Appendix L

IID Power Plant Water Use Evaluation

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Integrated Engineers & Contractors Corporation

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Memorandum

To: GEI Consultants, Inc.

From: Brandon Doering, Eddie Jordan

CC:

Date: September 15, 2009

Re: Imperial Irrigation District Power Plant Water Use Evaluation

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Introduction

Integrated Engineers and Contractors (IEC) has been engaged by GEI Consultants to research power plant related water issues in the Imperial Irrigation District (IID) service area as part of a larger study being conducted by GEI. The tasks requested included:

- A general review and summary of the current best practices and technologies related to power plant water usage.
- An economic comparison of technologies related to power plant water treatment and cooling requirements.
- A general review of current operating practices at the power plants in the IID service area, with a focus on the predominant geothermal facilities, plant water usage, and conservation practices.
- A summary of regulations governing water usage affecting IID area power plants, including state, local, and special district policies, including those of the California Energy Commission.

This study is intended to be an overview, rather than an in-depth analysis of individual plants or technologies. The recommendations presented are accurate as far as the available data allows, and are intended as a guide to further in-depth analysis prior to implementation.

Following the study itself, several Appendices are attached, which provide more comprehensive information on power plant types in general and water usage and treatments within those plants.

Summary of Findings

This evaluation focuses on power plant cooling technologies, as cooling systems are the predominant water users within most power plants. The study and cost comparison of cooling technologies takes into account the effects of the unique climate of the Imperial Valley, and demonstrates the significant effect of that climate on power plant performance and design. The most efficient way to generate electrical power on demand is still dependent on the Rankine thermal cycle, which requires the ability to effectively remove a large quantity of waste heat from the system, and water is still the simplest and most effective medium for the transport of that heat. In comparison with wet cooling, dry cooling methods are estimated to result in a power generation cost of about 17% more, and would result in a decrease in power production of 5% to 10% on hotter days. Hybrid wet/dry systems do alleviate some of this impact, but are still substantially more expensive than wet cooling systems.

Although dry and hybrid cooling systems have these drawbacks, the increasing scarcity of water resources is forcing changes in power plant design philosophy, often through increased regulatory pressure. The current regulatory environment is strongly encouraging, if not requiring, a change to dry or significantly reduced water use cooling options. This pressure, along with increased costs of water supplies, water-related environmental studies, and compliance with water regulations, and the increasing price of electricity, is making dry and hybrid cooling more feasible.

Existing geothermal plants requiring at least some water for cooling can still work to reduce water use through reclamation, and seeking or creating better quality water sources. Because the quantity of cooling water required often depends on the quality of the water available, a cleaner water source may offset some of the water volume required.

The concern for, and protection of, water resources remains an important topic for the foreseeable future. As some of the largest users of water, power plants will increasingly be the focus of public and regulatory scrutiny. Continuing efforts to identify and take advantage of water conservation opportunities and technologies will remain critical to their successful operation.

Imperial Irrigation District Case Studies

The predominant source of power generation in the Imperial Valley is geothermal, due to the unique geography of the Salton Sink. This being the case, the focus of the case studies of area power plants discussed on the following pages will rest solely on geothermal facilities.

Salton Sea KGRA Power Plants

The Salton Sea Known Geothermal Resource Area (KGRA) is located just to the southeast of the Salton Sea itself, and approximately 5 miles northwest of the town of Calipatria. This resource has the highest available geothermal fluid temperatures of any of the Imperial Valley geothermal sites, lending it well to flash steam generation technology. All of the ten existing power plants and most of the proposed plants in this area have been developed and are operated by one company, CalEnergy Generation. One plant is currently under development by Catalyst Hannon Armstrong Renewables, LLC.

All of the existing CalEnergy sites are similar in construction and operation. The Salton Sea resource provides these plants with highly saline geothermal fluid at more than 500°F through the plant production wells. This brine is flashed to produce steam in single or dual stages, depending on the turbine construction. The steam is cleaned to remove damaging minerals and contaminants, and fed to the power turbines to generate electricity. The remaining un-vaporized brine, which becomes supersaturated with silica, is processed to reduce the silica content and to remove other materials, then re-injected into the earth to maintain the geothermal aquifer.

Water usage at these plants is similar to the water usage at other steam plants, but these flash steam plants generate some of the required water as part of the power generation process. After the steam passes through the power turbines, it is cooled and condensed. Since the steam comes from the geothermal brine, rather than a boiler system, the steam condensate is not returned to the power cycle as it is in a traditional closed-loop steam cycle. Instead, the condensate becomes the primary source of water for plant process uses, including brine dilution, pump seal water, scrubber wash water, and cooling tower makeup. The quantity of water produced from the geothermal fluid is adequate to supply most of the plant water needed, which significantly reduces the amount of water required from external sources, as compared to the quantities used by other power plants, when compared on a per-megawatt basis. Any supplemental water required for plant operations is provided from the IID network of supply canals. This external source is also used for all of the domestic water needs after reverse osmosis treatment.

The plant cooling needs are handled by closed-loop evaporative (wet) cooling towers. As mentioned above, the cooling tower makeup supply uses condenser water first, and then filtered IID canal water as needed. Because the condenser water is a very clean source (basically distilled water), these cooling towers can normally achieve as many as twenty cycles of concentration before blowdown is required, as compared with ten cycles at most traditional steam power plants.

Plant waste water is disposed of on site. Cooling tower blowdown, reverse osmosis reject, and other process wastewaters are collected and either combined with the re-injected spent brine or returned to the earth through a dedicated injection well at each plant.

A unique characteristic of the Salton Sea area is the presence of artesian wells. These wells require less depth than other areas, and the natural pressure minimizes pumping power and other parasitic loads of the power plant.

A table of the CalEnergy plant names, power output capacities, and historical water usage is provided below:

Table 1: CalEnergy Plants in the Salton Sea KGRA

Plant Name:	Type:	Capacity (MW Net)	IID Water Use (AFY)*	AFY/MW
Salton Sea 1 **Salton Sea 2**	Dual Flash	10.0 17.0	9.9 (Combined meter)	0.4
Salton Sea 3 **Salton Sea 4**	Dual Flash	50.0 40.0	399 (Combined meter)	4.4
Salton Sea 5	Dual Flash	49.0	1200	24.5
Del Ranch	Dual Flash	42.0	948	22.6
Vulcan	Dual Flash	38.0	164	4.3
Leathers	Dual Flash	42.0	1354	32.2
Elmore	Dual Flash	42.0	1910	45.5
CE Turbo	Single Flash	10.0	0.0	0.0
Black Rock 1,2,3 (Proposed)	Single Flash	195	483 Est.	2.5
Black Rock 4,5,6 (Proposed)	Single Flash	195	483 Est.	2.5

*Past 10 year average use from delivery gate meters.

CalEnergy's proposed Black Rock facilities utilize a single flash technology, which minimizes water usage. This process requires a single flash, and then re-injects the brine at a higher temperature, which minimizes the silica fallout. In addition to the above CalEnergy plants, another firm, Catalyst Hannon Armstrong Renewables (CHAR, LLC), is developing two identical power plants located just to the northeast of the CalEnergy complex. Because the geothermal resource is basically the same, the CHAR plants will utilize dual flash technology similar in design type and operation to the other Salton Sea plants. These plants will also use the same 500°F geothermal resource and the plants will use flash steam technology. The condensate water produced will be used in wet cooling towers, with supplemental water to be provided from IID canals. Following is the planned output and water usage data:

Table 2: Proposed CHAR Plants in the Salton Sea KGRA

Plant Name:	Type:	Capacity (MW Net)	IID Water Use (AFY)	AFY/MW
Hudson Ranch 1	Dual Flash	49.9	850 Est.	17.0
Hudson Ranch 2	Dual Flash	49.9	850 Est.	17.0

East Mesa KGRA

The East Mesa geothermal resource area is located approximately 18 miles from El Centro on the east side of the Imperial Valley. The East Mesa area is generally a lower-temperature resource than the Salton Sea KGRA, and primarily supports binary cycle geothermal plants. The power generation facilities include the Ormesa and GEM plants, which are owned and operated by Ormat Technologies, Inc.

Ormat employs their proprietary Ormat Energy Converter (OEC) modular power plants at each of the Ormesa facilities. These units utilize a binary cycle based on a working fluid mixture of isopentane and isobutane. The geothermal brine is used to vaporize the working fluid in the OEC unit, and then is returned to the ground through a set of injection wells to be reheated. The vaporized working fluid, contained in a closed system, drives the turbine, and then is cooled and condensed in a heat exchanger, completing the cycle.

Water usage is virtually all for condenser cooling. The Ormesa plant cooling is handled by wet cooling towers, which are supplied with makeup water from the IID canal system. Water usage at the Ormesa plants is higher than for other types of thermal power plants, which is typical of plants using lower-temperature heat resources, such as the East Mesa KGRA. In a plant utilizing a lower-temperature heat resource, more heat must be removed from the condenser for each unit of electricity generated, in comparison with plants using higher-temperature heat resources, such as flash steam geothermal and fossil fueled steam plants. Compounding the higher water use required for cooling, the binary plants have no steam condensate available to offset the water needed in the cooling towers.

Despite the generally lower temperature of the East Mesa, there are wells producing brine of sufficient temperature to operate some flash steam generation units. The GEM II and III facilities use flash technology to produce power primarily in support of the auxiliary loads of the nearby Ormesa plants. The condensate recovered from the flashed steam is used to cool the plants, eliminating the need for cooling water.

The East Mesa KGRA brine production wells are usually lower temperature and pressure than those in the Salton Sea area, and so require more pumping power and increased parasitic loads for these facilities.

Table 3: Ormat Plants in the East Mesa KGRA

Plant Name:	Type:	Capacity (MW Net)	IID Water Use (AFY)*	AFY/MW
Ormesa 1	Binary	38.0	1665	43.8
Ormesa 1E	Binary	8.0	923	115.4
Ormesa 1H	Binary	12.0	1040	86.7
Ormesa 2	Binary	18.0	1993	110.7
GEM 2	Dual Flash	22.0	-	-
GEM 3	Dual Flash	18.0	-	-

*Past 10 year average use from delivery gate meters.

Heber KGRA

The Heber plants are also owned and operated by Ormat, and both have been upgraded from their original configurations with the installation of additional binary OEC units.

Heber 1 is primarily a flash steam plant. The geothermal brine is flashed in two stages to produce steam for the primary generators, while the added binary-powered generator uses the heat energy still remaining in the turbine exhaust to generate additional power. As with other flash plants, the steam condensate is reused, reducing the water required from external sources. The only significant water use is for cooling tower water makeup. The cooling system is a closed-loop evaporative (wet) system, and all makeup water not supplied by condensate is provided by water from the IID canal, following filtering to remove sediments and organic material. The spent brine is re-injected into the earth, while the cooling tower blowdown, storm water, and any excess condensate is disposed of into surface drains which eventually feed the New River and the Salton Sea.

The geothermal resource at the Heber 2 plant is not hot enough to be effectively used in a flash system. Instead, Heber 2 is a binary system based on the Organic Rankine Cycle (ORC) and utilizing seven proprietary Ormat Energy Converter (OEC) generating units. The brine pumped from the production wells is passed through the OEC heat exchangers, where it vaporizes the isopentane working fluid. The vapor drives the turbines, generating electricity, and then passes to the condenser, where it returns to a liquid state. The condensers are cooled by a closed-loop wet cooling tower system. Since all of the geothermal brine is returned to the resource aquifer, and none is used for steam production, there is no condensate to be recovered for other uses. All of the cooling tower makeup water is therefore supplied from the IID canal, which significantly increases the water usage figures. Blowdown from the cooling tower basin is disposed of to area surface drains, as at the Heber 1 plant.

The Heber KGRA production wells, similar to the East Mesa wells, are lower in temperature and pressure, and also require increased pumping power and associated parasitic loads.

Table 4: Ormat Plants in the Heber KGRA

Plant Name:	Type:	Capacity (MW Net)	IID Water Use (AFY)*	AFY/MW
Heber 1	Dual Flash/Binary	52.0	1156	22.2
Heber 2	Binary	48.0	3663	76.3

*Past 10 year average use from delivery gate meters.

Brawley KGRA

Construction is nearing completion on the first of two geothermal plants to be located just north and east of the town of Brawley. These plants are being built by Ormat and will utilize six of their proprietary Ormat Energy Converters at each plant to take advantage of this lower-temperature resource. As with the existing OEC-equipped facilities, the brine pumped from the production wells is passed through the OEC heat exchangers, where it vaporizes the isopentane working fluid. The vapor drives the turbines, generating electricity, and then passes to the condenser, where it returns to a liquid state. The condensers are cooled by a closed-loop wet cooling tower system, and the cooling tower makeup water is supplied exclusively from the IID canal. The geothermal brine is returned to the resource aquifer through a set of injection wells, as is all the blowdown from the cooling tower basin, resulting in no liquid discharge from either plant site.

The East Brawley plant will be constructed nearly identically to the nearly completed North Brawley plant. The OEC equipment at the East plant will incorporate newer technology that is expected to enable the plant to produce the same electrical output while using less water in the cooling tower loop.[1]

Table 5: Proposed Ormat Plants in the Brawley KGRA

Plant Name:	Type:	Capacity (MW Net)	IID Water Use (AFY)*	AFY/MW
North Brawley (Construction)	Binary	49.9	6600 Est.	132.3
East Brawley (Proposed)	Binary	49.9	5500 Est.	110.2

*Past 10 year average use from delivery gate meters.

One plant near Brawley is also under development by Ram Power, Inc., and will be located a few miles east of the town near IID's East Highline Canal. This plant will extract geothermal brine at an expected temperature of 350 to 400°F, and utilize dual flash technology to produce steam for the turbine generators. The cooling water source will be first the steam condensate, with the balance from IID. The plant is expected to be online in 2012, with other identical units to follow. Following is the planned output and water usage data for the Ram East Brawley plant:

Table 6: Proposed Ram Power Plant in the Brawley KGRA

Plant Name:	Type:	Capacity (MW Net)	IID Water Use (AFY)	AFY/MW
Ram East Brawley	Dual Flash	50.0	800 Est.	16.0

Comparative Cost Analysis of Cooling Systems

The cost analysis for this study focused on the closed-loop evaporative (wet) cooling, dry cooling, and hybrid cooling technologies as these are the three primary cooling systems being explored for power plants in Imperial Valley. As previously mentioned, closed-loop evaporative systems are currently the most popular systems due to lower capital costs. However, due to decreasing fresh water supplies, both dry cooling and hybrid cooling systems are being heavily explored for future installations. The cost analysis for these systems was based on information found in literature as well as budgetary cost estimates provided by several major equipment vendors. It should be noted that the costs in the following sections are presented as qualitative estimates and are not meant to represent any specific

[1] Per Ormat. Information for this technology was not provided for validation.

power plant in Imperial Valley. Even though there is excellent agreement among estimates found in other studies, there may be substantial differences in cost estimates for an installation at a particular site.

The cost estimates for this study include everything to construct and operate the entire plant including equipment, engineering, site preparation, erection, installation, commissioning, maintenance, labor, water usage, and fuel consumption for the combined cycle plants. Broad estimates of this kind cannot include the level of detail that is used in actual design calculations but is suitable for this qualitative study.

The following sections provide a description of the equipment and costs for each cooling technology for a 50 MW Binary Geothermal plant with a 300°F source, a 50 MW Dual Flash Geothermal Plant with a 400°F source, and a 500 MW Combined Cycle plant. It should be noted that exploration, drilling, and other geotechnical costs were not included in this analysis. For each plant, a levelized cost of electricity (LCE) was determined taking into account capital and O&M costs, taxes, depreciation, incentives, debt financing, cost of equity, etc. The assumptions used for each plant are shown in Table 7. The performance of each plant was evaluated using annual weather data and then compared to Southern California Edison's Time of Delivery periods to more accurately predict performance and revenue losses during peak demand periods for dry cooling technologies.

Table 7: Cost Analysis Assumptions for Base Case

	Binary Geothermal	Dual Flash Geothermal	Combined Cycle
Plant Capacity (MW)	50	50	500
Availability (%)	95%	95%	95%
Project Life (y)	20	20	20
Debt Term (y)	15	15	15
Debt Percentage (%)	60%	60%	60%
Cost of Equity (%/y)	15%	15%	15%
Interest Rate on Debt (%/y)	6.5%	6.5%	6.5%
Investment Tax Credit (%)	10%	10%	10%
Discount Rate (%)	10.5%	10.5%	10.5%
Depreciation-MACRS (y)	5	5	20
Federal Tax Rate (%)	35%	35%	35%
State Tax Rate (%)	8.84%	8.84%	8.84%
Inflation/Escalation Rate (%)	2.5%	2.5%	2.5%
Water Cost ($/acre-ft)	$100 - $400	$100 - $400	$100 - $400

Closed-Loop Evaporative (Wet) Cooling

The two main cost components of a closed-loop evaporative (wet) cooling system are the cooling tower and the shell-and-tube surface condenser. Other cost components include the tower basin, electrical and control systems, circulating water system systems, water supply and intake structure, water treatment and blowdown equipment, auxiliary cooling, installation and other miscellaneous costs. Budget prices were obtained for wet cooling towers and surface condensers for the Binary, Dual Flash, and Combined Cycle plants. Weather data was used to develop a series of operating conditions to determine suitable equipment sizes for operation in Imperial Valley. In all cases, the hot water temperature was assumed to be 110^{o}F with a condenser terminal temperature difference (TTD) of 10^{o}F. Other equipment costs were taken from previous studies or designs. Operating cost for the cooling equipment includes the power required to operate the pumps, fans, water treatment equipment, as well as costs for maintenance and water consumption. A summary of the plant costs, performance, and levelized cost of energy is shown in Table 8.

Table 8: Costs and Performance for Power Plants with Closed-Loop Evaporative (Wet) Cooling

	Binary Geothermal			Dual Flash Geothermal			Combined Cycle		
Cooling Type	Wet			Wet			Wet		
Plant Capacity (MW)	50			50			500		
Capacity Factor (%)	93%			93%			93%		
Generation (MWh/y)	426,792			426,792			4,267,922		
Total Plant Installed Cost ($/kW)	$2,790			$2,777			$908		
Cooling System Cost ($/kW)	$24			$16			$10		
Total Non-Fuel O&M ($/kW-y)	$150			$135			$54		
Water Cost ($/acre-ft)	$100	$250	$400	$100	$250	$400	$100	$250	$400
Plant Levelized Cost ($/MWh)	**$69**	**$72**	**$75**	**$66**	**$67**	**$68**	**$77**	**$78**	**$78**

Dry Cooling

Only a direct dry cooling system with a mechanical draft air-cooled condenser was analyzed for the binary and combined cycle plants for this study. Even though indirect systems may be more efficient, the added cost of such a system generally does not improve the performance enough to make it cost effective. Additionally, an air cooled condenser for a dual flash plant has not been done in the United States. In fact, only the 12 MW Verhkne-Mutnovsky flash geothermal plant in Russia currently uses dry cooling technology. Given that the condensate from the turbine exhaust is generally used to help cool the plant, it would not make sense to utilize 100% dry cooling. Therefore, dry cooling for the dual flash plant was not included in this study.

The main cost components for a dry cooling system are the air cooled condenser (ACC) and the fans. Other cost components include the ACC support structure, electrical and controls systems, auxiliary cooling, installation and other miscellaneous costs. Budget prices were obtained for the ACC and fans for binary and combined cycle plants. Additional components were estimated using other studies and budgetary estimates from other projects. The condenser was designed for an initial temperature difference (ITD) of 15^{o}F for the binary geothermal plant due to the properties of the iso-butane fluid. A larger ITD would more than likely cause the turbine to trip in the summer due to the large increase in back pressure. The condenser for the combined cycle plant was designed with an ITD of 20^{o}F for similar reasons. However the system could alternatively be designed to allow a reduction in the output of the gas turbines to help reduce steam flow and back pressure on the steam turbine. Operating costs for the cooling system only include the power to operate the fans and water usage needed for auxiliary cooling. However, due to the increase of back pressure on the turbine during the hot summer days, there is a large reduction in plant performance during peak demand periods of the day. To help relate these performance losses to lost revenue, weather data and Southern California Edison's feed-in tariff rates were used to calculate the time value generation for each plant. Figure 6 illustrates how ambient temperature affects the performance of a 50 MW binary geothermal power plant. Table 9 provides a summary of the plant costs, performance, and levelized cost of energy.

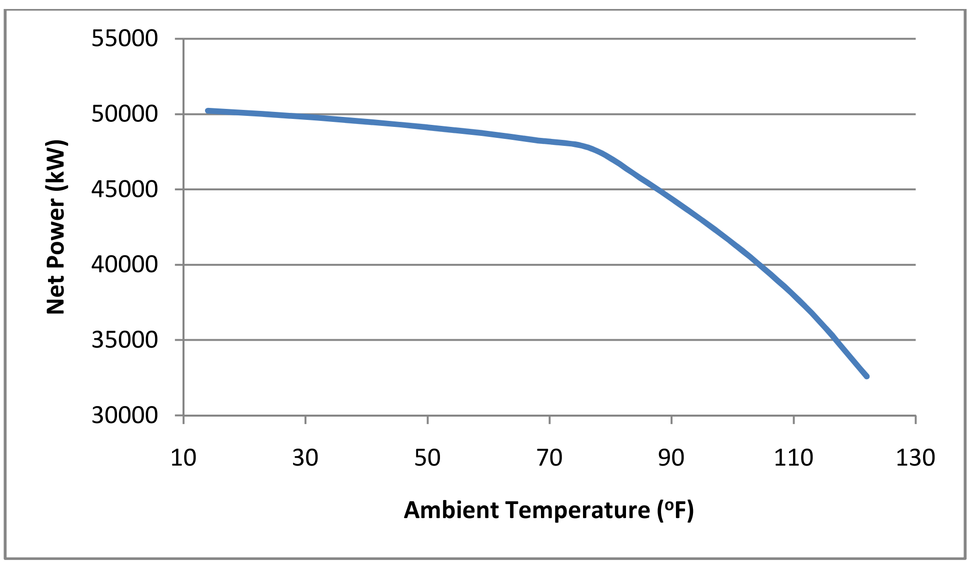

Figure 1: Performance of a 50 MW Binary Geothermal Power Plant

Table 9: Costs and Performance for Power Plants with Dry Cooling

	Binary Geothermal			Combined Cycle		
Cooling Type	Dry			Dry		
Plant Capacity (MW)	50			500		
Capacity Factor (%)	85%			86%		
Generation (MWh/y)	389,636			3,965,092		
Total Plant Installed Cost ($/kW)	$3,123			$1,112		
Cooling System Cost ($/kW)	$247			$146		
Total Non-Fuel O&M ($/kW-y)	$147			$50.7		
Water Cost ($/acre-ft)	$100	$250	$400	$100	$250	$400
Plant Levelized Cost ($/MWh)	**$81**	**$81**	**$81**	**$83**	**$83**	**$83**

Hybrid Wet/Dry Cooling

Hybrid cooling systems employ a combination of both wet and dry cooling technologies. These systems are designed to use a limited amount of water during the hottest periods of the year to mitigate the large losses in the plant performance associated with all dry operation. For this study, the cooling systems were designed to limit annual water use to about 20% of that required for the wet cooling systems while still performing significantly better than the dry cooling only systems. For this study, the hybrid systems consisted of a common evaporative condenser with the capability for both wet and dry operation. The system includes components of both the wet cooling and dry cooling systems discussed above. The operating cost for the system includes power for fans, pumps and water usage. The condenser is designed for an ITD of 40^{o}F when operating as an air cooled condenser (ACC) and a TDD of 10^{o}F when operating like a wet cooled condenser. This allows for minimal performance losses associated with dry cooling while greatly reducing the capital cost because of the smaller systems. A summary of the costs, performance, and levelized cost of the systems is shown in Table 10.

Table 10: Costs and Performance for Power Plants with Hybrid Cooling

	Binary Geothermal			Dual Flash Geothermal			Combined Cycle		
Cooling Type	Hybrid			Hybrid			Hybrid		
Plant Capacity (MW)	50			50			500		
Capacity Factor (%)	90%			92%			91%		
Generation (MWh/y)	412,398			420,972			4,170,922		
Total Plant Installed Cost ($/kW)	$2,973			$2,910			$997		
Cooling System Cost ($/kW)	$147			$105			$69		
Total Non-Fuel O&M ($/kW-y)	$155			$150			$54		
Water Cost ($/acre-ft)	$100	$250	$400	$100	$250	$400	$100	$250	$400
Plant Levelized Cost ($/MWh)	**$76**	**$76**	**$77**	**$72**	**$72**	**$73**	**$80**	**$80**	**$81**

Regulatory Water Use Requirements

In accordance with the scope of this project, this section provides a summary of the regulatory requirements related to power plant water use within the IID service area. This summary includes an outline of the submittals and documentation required for the necessary operating permits, the water use restrictions affecting the power plant, and the water conservation requirements related to plant operations.

In general, the approval and permitting of any power plant affected by the following regulations is handled under the umbrella of either: the California Energy Commission (CEC) review, for plants 50 megawatts (MW) and larger; or the county/local building permit process, for plants under 50 MW. As part of the permit review, these agencies ensure compliance with all of the federal, state, and local regulations discussed below prior to approval of the project and issuance of permits. In cases of water use policy, the permitting agency will rely on the recommendation of the State Water Resources Control Board (SWRCB) in making its decision.

State and Regional Water Quality Control Board Regulations and Policy

The primary law governing water quality regulation in the State of California is the Porter-Cologne Water Quality Control Act of 1967, together with its amendments and revisions (Division 7 of the California Water Code). This Act established the State Water Resources Control Board (SWRCB) and under that, nine Regional Water Quality Control Boards (RWQCB). These agencies are responsible for the implementation of the provisions of the Porter-Cologne Act, and also have been delegated the authority for the implementation of the federal Clean Water Act (CWA) requirements by the U.S. Environmental

Protection Agency (EPA). The following State code excerpts and Water Board plans and policies are directly derived from the Porter-Cologne Act.

California Water Code, Section 13550 and following: This section of the Water Code discusses the wasteful uses of potable water, and includes water used for cooling purposes in that category. The Code mandates that recycled water be used instead of potable water for cooling, provided that the following conditions exist:

- The source of recycled water is of adequate quality and is available in sufficient quantity and reasonable cost.
- The use of recycled water does not adversely affect any existing water rights.
- The use of recycled water does not impact public health.
- The use of recycled water will not degrade downstream water quality or harm plant life, fish, or wildlife.

There are several existing power plants, including at least one in the IID service area (Niland) using potable water for cooling, having demonstrated the absence of one or more of these conditions. However, the CEC/SWRCB has very seldom allowed this option.

Water Quality Control Plan (Basin Plan), Colorado River Basin Region: This plan is developed by the Colorado River Basin RWQCB, and provides definitive standards and guidelines for water quality in accordance with the state Porter-Cologne Act and the federal Clean Water Act. The Basin Plan provides water quality standards for discharges from industrial users, defines the beneficial uses of state waters, and lists which sources may be used for each specific beneficial use. Power generation is included in the beneficial use of many of the area water sources under the general category of industrial use. The Basin Plan, Chapter 4, Section II, discusses the permits potentially required for operation of a power plant within this region:

- A Waste Discharge Requirement (WDR) is prescribed for any discharge or proposed discharge from the plant that could affect the quality of the waters of the state, other than discharge into a community sewer system, per the California Code of Regulations (CCR) Section 13263. The submittal requirements for this permit include full information about the site and specific information regarding the quantity and constituents of the discharge flow.
- A National Pollutant Discharge Elimination System (NPDES) permit may also be required for the discharge. Section 122 of Title 40 of the Code of Federal Regulations (40 CFR) requires that NPDES permits be obtained for all point source discharges to "waters of the United States". waters of the United States is defined in Section 122.2 and is generally interpreted to mean any surface water in the State, including lakes, rivers, streams, wetlands, mudflats, sandflats, sloughs, or playa lakes. Although this is a federal permit, it is administered by the RWQCB by authority delegated to the State of California. The application and submittal information are the same as for the WDR above.

- If the facility is a Geothermal Power Plant, the California Division of Oil, Gas, and Geothermal Resources (DOGGR) will work with the RWQCB to issue permits related to discharges of waste below the surface, such as via an injection well.

This Basin Plan generally affects the permitting process for all new IID geothermal developments, as well as renewal of the operating permits for the existing plants.

Water Quality Control Policy on the Use and Disposal of Inland Waters Used for Power Plant Cooling: (Resolution No. 75-58) This policy is one of the primary guidelines used by the SWRCB when evaluating a new power plant site for approval. The policy states that use of fresh inland waters should only be used for power plant cooling if other sources or other methods of cooling would be environmentally undesirable or economically unsound. This SWRCB policy requires that power plant cooling water should come from, in order of priority:

- Wastewater being discharged to the ocean
- Ocean water
- Brackish water from natural sources or irrigation return flow
- Inland waste waters of low total dissolved solids (TDS)
- Other inland waters

For the IID service area, obviously the first two sources are eliminated. The chief fresh water source in the IID area, the Colorado River and the associated canals stemming from it, falls into the final category.

Also contained within this Policy is a statement of water discharge prohibitions involving once-through cooling and closed loop cooling blowdown. These prohibitions are codified and defined in the aforementioned Basin Plan.

Policy with Respect to Water Reclamation in California (Resolution 77-1): This policy specifically addresses wastewater and encourages its reuse rather than disposal. While primarily directed toward municipal wastewater producers, the impact of this policy on power generation is similar to the above Resolution No. 75-58, encouraging the possible use of such waste water in cooling systems.

This policy could also be applied to the discharge of waters from a power plant, especially for new developments, to encourage the recovery of waste waters with ZLD systems or similar methods.

County Regulations and Policy

Imperial County regulation of water use at power generation facilities is part of the building permit process for a new or expanded plant. For plants using waters under state and federal jurisdiction as described above, the county will require proof of review and approval by the RWQCB prior to issuing the permit. For use of waters under county jurisdiction, the following county policies are applied.

The county policy toward power generation water use can be found in the "Geothermal/Alternative Energy and Transmission" Element of the County General Plan (2006). This is stated in several objectives:

- Maintain at least the present level of agricultural production while encouraging efficient water use.
- Provide for geothermal water use of 180,000 acre-feet of water per year; geothermal development will have first priority for use of "saved" and/or excess water over other uses over which the County has jurisdiction.
- Encourage the efficient utilization of water in geothermal/alternative energy operations, and foster the use of non-irrigation water by these industries.
- Encourage recognition of the importance of water to fish and wildlife resources and the recreational uses of Imperial County.

These objectives are also consistent with the ongoing policies of the IID. As an additional reflection of this policy, the Conditional Use Permit language for several of the local geothermal plants using IID water reads: "Permittee shall diligently pursue the development of alternative sources to replace the use of irrigation water."

Indirectly, Division 22 of the County Municipal Code may also have an impact on water use and disposal for some geothermal power plant cases, as it regulates the well drilling and groundwater management.

The "Water Element" of the County General Plan does not mention power generation water use specifically, but provides an outline of the overall conservation and water management goals of the County.

City Regulations

The cities within the IID service area do not have specific regulations or policy governing power plant water use. All of these cities' water systems are potable water, the use of which is addressed by the California Water Code mentioned above. In addition, the individual treatment plants receive their water from the Colorado River via the IID distribution network. This then places it under the aforementioned SWRCB policies.

Discharge from the cities' wastewater treatment facilities could possibly be used for power plant cooling water, and this would be encouraged under the CWC rules for recycled water. However, this has been considered for several of the area plants, but rejected on the basis that it would reduce the relatively fresh water flows reaching the Salton Sea. Any fresh water flow reduction would more rapidly increase the Sea's salinity, and have a negative environmental impact on fish and wildlife.

California Energy Commission Regulations and Policy

While the California Energy Commission has no water regulations of its own, it acts as a central review agency and overseer to ensure that the power plants within the state are sited and operated in compliance with all applicable laws and regulations. In this capacity, it has direct jurisdiction over all power generation facilities of 50 MW and larger, together with supporting infrastructure. When evaluating power plant water use, the CEC bases its policy on input from RWQCB and on the interpretation of the Water Code by the CEC staff, and accepts comment and input from the public.

The CEC has not directly issued a formal statement of policy in regard to different cooling technologies, but overall has made very clear a strong encouragement of very low water use systems, such as dry and hybrid cooling. One staff report published by the CEC, "Energy Facility Licensing Process: Water Supply Information" recaps and refers to SWRCB Resolution 75-58 for the preferred water sources for power plant cooling, and the potential problems associated with each source. It then introduces and explains dry and hybrid cooling as alternatives to the traditional wet cooling tower systems. Another report, the "Energy Facility Licensing Process: Developers Guide of Practices and Procedures" states that, in regard to water resources, the CEC "seeks to minimize the impact on the state's water resources by encouraging use of less water-intensive technologies." In the CEC Rules of Practice and Procedure for Power Plant Certification, Appendix B lists all of the information an applicant must submit for the certification review process:

- Executive summary and project description with owner/developer information.
- Any studies or analyses previously required by the CEC following the original Notice of Intent.
- Contingency plans for premature facility closure.
- A brief discussion of alternatives to the proposed facility that may achieve similar goals while avoiding possible detrimental impacts.
- A discussion of the existing environmental conditions and the proposed impacts due to construction and operation of the facility, including cultural, land use, noise, traffic, visual, socioeconomic, air quality, health, hazardous materials, safety, and waste management impacts, and the effects on biological, water, soil, and geological resources.
- Engineering design.
- Identification of and demonstration of compliance with, all applicable laws and regulations.

This document requires that alternative cooling technologies be considered, and that if they are not used, the submittal must include "an explanation of why alternative water supplies and alternative cooling are 'environmentally undesirable,' or 'economically unsound.'" A similar statement is included regarding the use of ZLD systems for treating waste water.

There have been no new steam power plants in the past several years to receive CEC approval without employing either dry cooling or recycled water with closed-loop cooling. It is expected that this policy will continue, and likely become even more stringent in the future.

California Division of Oil, Gas, and Geothermal Resources

The Division of Oil, Gas, and Geothermal Resources (DOGGR) does not have any regulations governing the use of surface waters for power plant use, but rather focuses on the development of the applicable underground resource itself.

Other Local Agencies

City and county agencies in other areas have not been found to have specific regulations and policies related to power plant or industrial water use. Since most surface waters are considered Federal jurisdiction, the local agencies normally do not have the authority to regulate their use. Once the water is within a municipal water system, these agencies can control connections and rates, but still do not regulate how individual customers use their water, other than typical residential restrictions such as lawn watering times. Large agricultural and industrial customers, including power plants, normally negotiate their own water contracts with suppliers, and any water use restrictions are contained within those contracts.

Water use policies of local agencies, if they exist, are generally statements encouraging conservation and assuring support of local water users over water exporters. Planning and zoning commissions could theoretically use Conditional Use and Building permits to control water uses, but all those processed examined simply required that some kind of agreement for sufficient water supply was in place prior to issuance of a permit. The Imperial County General Plan and associated Elements mentioned above are actually the most specific and comprehensive of the county plans reviewed.

Summary and Recommendations

In summary, water remains an important part of the design and operation of most modern power plants; however, there is increasing pressure to reduce or eliminate its use for power generation. The most efficient way to generate electrical power on demand is still dependent on the Rankine thermal cycle in some variation, which requires the ability to effectively remove a large quantity of waste heat from the system. Water is still the simplest and most effective medium for the transport of that heat. The increasing scarcity of water resources and costs, though, as well as public and regulatory pressure, is forcing changes in power plant design philosophy and providing new, more water-efficient design options. Since cooling water has always been the predominant plant water use, this has been the focus of these changes, and the result is the development of dry cooling technologies.

The design change from wet to dry cooling is still undeniably more expensive, but in some cases is becoming more of a viable alternative. Using the Binary geothermal plant model previously discussed, the per-megawatt-hour cost of wet cooling is $69, while dry cooling is $81 per MWh, and hybrid cooling is somewhat less expensive at $76 per MWh. This premium of approximately 17% for dry cooling would likely be a serious drawback from an economic standpoint. Additionally, dry-cooled plants are also less efficient than wet-cooled plants in desert areas like Imperial Valley. Dry cooling technologies are capable of handling the entire cooling load up to an ambient temperature of 85-90^{o}F. However, beyond that point the air temperature becomes too high for effective cooling and the plant performance suffers dramatically as a result. For example, on an 110^{o}F day, a dry cooled plant will have an energy production penalty of approximately 5-10% as compared to a wet cooled plant. Therefore, the plant will be producing less power during peak demand periods of the day which is when it is needed most. However, as the costs of water supplies, water-related environmental studies, and compliance with water regulations continue to rise, some are still finding dry cooling an increasingly attractive option. The performance losses and increase in capital costs will also become less of an issue as electricity prices rise. A summary of the costs for each cooling technology, performance, and levelized cost of energy is in Table 11.

Table 11: Summary Costs and Performance for Power Plants with Wet, Dry, and Hybrid Cooling

Plant Type	Cooling Type	Plant Capacity (MW)	Capacity Factor (%)	Generation (MWh/y)	Water Cost ($/acre-ft)	Levelized Cost ($/MWh)
Binary Geothermal	Dry	50	85%	389,636	$100	$81
					$250	$81
					$400	$81
Binary Geothermal	Wet	50	93%	426,792	$100	$69
					$250	$72
					$400	$75
Binary Geothermal	Hybrid	50	90%	412,398	$100	$76
					$250	$76
					$400	$77
Dual Flash Geothermal	Wet	50	93%	426,792	$100	$66
					$250	$67
					$400	$68
Dual Flash Geothermal	Hybrid	50	92%	420,972	$100	$72
					$250	$72
					$400	$73
Combined Cycle	Dry	500	86%	3,965,092	$100	$83
					$250	$83
					$400	$83
Combined Cycle	Wet	500	93%	4,267,922	$100	$77
					$250	$78
					$400	$78
Combined Cycle	Hybrid	500	91%	4,170,922	$100	$80
					$250	$80
					$400	$81

The recommendation that can be derived from this general overview is that consideration should be given to alternative cooling technologies for new power plant design, although it would initially appear undesirable from a production and economic standpoint. For larger plants (greater than 50 MW), the inclusion of dry cooling in the design study is already required, and this may be required for smaller plants in the future. As water costs and related impacts continue to increase, the alternative cooling technologies will become more feasible.

For existing plants with wet cooling, the feasibility of changing to dry cooling would no doubt be cost-prohibitive for the remaining life of the plant, unless major changes are already planned. Despite this, possibilities may still exist for water conservation at these plants. Detailed recommendations are difficult with the general nature of the data acquired in this study, but some general recommendations can be made:

1. Increase cooling tower cycles to reduce blowdown and makeup water required, if possible.
2. Investigate the availability and feasibility of reclaimed water to reduce fresh water demand.

3. Where water is discharged from the plant, examine the possibility of its treatment and recovery.

The critical factor for all of these options is water quality. If incoming water is of higher quality, it can be used through more cooling cycles, resulting in less water discharge. Cleaning the incoming water can provide this higher quality, while cleaning the discharge water allows it to be reclaimed and reused. In other words, a cleaner water source may offset some of the water volume required. Further detailed study of individual plant processes may yield additional water conservation opportunities.

In conclusion, the concern for, and protection of water resources is sure to remain an important topic for the foreseeable future. As some of the largest users of water, power plants will increasingly be the focus of public and regulatory scrutiny. Continuing efforts to identify and take advantage of water conservation opportunities and technologies will remain critical to their successful operation.

Appendices following

Appendix A

Overview of Power Plant Water Uses

Water is critical to the power production process in the majority of plants throughout the world, including most of those plants within the IID service area. Water is used for boiler feed makeup, cooling, emissions control, performance enhancement, domestic needs, and other miscellaneous uses. A general discussion of the different ways water is used in power plants is provided below. This is followed by a summary of the types of plants in operation within the IID service area and a more detailed discussion of water uses specific to the different types of IID area plants.

Boiler Feed Water

The typical thermal power plant uses some variation of the basic Rankine vapor power cycle. Simply described, the working fluid in this process (usually water) is pumped into a boiler, where it is heated to create pressurized steam. The energy of this steam is then released through a turbine that powers the electrical generator. The turbine exhaust steam is then condensed back to a liquid and returned to the pump, completing the cycle.

Although the water used for this cycle is contained in a closed system, there are some losses. These losses include steam loads, blowdown, and leaks. Steam loads are most common in cogeneration plants, where some of the steam may be removed from the cycle for heating or other process needs. The steam removed is usually consumed by that process, and does not return to the boiler feed system. Blowdown is a process where some of the boiler feed water is removed to control contaminants and chemical water treatment levels in the system. As the chemicals break down or react with contaminants, a continuous small flow of water, or blowdown, is drained from the system, keeping the levels from building up. Finally, there are inevitably some leaks in any system. To compensate for these losses, a make-up system adds water to replace the loss and maintain required water levels in the system.

The water used for make-up in boiler feed systems is usually extensively treated to remove all harmful minerals and other impurities to minimize the possibility of corrosion and reduce the quantity of treatment chemicals used.

Cooling Water

The largest use and consumption of water in most power plants is for cooling and condensing the steam after it has passed through the turbine. Although the steam in the power cycle has spent much of its energy in spinning the turbine, the turbine exhaust still contains a large amount of heat energy. The pressure and temperature of the steam at this stage is too low for use in generating additional power, but the steam must be condensed back to liquid form in order to be pumped back to the boiler. Therefore, this excess heat energy must be rejected to the environment.

Since water is easily transported and has a very high capacity for heat absorption and transfer, it has been the cooling medium of choice for power plants since their inception. The steam is passed through one side of a special heat exchanger called a condenser, which returns the steam to a liquid state. Cooling water is circulated through the other side of the condenser, absorbing heat from the steam. The heat transferred to the cooling water is then transported to the environment with the water.

In addition to cooling and condensing steam in the power cycle, water is also often used for cooling generator windings, engines, and other equipment within the plant. The water quality required for cooling systems varies depending on the type of system, and ranges from very low for once-through systems where brackish or untreated river water may be used, to nearly potable quality for closed-loop cooling systems.

Other Water Uses

While cooling and boiler feed typically account for 90% or more of the water used in power plants, there are other minor, but important uses water uses in power production. Virtually all plants will use some water for personnel domestic needs and for general plant cleaning and maintenance. Some natural gas-fired turbines may use high-purity water for direct injection into the turbine to control emissions in the exhaust stream and to enhance performance, while some geothermal plants may pump surface water into a geothermal rock layer through an injection well to produce or enhance steam production in an extraction well field.

Appendix B

Overview of Power Plant Types and Operation

Geothermal Power Plants

The largest number of power plants in the IID service area use geothermal energy for electrical power production. Several Known Geothermal Resource Areas (KGRA's) have been designated in the Imperial Valley area and developed for power generation using primarily two types of technology: flash steam power and binary cycle power plants. The type of technology used in a particular plant depends on the temperature of the geothermal resource. Higher temperatures (usually above 350°F) allow the use of flash steam power, while lower temperature resources utilize binary cycle systems. A number of plants employ both systems, using the flash steam directly in the first stage, then using the remaining lower-temperature heat energy in the flow stream to power a binary cycle. Since each geothermal resource is unique, geothermal power plant design is tailored to best take advantage of a given resource, and many variations and hybrids of these basic designs may be used.

Flash steam geothermal power plants extract high-temperature brine from a set of production wells and pipe it to a flash tank. The brine is sprayed into the tank, which is held at a lower pressure than the incoming brine. The sudden reduction in pressure causes a portion of the water to immediately vaporize (flash). The steam produced is separated from the brine and sent to a steam turbine, which is used to power an electrical generator. The flash steam process may be done in several stages at different pressures to maximize the steam, and in turn, the electrical energy produced. The remaining brine is then pumped back into the ground via a dedicated injection well. This reinjection not only keeps the brine from contaminating the surface environment, but also avoids excessive depletion of the geothermal resource fluids and prevents subsidence (sinking) of the ground in the surrounding area. The steam, having passed through the turbine, is condensed, and the water is used for plant cooling or other purposes. This type of plant is typical of the Salton Sea KGRA.

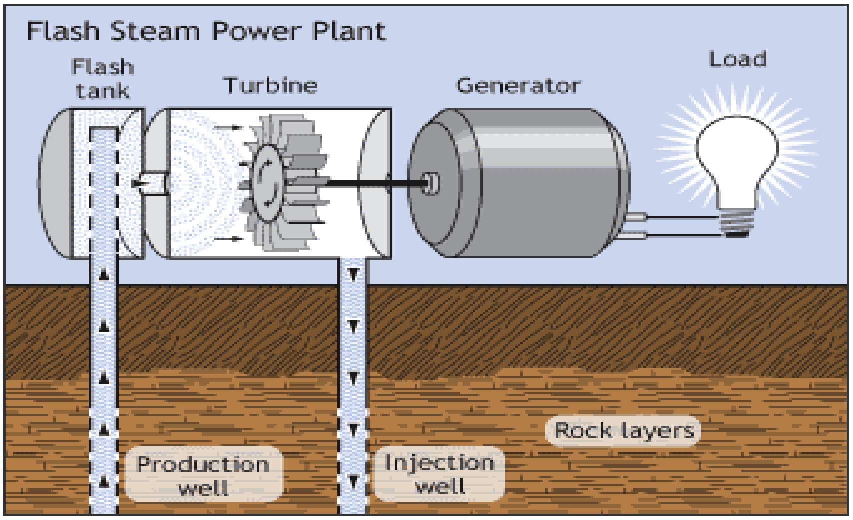

Figure 2: Simplified Illustration of a Flash Steam Plant (Courtesy of US DOE)

Binary cycle power plants are used where the temperature of the geothermal resource is too low to effectively create steam from the geothermal brine. Instead, the brine is used in a heat exchanger to heat another working fluid with a significantly lower boiling temperature. Usually, this secondary working fluid is some type of hydrocarbon such as isopentane or isobutane. The basic Rankine vapor power cycle is still used, but the new working fluid allows the cycle to operate effectively at a lower overall temperature. The heat from the geothermal brine flashes the working fluid into vapor, which is then used to power the turbine generator. The working fluid is then condensed and pumped back to the heat exchanger to complete the cycle, while the geothermal brine is injected down a dedicated well to maintain the resource. Since both loops are closed systems, these plants have virtually no emissions.

Cooling requirements for binary plants are typically greater than for other plant types, due to the narrower and lower working temperature range. The thermodynamic efficiency of a power plant is directly related to the temperature difference between the absolute high temperature of the steam (or other working fluid) entering the turbine and the absolute low temperature of the liquid leaving the condenser. In a geothermal power plant, the high temperature of the cycle is limited by the temperature of the geothermal resource. When using a lower temperature resource, the thermodynamic cycle is inherently less efficient, and more heat is rejected for the amount of electricity generated, in comparison with using a high-temperature resource. Consequently, the cooling requirements of these plants are higher than for other plant types, when compared on a per-megawatt basis.

Binary plants are employed in the Heber, East Mesa, and Brawley KGRA's of the Imperial Valley, where the temperature of the geothermal resources are lower than that found in the Salton Sea KGRA.

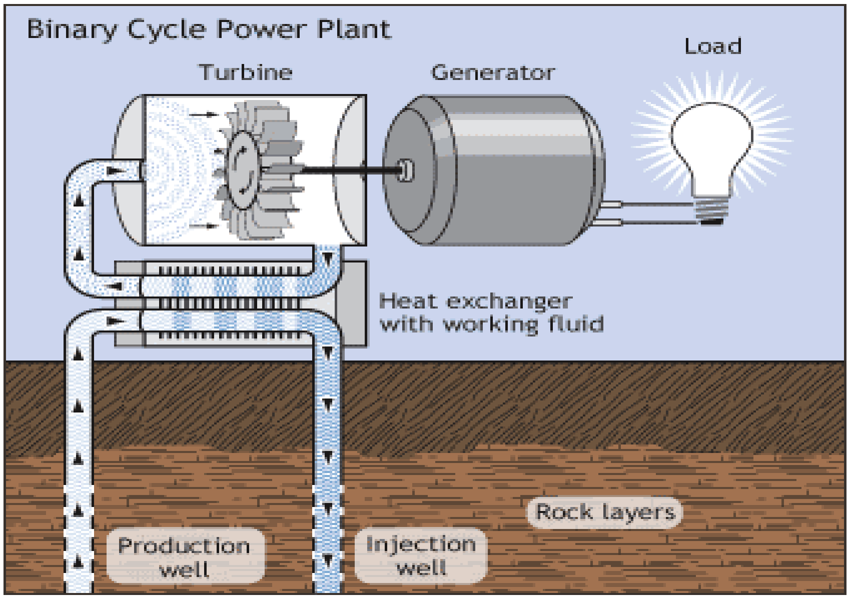

Figure 3: Simplified Illustration of a Binary Cycle Plant (Courtesy of US DOE)

In some cases, a combination of flash and binary cycles is employed within the same plant. High temperature and pressure brine is flashed and the steam is separated for direct use in the steam turbine, while the remaining hot brine is used to power the binary cycle turbine. The number of flash stages and combinations used depends on the characteristics of the geothermal resource.

Both types of geothermal plants generally use water for condenser cooling purposes. A flash plant often uses condensed steam from the power production process as cooling tower makeup. A binary plant, not having this water available, must rely on an external water source for cooling tower makeup. In both cases, blowdown waste water from the cooling tower and water treatment systems is often added to the re-injected brine, or injected through a dedicated well. This not only helps to recharge the thermal aquifer, but also eliminates the need for discharge water treatments and permits and the contamination of surface waters.

Biomass Power Plants

Biomass power plants represent only a small percentage of the power industry, but when used, their appeal is in the use of resources that are often otherwise wasted. Biomass plants also use the normal steam cycle, heating water in a boiler to power a steam turbine generator. The fuel used in biomass plant boilers varies widely however, and includes organic municipal waste, agricultural processing waste, wood and wood byproducts, and manure. The size and output of biomass plants is typically small, as the quantity of fuel required for a given heat output is much larger and the firing temperature lower than for fuel sources such as coal and natural gas. Water use in biomass plants is usually for boiler feed and cooling water makeup. Biomass plants in the IID and surrounding area include Colmac Energy in Mecca, CA and a proposed refurbishment of an old plant by Green Hunter Energy in El Centro, CA.

Combined Cycle Power Plants

As the name implies, combined cycle plants use more than one technology to produce electrical power. The most common type of combined cycle plant in use combines a natural gas fired turbine generator and a steam turbine generator. First, the gas turbine is used to run one generator directly, and then the heat from the turbine exhaust is used to boil water in a heat recovery steam generator (HRSG). The HRSG provides steam to a steam turbine connected to a second generator.

The gas turbine part of the cycle uses far less water for power generation than an equivalent steam turbine. Gas turbine water uses include auxiliary system cooling, water injection, and inlet air cooling. Auxiliary cooling water, if used, is usually limited to generator winding and lube oil cooling. Water injection in gas turbines uses highly purified water sprayed directly into the combustion area to reduce emissions by controlling the exhaust temperature, and can also be used to enhance power output by increasing the mass flow rate through the turbine. Finally, water is also used for inlet air cooling of the gas turbine units on hot days through the use of fogging or evaporative cooling units.

The steam turbine portion of a combined cycle plant is the big water user. As with the other steam cycle plants, water is used for condenser cooling and boiler feed water makeup. The largest combined cycle plant in the area is located in El Centro and owned by the Imperial Irrigation District.

Solar Thermal Power Plants

Solar thermal plants are receiving increased development interest as another clean energy alternative. At this stage, there are basically two types of solar thermal power plants being built or under development. The more traditional type uses focused mirrors to heat water either directly or through an intermediate working fluid, and uses the steam to power a normal steam turbine. Water is used not only for the normal condenser cooling and boiler feed makeup, but is also required on an intermittent basis for washing the mirrors.

The second type of solar thermal plant is a specialized system based on the Stirling engine. The solar energy is focused on self-contained generation units housing the engine, generator, and working fluid in a closed-loop design. The only water normally used in this case is for occasional washing of the mirrors.

Appendix C

Overview of Power Plant Cooling Technologies

Without effective cooling methods, the normal vapor power cycle of a thermal power plant would be impossible to maintain. The thermodynamic efficiency of the Rankine steam cycle is directly related to the temperature difference between the absolute high temperature of the steam entering the turbine and the absolute low temperature of the liquid leaving the condenser. Within practical limits, the lower the pressure and temperature of the cooling side of the condenser, the better the overall plant efficiency will be for a given high temperature.

Most thermal power plants reject heat either by once-through water cooling or by a closed-loop cooling tower system. With the increasing concern for water conservation and environmental protection, dry cooling and hybrid systems are also being developed to reduce the water demand. Following is a discussion of each of these cooling systems, along with their respective advantages and disadvantages.

Once-Through Cooling

With a once-through cooling system, water is withdrawn from a large source, usually a lake, river, or ocean; circulated through the condenser where it absorbs the waste heat; and then returned to the source body of water, having passed only once through the cooling system. This type of system uses large quantities of water in comparison with the other cooling system types, and is usually limited to plants located near very large bodies of water. The advantages of this type of cooling system are that relatively little water is actually consumed, since it is not evaporated; and that little or no water treatment is required, other than screening for large debris and fish. The disadvantage is that, since the water used is warmer (between 5 and 25°F) when returned to the source, there significant concern for environmental impact. Warmer water can cause harm to fish and plant organisms directly by thermal shock or disruption of thermally sensitive life cycles. Indirectly, the warmer water can affect aquatic life by leading to the excessive growth of algae and other invasive plant or animal species, which then compete with native species for aquatic oxygen and food. Another disadvantage is that smaller fish and organisms may be killed due to being trapped against inlet screens or passing through pumps and other equipment. Because of these concerns, once-through cooling is highly discouraged or prohibited in most new power plant designs, and older plants using once through cooling are in some cases being retrofitted with other cooling system types.

Closed-Loop Evaporative (Wet) Cooling

The most common cooling system for medium and small power plants is closed-loop evaporative cooling, also known as wet cooling. The potential water sources for wet cooling systems include potable and reclaimed water systems, pumped ground water, and surface waters such as lakes, rivers, and canals. The main components of the wet cooling system are the condenser, cooling tower, circulation pumps, and interconnecting piping. The cooling water picks up heat in the condenser as it passes through and condenses the turbine exhaust steam, and is then sent to the cooling tower. In the cooling tower, the water falls down through a system of baffles, while fans draw air across or up through the water flow as shown in Figure 3. This arrangement provides a large contact area between the water droplets and the moving air, which evaporates a significant portion of the water and cools the remainder. Cool water falling to the basin below the tower is collected and pumped back to the condenser to complete the loop. The water lost to evaporation is replaced with fresh water from the source to maintain a minimum level in the collection basin. The advantage of this type of system is its relatively low cost, small footprint, and high cooling effectiveness, especially in dry climates. The corresponding disadvantage is that, while this system withdraws much less water than a once-through system, the water it does withdraw is consumed, rather than being returned to the source. Direct environmental impact is relatively low, but the indirect effect, by consuming increasingly precious water resources, is causing more scrutiny and restriction of this cooling method.

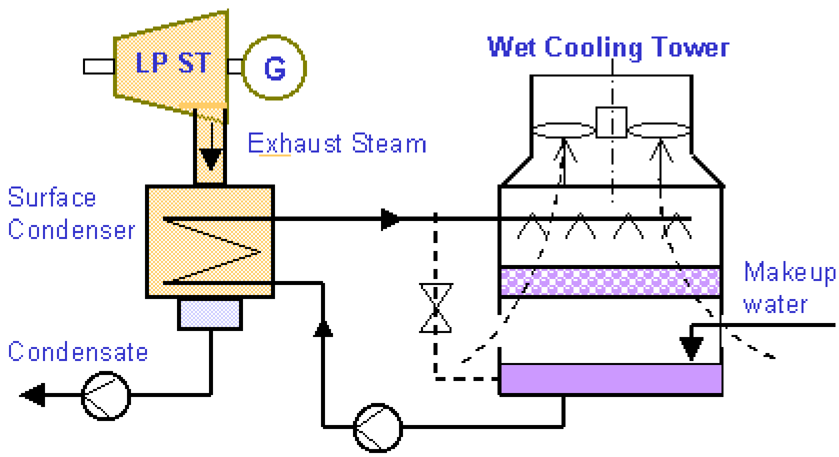

Figure 4: Simplified Illustration of a Closed-Loop Evaporative Cooling System

Water quality for closed-loop systems is of significant importance, and is much higher than for once-through systems. As water in the loop is lost to evaporation, it leaves behind whatever minerals or contaminants were present in the original source water. After a certain number of cycles through the cooling loop, the concentration of these substances reaches a point at which it begins to cause scaling or corrosion within the condenser, pumps, and piping. In addition, various other chemicals are necessarily added to the recirculation loop to control organic growth and help fight corrosion. These chemicals are also concentrated as evaporation continues. In order to control the mineral and chemical concentrations within prescribed limits, a portion of the water is continually removed from the system and disposed of in a process known as blowdown, and is replaced by fresh water from the source. The implication is that the better the water quality of the source make-up water, the more cycles of concentration can be achieved in the system before blowdown is necessary, resulting in less blowdown flow and consequently, less makeup water required. This generally restricts water sources for closed-loop system makeup to relatively clean fresh water. These sources include potable water (although used very rarely), pumped ground water (if the ground water is relatively low in minerals), reclaimed water from treatment plants, and river or lake water (increasingly restricted use). Often, these sources undergo filtering or other treatments before being used in closed-loop systems.

Dry Cooling

As the name implies, dry cooling systems use little or no water in the process of cooling and condensing the turbine exhaust steam. Direct dry cooling systems for power plants employ large air-to-steam heat exchangers in, similar to an automobile radiator, in place of the traditional condenser. As the steam passes through the air-cooled condenser (ACC), air is blown across the exterior cooling fins, removing the heat directly to the environment as shown in Figure 4.

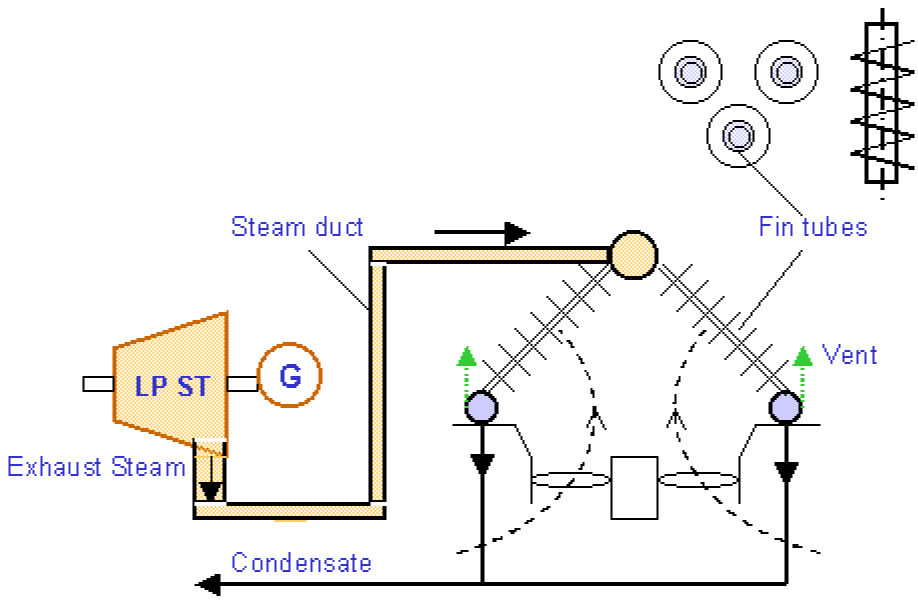

Figure 5: Simplified Illustration of a Direct Dry Cooling System

An indirect dry cooling system is similar, but instead of the air-to-steam heat exchanger, a traditional condenser is used to transfer the heat from the steam to a closed water loop, which is itself then cooled in an air-to-water heat exchanger. This arrangement is more efficient from a heat transfer standpoint, but does involve additional equipment. Since there is no evaporative water loss for either type of dry cooling system, water consumption is nearly eliminated. This makes dry cooling increasingly attractive as water resources become more limited. However, there are disadvantages to these systems, including significantly higher initial cost, greater space requirements, and reduction in plant power output under some conditions.

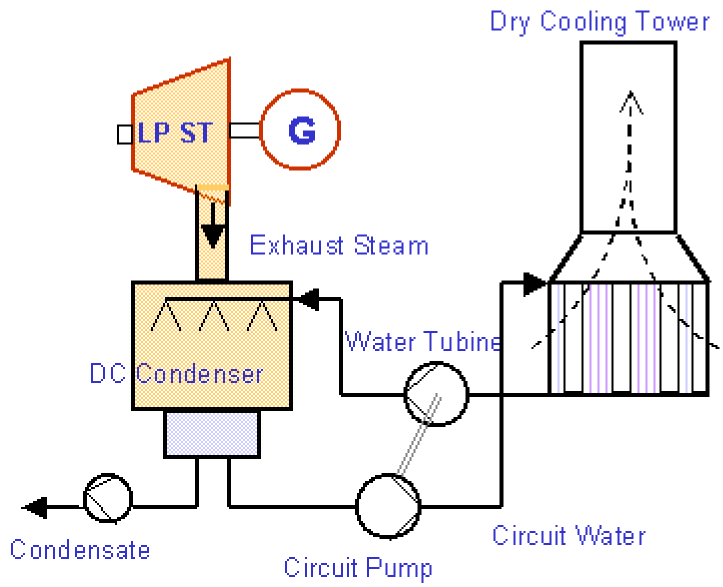

Figure 6: Simplified Illustration of an Indirect Dry Cooling System

Power output from a steam turbine depends greatly on the temperature to which the exhaust can be cooled. A low cooling temperature is essential for maintaining a low turbine exhaust pressure and maximizing the pressure difference across the turbine, which determines the achievable power output. Without the evaporation of water, the effective condenser cooling temperature is limited by the ambient air temperature (dry bulb temperature), which can be as much as 30°F warmer than air cooled by evaporation (wet bulb temperature). For plants with a relatively small temperature difference between the high and low power cycle temperatures, such as in many geothermal plants, the inability to cool down to the wet bulb temperature on a warm day can result in a reduction of as much as 50% in plant output and efficiency.

Hybrid Wet/Dry Cooling

In an effort to mitigate the power loss disadvantage of dry cooling systems, but still maintain the water consumption reduction, hybrid wet/dry cooling systems have been developed. Hybrid cooling uses similar heat exchange systems to the dry cooling systems described above, but adds some form of wet cooling at the interface with the ambient air. Some systems employ a fine water spray in the airstream ahead of the radiator, while others use a wet media much like a swamp cooler to cool the incoming air to the wet bulb temperature before it passes through the radiator fins. Another option used is deluge cooling, where the normally air-cooled tubes of the radiator are cooled directly with a water stream. Depending on the environmental and plant parameters, these methods may be employed either continuously or only as needed under certain conditions, such as on very hot days. Due to the variety of needs and climate conditions at different plants, hybrid cooling systems are usually tailored specifically to each installation. While these systems do not eliminate water consumption completely, water use with hybrid cooling can reduce consumption to between 5% and 70% of wet cooling levels. The major disadvantages of these systems are the cost, complexity, and increased maintenance requirements.

Appendix D

Overview of Intake Water Treatment Technologies

The use of water in a power plant is not only concerned with the availability of the water source, but also with its quality. The difficulty and expense of treating source water to meet plant system requirements, and the disposal of wastes generated in the treatment process, can have a significant effect on the selection of that source.

Filtration Systems

Water filtration systems are used in cases where the water source contains particles that could adversely affect the downstream process. In the power plant setting, filtration is commonly used when the source is river or canal water, preventing suspended solids and similar contaminants from entering makeup water feeds. Filtration systems are also used to protect high-purity water treatment systems further downstream. Generally, simple filtration is the least expensive treatment option, with the selection of filter media and flows tailored to the plant needs and incoming water quality. Filtration typically produces water quality suitable for cooling tower makeup use in cases where river, canal, or reclaimed waste water is used as a source.

Reverse Osmosis/De-ionized Water Systems

Reverse osmosis (RO) systems are widely used to produce potable quality (or better) water. In the power industry, most plants will employ an RO system coupled with a de-ionized (DI) water system, to produce highly purified water for boiler feed makeup and other processes requiring very pure water. An RO system essentially uses pumps to force water through a special porous membrane to remove not only very small particles, but also most dissolved minerals and salts. The DI portion of the system then uses ion-exchange resins to further purify the water by removing those mineral ions still remaining. As part of the purification process, the RO/DI system produces a concentrated waste water stream containing all of the removed minerals and particles. This waste is discharged, usually to a municipal sewer, or it may be treated at the plant site.

Chemical Treatments

Various chemical treatments are applied to water within the closed cooling and boiler systems in a power plant. These chemicals are used to control biological growth, which contributes to fouling of piping and to health hazards; to control mineral concentrations, which can lead to scale and reduced heat transfer characteristics; to reduce foaming in cooling tower basins and other systems; and to control dissolved gasses like oxygen and carbon dioxide, which can cause severe corrosion problems. The plant water systems are kept in careful balance through measured chemical injection and periodic blowdown. The drawback of chemical treatments is that they necessarily increase the quantity of substances other than water in the process stream. As the chemicals break down or combine with the original contaminants, they eventually reach concentration levels that require blowdown to keep the process in balance. To keep the required chemical treatment to a minimum, incoming process makeup water that is as clean as possible is highly desirable.

Appendix E

Overview of Discharge Water Treatment Technologies

In accordance with state and federal regulations, any waste water discharged from a power plant must not adversely affect the area ground and surface waters. If the contaminants in the discharge stream are within prescribed limits, it is permissible to discharge the waste water directly to a surface body or to a municipal waste water system. If not, some form of treatment must be applied to ensure that excessive contaminants do not reach the environment. Following are brief descriptions of some of the methods used in the IID area for waste water treatment.

Re-Injection Wells

Most geothermal power plants provide for the re-injection of fluids withdrawn from geothermal wells. After the heat is removed in the power production process, the fluid (usually brine) is pumped down a set of dedicated injection wells back into the earth. This not only disposes of the brine, which would contaminate surface waters, but also recharges the geothermal aquifer, maintaining the continued availability of the geothermal resource, and avoiding ground subsidence (sinking) in the area.

In addition to reinjection of withdrawn brine, blowdown waste streams from boiler feed water loops, cooling towers, and RO/DI systems are often disposed of through an injection well. Often, these waste streams have chemical and mineral content similar to the brine already present in the geothermal aquifer, in concentrations usually less than that in the natural brine, so this disposal method has no detrimental effect on the geothermal aquifer.

Surface Impoundment

Occasionally, there may be upsets in the brine injection system, and in this case, the brine is directed to an impoundment pond. These ponds are specially lined and monitored to ensure that none of the impounded contaminants are allowed to enter surface or ground water. The water in the pond evaporates, leaving behind the minerals and other contaminants, which can then be collected and disposed of, as necessary. This impoundment treatment may in some cases also be used as the primary treatment for other discharges, such as blowdown from cooling systems or waste from intake water treatments.

Zero Liquid Discharge Systems

As stricter limits are imposed on contaminant discharge levels, Zero Liquid Discharge (ZLD) systems are increasingly used in many power plants and other industrial facilities. The ZLD system takes the waste stream and heats it in a series of heat exchangers to evaporate the liquid, leaving the minerals and contaminants as solid waste for disposal. The evaporated vapor is then condensed, and can then be reused wherever high-purity water is needed within the plant, providing the additional benefit of reducing plant water intake quantity and treatment requirements.

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CalEnergy Generation: www.calenergy.com

California Code of Regulations: www.calregs.com

California Department of Water Resources: www.water.ca.gov

California Division of Oil, Gas, and Geothermal Resources: www.conservation.ca.gov/dog

California Energy Commission: www.energy.ca.gov

California Water Code (Porter-Cologne): www.swrcb.ca.gov/laws_regulations/docs/portercologne.pdf

Catalyst Hannon Armstrong Renewables (CHAR), LLC: www.charllc.com

City of Brawley, California: www.cityofbrawley.com

City of El Centro, California: www.cityofelcentro.org

City of Imperial, California: www.imperial.ca.gov

County of Imperial, California: www.co.imperial.ca.us

Imperial Irrigation District: www.iid.com

Ormat Technologies, Inc.: www.ormat.com

State Water Resources Control Board: www.swrcb.ca.gov

Vendors for Equipment and Budgetary Estimates

GEA Power Cooling Inc.: www.geaict.com

Manning & Lewis Engineering Company: www.manninglewis.com

SPX Corporation: www.spx.com

Yuba Heat Transfer, LLC: www.yuba.com

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