.[49]

As an example of site location/climate variability, an evaluation of alternate cooling systems for a 250 MW parabolic trough CSP plant located in the Mojave Desert in California concluded that dry cooling would provide 5% less electric energy than a recirculating wet cooling system on an annual basis and increase the cost of the produced electricity by 7 to 9%.[50] An evaluation for a solar plant in

[44] CEC Report at 5-39.
[45] Initial Temperature Differential (ITD) is the difference between the temperature of the condensing steam and the inlet air dry bulb temperature.
[46] Total Evaluated Costs include the cost of evaluated power of $3625/kW under the same assumptions discussed for the Wet Cooling System.
[47] WorleyParsons. FPLE - Beacon Solar Energy Project: Dry Cooling Evaluation. WorleyParsons Report No. FPLS-0-LI-450-0001. WorleyParsons Job No. 52002501 at 7. February 2008.
[48] CEC Report at 5-21.
[49] CEC Report at 5-23.
[50] DOE CSP at 5 (citing to WorleyParsons. FPLE - Beacon Solar Energy Project: Dry Cooling Evaluation. WorleyParsons Report No. FPLS-0-LI-450-0001. WorleyParsons Job No. 52002501. February 2008). See Appendix B for full cost comparison of all alternatives.

New Mexico, however, found that a wet cooling system would decrease the levelized cost of electricity by 1.4 to 4% compared to a dry cooling system.[51]

In general, a dry cooling system is designed to maintain a certain back pressure for a given heat load at a given ambient temperature.[52] When the ambient temperature exceeds the design temperature, the back pressure will be higher than design, resulting in a higher plant heat rate. For a steam cycle with a fixed heat input, this translates to a lower power output. If the heat input can be increased, the plant output may be maintained but fuel costs will increase.

Additionally, steam turbines are designed with an upper limit on back pressure. As this limit is reached (at times of high ambient temperature) steam flow must be reduced to avoid damage to the turbine. Reduced steam flow leads to reduced power output (lost MWh) from the steam cycle. In the case of a combined-cycle unit, if exhaust gas does not have an outlet alternative to the heat recovery steam generator (HRSG) the output from the combustion turbine will be reduced as well, further impacting energy output.[53]

In a more detailed penalty analysis, the CEC report demonstrates that the types of costs are highly dependent on dry-cooling system design criteria. For example, a system designed with a low operating pressure and a low ITD, may have very high capital and evaluated power costs when compared to a system designed with a higher operating pressure and/or ITD. However, if the latter system is forced to operate at conditions beyond its design criteria, for example at a much lower ITD as ambient temperatures increase and approaching maximum back pressure, capacity and heat rate penalties can get very high, leading to significant capacity reductions and increased costs per MWh.[54]

Conclusion

Power plants operating at high thermal efficiencies require less cooling water and cost less to operate. High thermal efficiencies are not as easily achieved with dry cooling systems because ambient dry bulb temperatures are always higher than ambient wet bulb temperatures. There is a tradeoff between steam flow, water use, and energy output under the various cooling systems which need to be evaluated on a site-specific basis, placing a value on water, fuel, emissions, and the subsequent effects on electric rates.

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[51] New Mexico Central Station Solar Power: Summary Report. EPRI, Palo Alto, CA, PNM Resources, Inc., Albuquerque, NM, El Paso Electric Co., El Paso, TX, San Diego Gas & Electric Co., San Diego, CA, Southern California Edison Co., Rosemead, CA, Tri-State Generation & Transmission Association, Inc., Westminster, CO, and Xcel Energy Services, Inc., Denver, CO: 2008. 1016342.

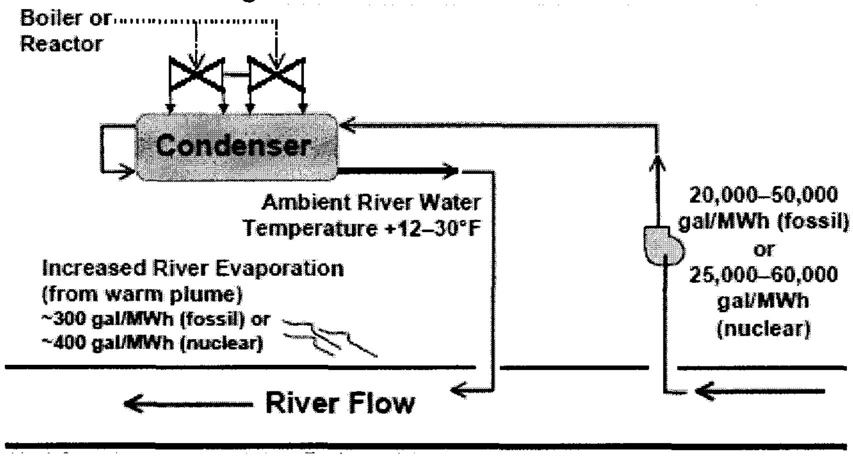
[52] CEC Report at 5-30. Design ambient temperature is normally set at a value well below maximum temperature expected at site during hottest periods of the year.

[53] CEC Report at 5-31.

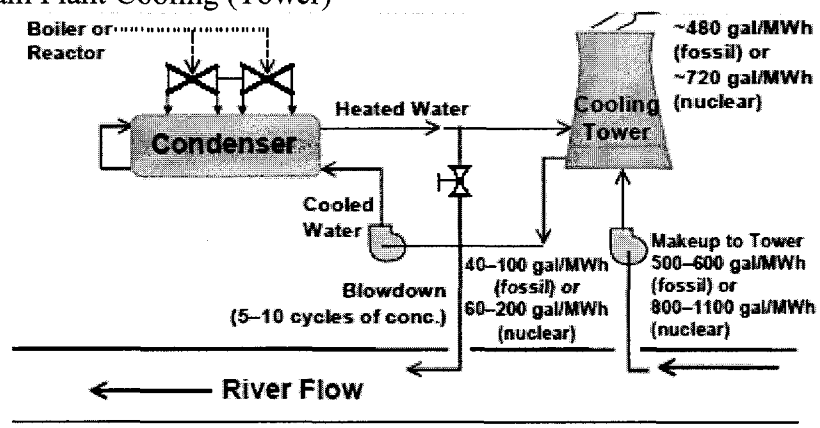
[54] For a detailed analysis of various penalty scenarios, see CEC Report at 5-31 – 5-39.

APPENDIX A: COOLING SYSTEM TYPES

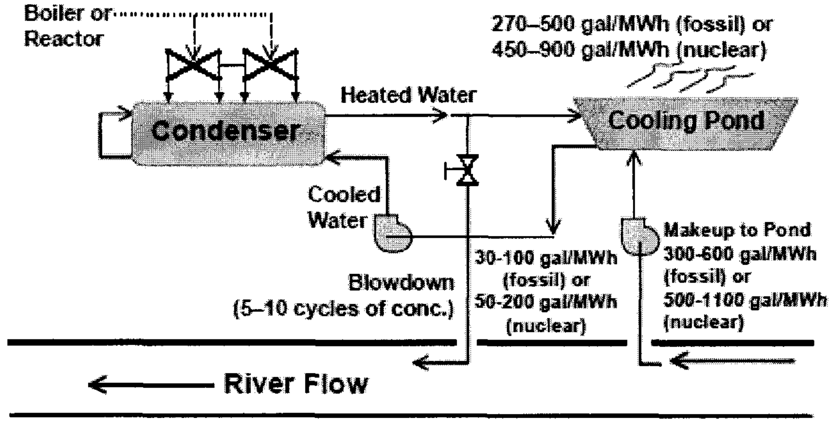
Once-Through Steam Plant Cooling[55]



Recirculated Steam Plant Cooling (Tower)



Recirculated Steam Plant Cooling (Pond)[56]



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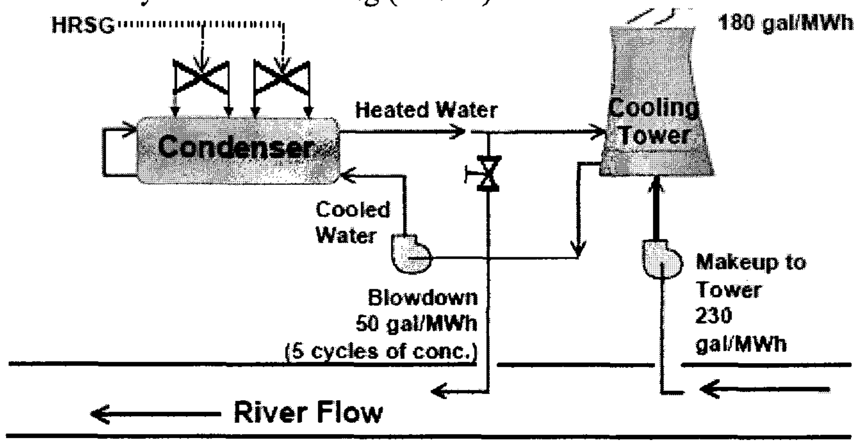
[55] All illustrations, except Hybrid System, from EPRI, Water & Sustainability (Volume 3): U.S. Water Consumption for Power Production—The Next Half Century, at 3-2. Palo Alto, CA: 2002. 1006786.

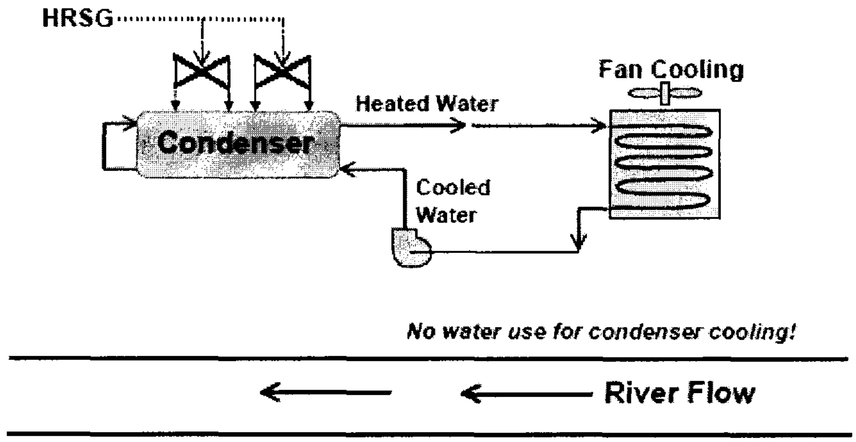
[56] EPRI, at 3-4.

Recirculated Combined-Cycle Plant Cooling (Tower)

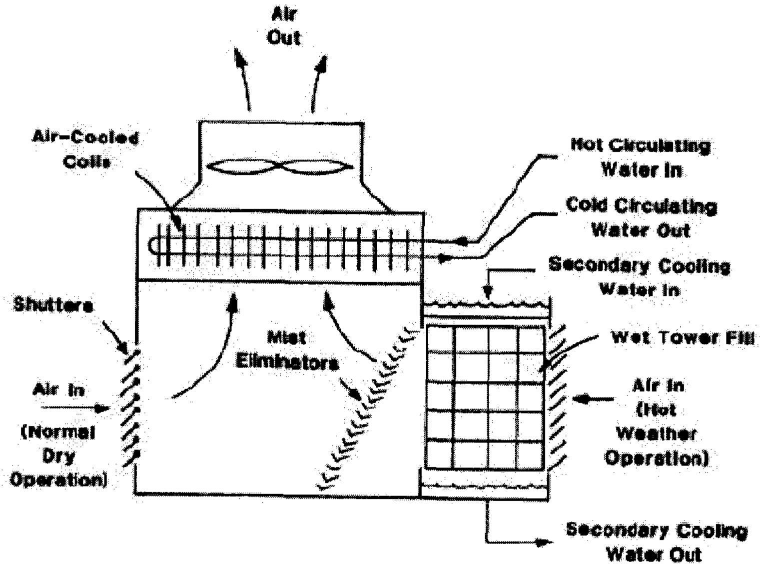


HRSG: heat recovery steam generator

Recirculated Combined-Cycle Plant Dry Cooling (Direct)



Hybrid System (Pre-Cooling)[57]



[57] California Energy Commission, Comparison of Alternate Cooling Technologies for California Power Plants Economic, Environmental and Other Tradeoffs, at 2-15 (February 2002)

APPENDIX B: WORLEYPARSONS CAPITAL COST SUMMARY[58]

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**

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

[58] WorleyParsons. FPLE - Beacon Solar Energy Project: Dry Cooling Evaluation. WorleyParsons Report No. FPLS-0-LI-450-0001. WorleyParsons Job No. 52002501. at 7, February 2008.