4. CLOSED-CYCLE COOLING SYSTEMS

1.0 BACKGROUND

Closed-cycle cooling systems are an increasingly common technology used to provide the necessary heat rejection for steam electric power plants. Environmental and regulatory trends have made these systems—both wet and dry cooling—the nearly universal cooling option for newly-constructed power plants. California reflects this trend as well, with new and repowered facilities adopting this approach and reducing impingement and entrainment impacts to California's coastal waters.

Unlike screening technologies, closed-cycle systems, as a retrofit technology, will more broadly affect a facility's operation and may trigger other environmental effects that may require mitigation of their own. These effects may be more pronounced at an aging facility that is less efficient and more susceptible to process changes.

This chapter provides general background information on the types of closed-cycle cooling systems their function and some secondary effects of their use as a retrofit technology.

2.0 HEAT TRANSFER

The function of any cooling technology is to transfer waste heat from the turbine to the environment as efficiently as possible. In a wet cooling system, heat rejection from a cooling tower is primarily due to the evaporation, or latent heat, of water into the surrounding air and is responsible for approximately 80 percent of the tower's cooling capacity. Sensible heat transfer, which results from the direct contact between warm water and cooler surroundings, provides the remaining 20 percent. In either a natural or mechanical draft tower, latent and sensible heat transfer must be maximized in order to achieve the full cooling capacity at the most economically efficient rate (Hensley 2006). Dry cooling systems, as the name implies, do not use water as a cooling medium and instead rely on sensible heat transfer only.

Because wet cooling towers rely primarily on evaporation, their overall efficiency is governed by the differential between the circulating water temperature in the tower and the wet bulb temperature of the ambient atmosphere. The wet bulb temperature measures the ambient air temperature (also referred to as the "dry bulb" temperature) and the relative humidity of the surrounding atmosphere. By accounting for the saturation level of the atmosphere, the wet bulb temperature represents the additional cooling capacity that can be exploited by wet cooling towers through evaporation. Thus, wet cooling towers function most efficiently in environments where the relative humidity is low and the surrounding atmosphere can more rapidly accommodate evaporative heat loss. This does not preclude their use in more humid environments, however, since the wet bulb temperature, on average, will always be lower than the dry bulb temperature (Hensley 2006).

In theory, a wet cooling tower can lower the temperature of the circulating water to the ambient wet bulb temperature if sufficient evaporation is achieved. In practical application, however, this is not feasible due to the diminishing ability of the tower to induce evaporation in the circulating water as the temperature decreases. A wet cooling tower designed to achieve the ambient wet bulb temperature would need to be extraordinarily large in order to achieve the desired air-water interaction to facilitate the necessary evaporation. Instead, the design of wet cooling towers is based on the "approach" temperature, which is the difference between the temperature of the water exiting the cooling tower and the ambient wet bulb temperature.[1]

The approach temperature is critical to estimating the overall size and cost of the cooling tower, and is fixed prior to design based on the ambient conditions and the desired cooling capacity. Common industry practice does not call for the design of a wet cooling tower with an approach temperature that is less than 5ºF. In general, as the wet bulb temperature decreases the economically achievable approach temperature will increase. An accepted industry practice is to start with an approach temperature of 10ºF and adjust upwards if site-specific conditions warrant (Hensley, 2006). In general, as the wet bulb temperature decreases the economically achievable approach temperature will increase.

Dry cooling systems rely solely on radiation and convection to reject heat from the steam cycle. Their overall efficiencies are largely governed by the dry bulb temperature of the surrounding atmosphere. The dry bulb temperature is synonymous with what is commonly referred to as "air temperature" and is measured using a thermometer freely exposed to the air but shielded from any radiation source (sunlight) or moisture condensation. Except when the relative humidity is 100 percent and the dew point is equal to the air temperature, the dry bulb temperature will always be higher than the corresponding wet bulb temperature.

Like wet systems, dry systems are also limited in how close they can come to approximating the governing cooling variable (dry bulb). As a dry system approaches the dry bulb, the efficiency of the system drops off dramatically and requires an increasingly larger cooling surface area to achieve progressively smaller gains in cooling capacity. Costs will also increase substantially as the system and its associated operational demands grow, making the diminishing returns of a large system designed to maximize the theoretical cooling capacity economically unpalatable (Hensley 2006). Instead, the level of cooling in a dry system is a function of the initial temperature difference (ITD), which reflects the difference between the dry bulb temperature of the ambient atmosphere and the temperature of the steam condensate in the system.

A lower ITD in a dry system translates to a cooler steam condensing temperature and a lower backpressure at the steam exhaust point, which in turn limits the loss of turbine efficiency. Lower ITD values enable a facility to operate under more demanding conditions, but are comparatively larger and require more operating power than a system designed for a higher ITD. For example, a system with an ITD of 20 ºF might have an initial capital cost 67 percent higher than a comparable system designed with an ITD of 35 ºF. Operating costs might be twice as high or more (EPRI 2002b), although these costs will be partially offset by the increased efficiency.

[1] Under certain conditions, the ambient wet bulb temperature used for design purposes may be increased if the arrangement of the cooling tower cells or local climate factors results in the reuptake or recirculation of the warm, humid tower exhaust. This modified temperature is referred to as the "entering wet bulb."

While design ITD values vary from place to place depending on the relative climatic conditions, recent applications have used design ITD values ranging from 35 to 45 ºF, which are considered applicable to coastal sites in California.

3.0 EVAPORATIVE COOLING SYSTEMS

Evaporative cooling systems, more often referred to as "wet cooling towers", function by transferring waste heat to the surrounding air through the evaporation of water, thus enabling the reuse of a smaller volume of water several times to achieve the desired cooling effect. Compared to a once-through cooling system, wet cooling towers may reduce the volume of water withdrawn from a particular source by as much as 97 percent depending on various site-specific characteristics and design specifications. The environmental benefits associated with a closed-cycle system, through their reduced water use, may be substantial when compared to a once-through system but are not without significant drawbacks of their own.

Consideration must be given to other environmental impacts (air emissions, visual, noise, etc.) that may result from the use of a closed-cycle system and the comprehensive cost associated with its installation and operation. In a retrofit situation, where a wet cooling tower is proposed to replace a once-through cooling system, these impacts may be greater, and come at a higher cost, than for a facility that adopts closed-cycle cooling from the start.

3.1 NATURAL DRAFT COOLING TOWERS

Wet cooling towers are classified into two broad categories depending on the mechanism used to induce draft—the flow of cooler, drier air through the tower: natural or mechanical. The term "cooling towers" usually calls to mind the tall, hyberbolic shape of natural draft cooling towers (Figure 4–1). These towers rely on the naturally-occurring chimney effect that results from the temperature difference between warm, moist air at the top of the tower and cooler air outside. . Fans are not required to maintain the flow of air, but hyperbolic towers must be fairly tall to achieve the desired temperature differential. The overall height of these structures can approach 500 feet or more.

Natural draft towers were not considered at any of the coastal power plants that are part of this study, primarily due to the increased cost and difficulty of placing such large structures at existing facilities. All of the coastal power plants in California are located within Seismic Zone 4 of the Uniform Building Code (UBC) (ICBO 1997). Standards for this zone are the most stringent with regard to structural integrity and resistance to damage, and result in substantial increases in design and construction costs for progressively taller structures. In addition, placement of obtrusive structures 450 feet tall or more in the California Coastal Zone is unlikely at many locations given the Coastal Act's requirement that "development shall be sited and designed to protect views and… to be visually compatible with the character of surrounding areas, and where feasible, to restore and enhance visual quality in visually degraded areas." In many of the highly developed areas where California's coastal power plants are located, the cost and regulatory considerations, in addition to the likely local opposition, are not justified when compared to less-costly and less-obtrusive options that can achieve similar results.

Figure 4–1. Natural Draft Cooling Tower

3.2 MECHANICAL DRAFT COOLING TOWERS

Mechanical draft cooling towers rely on motorized fans to draw air through the tower structure and into contact with the water. Without the same need for height as natural draft towers, the mechanical draft design presents a much lower visual profile against the surrounding area with typical heights ranging from 30 to 75 feet, depending on local constraints and design considerations. The overall area devoted to cooling towers, however, may be comparable to natural draft units since one mechanical draft unit, or "cell", has a smaller cooling capacity. Mechanical systems are arranged into multi-cell units, which are collectively referred to as the cooling tower, and can be placed in a single row (inline) or back to back. Although often more feasible, and in some cases more practical, than natural draft towers, mechanical systems place an added draw on the facility's net generating output in order to operate the fans that induce the draft. Figure 4–2 shows a multi-cell mechanical draft cooling tower in an inline configuration.

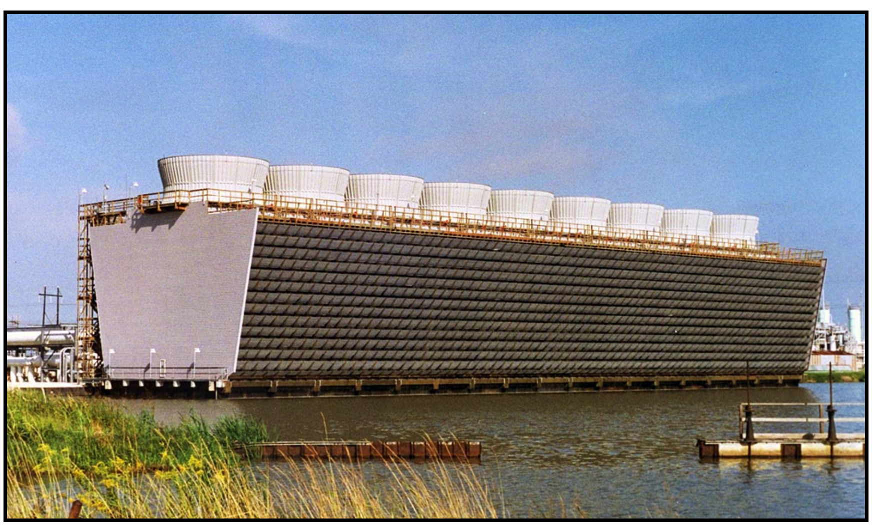

Figure 4–2. Multi-cell Mechanical Draft Cooling Tower

3.3 SALTWATER COOLING TOWERS

In the past, wet cooling towers were considered to be ill-suited for seawater applications due to the more corrosive effects of salt on construction materials, the degradation of the condenser performance due to scaling and the reduced rate of evaporation resulting from salt concentrations in the circulating water (Ying and Suptic 1991). Advances in tower design and construction materials have enabled cooling towers to be successfully deployed in numerous locations with high salinity water. Table 4–1 contains a list of facilities that have deployed wet cooling towers in high salinity environments (Marley 2001).

Table 4–1. Installation of Seawater/Saltwater Cooling Towers

Location	Project Owner	Design Flow (MGD)	Installation Year
Oklahoma, USA	Oklahoma Gas & Electric Company	87	1953
Kansas, USA	American Salt Company	7	1964
New Jersey, USA	Exxon Chemical Company	32	1968
Stenungsund, Sweden	ESSO Chemical AB	146	1969
Judibana Falcon, Venezuela	Lagoven Amuay	49	1970
Okinawa, Japan	Exxon Petroleum Company	21	1971
Florida, USA	Gulf Power Company	239	1971
Texas, USA	Dow Chemical Company	87	1973
Maryland, USA	Potomac Electric Power Co. Plant 3	376	1974
Virginia, USA	Virginia Electric Company	477	1975
North Carolina, USA	Pfizer Company	79	1975
California, USA	Dow Chemical Company	17	1976
Washington, USA	Italco Aluminum Company	59	1976
California, USA	Pacific Gas & Electric Company	538	1976
Texas, USA	Houston Lighting & Power Company	347	1977
Mississippi, USA	Mississippi Power Company	250	1980
Maryland, USA	Potomac Electric Power Co. Plant 4	376	1981
Arizona, USA	Palo Verde I Plant	849	1985
Arizona, USA	Palo Verde II Plant	849	1986
Florida, USA	Stanton Energy #I Station	289	1986
Arizona, USA	Palo Verde III Plant	849	1987
Texas, USA	Houston Lighting & Power Company	348	1987
Delaware, USA	Delmarva Power & Light	293	1989
California, USA	Delano Biomass Energy Company	28	1991
Florida, USA	Stanton Energy #2 Station	289	1995

Most cooling towers today, especially those in seawater environments, are built with materials that are more corrosion resistant than were used in the past (e.g., pressure treated wood) and designed for lower cycles of concentration to minimize impacts on the condenser. This lower cycle of concentration, however, means that a saltwater tower using seawater will often require more makeup water than a tower using freshwater.

All of the facilities in this study currently use seawater or brackish water for cooling in once-through cooling systems. Given the increasing demands on freshwater sources throughout California and state policies discouraging the use of freshwater as a cooling water source, all cooling towers designed in this study are assumed to rely on saltwater or brackish water as the makeup water source.

The average concentration of dissolved solids for seawater is approximately 35 parts per thousand. Input from cooling tower vendors and data from other seawater applications suggest that 1.5 cycles of concentration is an acceptably conservative estimate on which to base tower design specifications. The principal tower construction materials for facilities evaluated in this study are fiberglass reinforced plastic (FRP) and prestressed concrete cylinder pipe (PCCP) suitable for seawater application, unless site-specific factors warrant another selection.

Additional information describing the use of saltwater cooling towers can be found in the CEC's 2007 report, Cost, Performance, and Environmental Effects of Salt Water Cooling Towers.

3.4 GENERAL DESIGN AND CONFIGURATION

Wet cooling towers are designed with fill materials that promote heat transfer by maximizing the contact between a volume of water and the air flowing through the system. Splash fill creates smaller and smaller droplets by disrupting the cascading flow of water from top to bottom. Film fill draws water into progressively thinner sheets as it flows downward. Each method increases the surface area to volume ratio of the water, which in turn maximizes the heat transfer potential.

The heat transfer rate is also influenced by the relative water-to-air direction inside the tower structure. Crossflow towers place fill material along the inside perimeter of the structure surrounding a vacant central column, with water distributed through the fill material (rain zone) by a gravity flow system. Air is drawn horizontally through the rain zone before exiting vertically through the fan (Figure 4–3). Counterflow towers arrange fill material throughout the structure and use pressurized spray nozzles to distribute the water evenly through the rain zone. Air is drawn vertically through the tower in direct opposition to the falling water (Figure 4–4).

Counterflow towers are generally more efficient than crossflow towers because they tend to provide greater interaction between air and water in a given space. To achieve the same degree of cooling, a crossflow tower will be somewhat larger or require more individual cells, thus increasing initial construction costs and the overall tower footprint. Counterflow towers require marginally greater pumping capacities because of the design, but any increase in cost is considered insignificant and does not outweigh the advantages that they provide over the crossflow design. With available space at California's coastal facilities often limited, the need to maximize cooling capacity in relation to the overall tower footprint was a primary consideration in this study; all tower designs are counterflow.

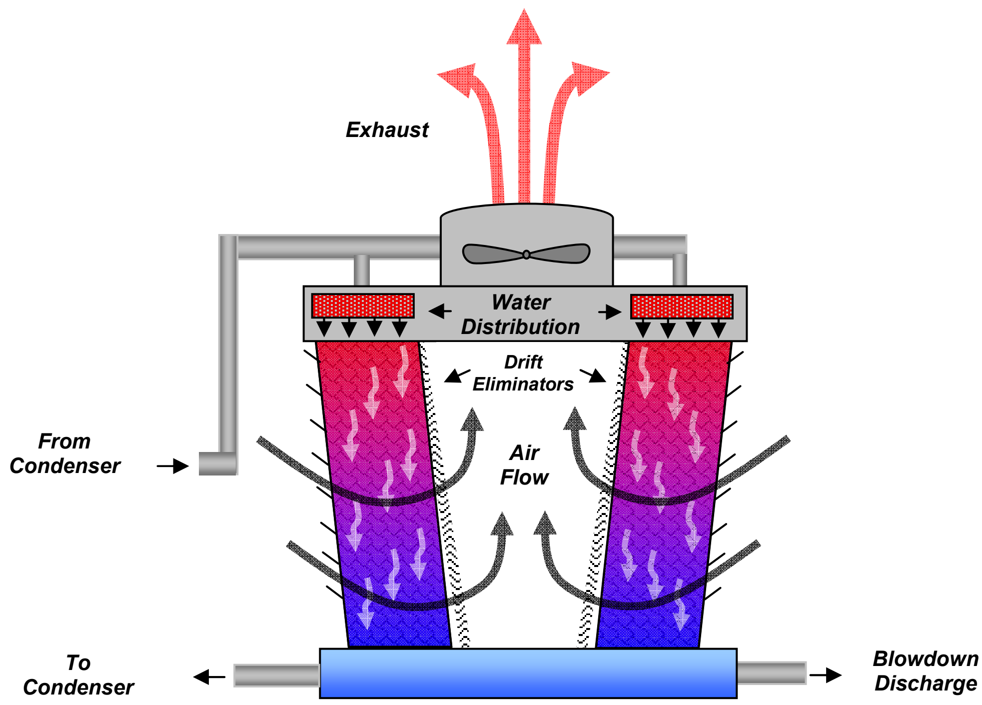

Figure 4-3. Crossflow Cooling Tower

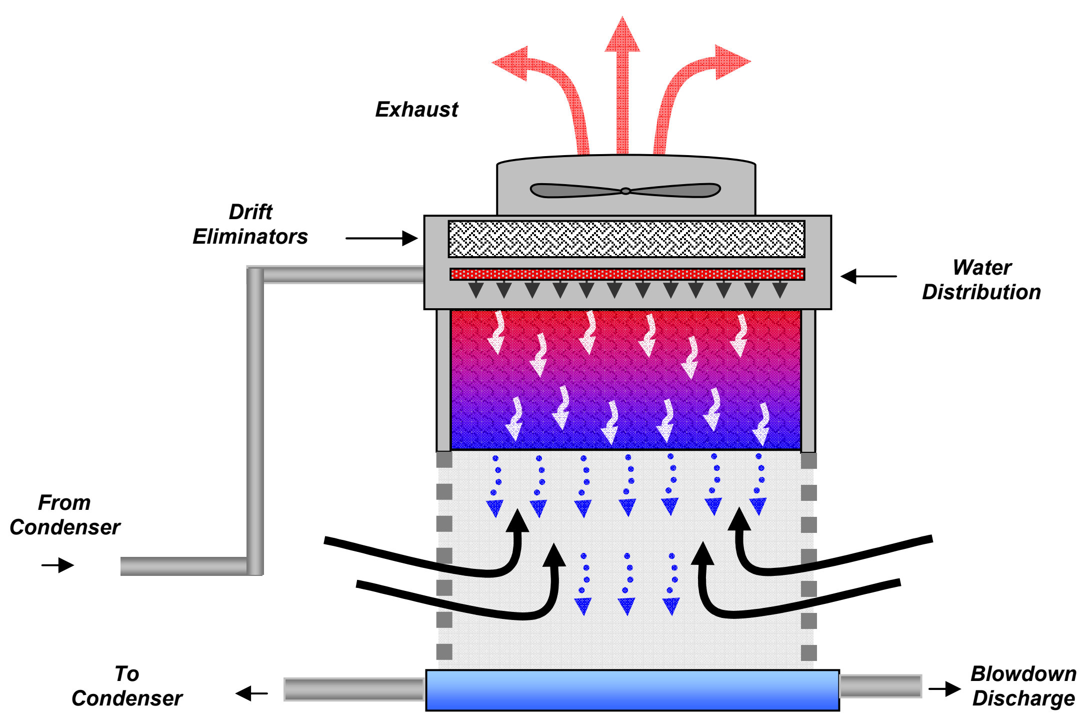

Figure 1-4. Counterflow Cooling Tower

3.5 SECONDARY ENVIRONMENTAL EFFECTS

Retrofitting a once-through cooling system with wet cooling towers will dramatically reduce the amount of water withdrawn from California's coastal waters up to 95 percent below their current levels and achieve a similar reduction of impingement and entrainment impacts as well. In most cases, converting to wet cooling towers will also reduce the size of any thermal plume in the receiving water, often at much cooler temperatures as well. These benefits do not come without some tradeoffs with secondary environmental effects, however, and may present permitting challenges that require mitigation measures or additional considerations.

The principal secondary effects relate to increased air emissions, visible plume and drift, and changes to the wastewater discharge.

3.5.1 FINE PARTICULATE MATTER

The principal air pollutant emitted directly from wet cooling towers is small particulate matter. Dissolved solids in the circulating water result in fine particulate emissions (PM_{10}) when water droplets are ejected from the tower evaporate before they reach the ground. Total PM_{10} emissions can be conservatively estimated by assuming the full concentration of dissolved solids in any exiting water droplets will be converted to airborne PM_{10}. This method discounts the possibility that some droplets do not evaporate prior to deposition on the ground or structural surfaces and assumes that all particulate matter would be classified as PM_{10}. Some studies have suggested that PM_{10} estimates made with these assumptions may exaggerate actual emission rates from cooling towers (Micheletti 2006).

PM_{10} is a significant concern throughout most of California with nearly all counties designated as non-attainment areas, including all counties in which coastal facilities reside. Regulations for air emissions, including PM_{10}, are set by local Air Quality Management Districts or Air Pollution Control Districts (see Chapter 3) and would restrict cooling tower air emissions. If emission limits are significant enough, a facility retrofitting to wet cooling towers may be required to purchase PM_{10} offsets or reduction credits, although these credits are limited in many areas and would become increasingly expensive with new demand from several retrofitted power plants located in the same district.

Reclaimed water as the makeup water source can mitigate PM_{10} emissions due to its lower dissolved solids concentration. Its use, however, may be limited by the available volume and relative distance between the facility and the source.

Cooling tower particulate emissions are controlled through the use of drift eliminators—shaped materials that collect small water droplets as they exit the tower. All cooling towers evaluated in this study include drift eliminators capable of reducing drift to 0.0005 percent of the circulating water volume, or approximately 0.5 gallons per 100,000 gallons of flow. These eliminators are considered Best Available Control Technology (BACT) for PM_{10} emissions from mechanical draft wet cooling towers.

This study estimated direct PM_{10} emissions from wet cooling towers using the conservative approach using the following equation:

$$PM_{10} = F \times TDS \times C \times E \times 8.34\, {}^{lbm}\!/\!_{gal} \times 60\, {}^{\min}\!/\!_{hr}$$

where:

PM_{10}	= fine particulate emissions, in lbm/hr
F	= cooling tower circulating flow, in gpm
TDS	= total dissolved solids concentration in makeup water (3.5%)
C	= cycles of concentration (1.5)
E	= drift eliminator efficiency (0.0005%)

3.5.2 VISIBLE PLUME

Wet cooling towers often produce a visible plume—a column of condensed water vapor resulting from the exhaust's higher temperature and saturation level relative to the ambient atmosphere (Figure 4–5). A plume's density increases as the relative difference between exhaust and ambient temperatures grows. Its persistence is dependent on the speed at which the plume mixes with the ambient air and reduces the water vapor content below the saturation point. Visible plumes are typically more pronounced during winter months, although cool, humid conditions may also produce a substantial plume at any time of the year.

Figure 4–5. Visible Plume

In most cases, a visible plume does not cause any significant environmental impact to the surrounding area since the plume is no different from a cloud or fog. Concerns arise, however, when the plume creates or exacerbates a public nuisance or safety hazard. An atmospheric inversion may result in thick, persistent fog that reduces visibility levels on nearby freeways or bridges. A dense plume that remains aloft may interfere with airport operations and flight pathways. On an aesthetic level, the visual impact of a tall plume may be undesirable if located near commercial or residential areas, or areas designated for public recreational use.

Technologies can mitigate a visible plume's size and frequency and reduce its overall impact, although the initial costs are often substantially higher than a conventional system. One method uses additional fans that induce rapid mixing by drawing ambient air into the exhaust before leaving the tower. Results using this approach are generally mixed and can vary significantly depending on ambient atmospheric conditions; high humidity levels in the surrounding air can limit any plume reduction. A more reliable method combines a smaller dry-cooled component above a conventional wet tower to raise the exhaust temperature and reduce its humidity below the ambient atmosphere's saturation point.

Plume-abated, or hybrid, cooling towers are subject to more restrictive siting criteria than a conventional wet tower. The addition of the dry cooled component will add to the structure's overall height, sometimes by as much as 15 to 30 feet. This may conflict with local zoning ordinances restricting building height and visual impacts. Hybrid towers are more susceptible to the effects of exhaust recirculation and must be located at sufficient distances from other towers and obstructions. Individual cells cannot be configured in a back-to-back arrangement.

The initial capital cost of plume-abated towers is typically 2 to 3 times higher than conventional towers. This study conducted a comparative cost assessment between hybrid and conventional towers for Scattergood Generating Station. For Unit 1, the design-and-build cost estimate for a 6-celled hybrid tower was $10.2 million, while a conventional tower for the same unit cost only $2.9 million (Bruman 2007). This estimate did not include any operating cost increases.

3.5.3 PUBLIC HEALTH

Cooling tower operation can theoretically contribute to public health risks, specifically Legionella pneumophilia (Legionnaire's Disease), if individuals come in contact with contaminated water that has been left stagnant or is insufficiently treated. Legionnaire's Disease can be a significant health risk, especially when contracted by individuals with compromised immune systems or existing respiratory ailments. Annual incidents are rare, however, with little evidence of a wide-ranging threat to public health from properly-maintained cooling towers. Pathogen control in cooling towers is already required by state and federal regulations and is addressed by incorporating sufficient biofouling treatment systems into the initial design and following proper maintenance and worker safety procedures (DiFilippo 2001).

3.5.4 DRIFT

Small water droplets are ejected from the cooling tower as part of the exhaust, some of which may evaporate prior to settling on the surrounding area as drift. High-salinity drift may adversely affect sensitive structures and equipment without sufficient preventative maintenance efforts. At power plants, these concerns are most pronounced when drift settles on switchyards and transmission equipment, which may lead to arcing or flashover and cause significant damage to critical systems. Ideally, cooling towers are located in an area where these impacts are minor or manageable—downwind or at a sufficient distance to allow drift to settle out before coming in contact with switchyards. In saltwater environments, such as along California's coast, sensitive equipment is presumably designed to withstand some degree of salt drift occurring from wind and wave action. Cooling tower drift, however, will have a salinity level that is 50 percent higher than marine water.

Apart from onsite impacts, drift deposition is a relatively localized concern, causing spotting or mineral scaling and contributing to increased corrosion. More often cited, but poorly supported, is the effect of high salinity drift on agriculture. Salt deposition may affect particular crops under narrowly drawn conditions, but has not been shown to be a widespread or significant issue (CEC 2007).

Where possible, this study selected wet cooling tower locations that would minimize drift impacts on sensitive equipment, although space constraints at some sites resulted in less-than-optimal placement. No attempt was made to quantify the cost or considerations involved in relocating or upgrading switchyard equipment.

3.6 WASTEWATER DISCHARGE

Most steam electric power plants in California discharge low volume, or in-plant, wastes along with the main condenser cooling water. These wastes, which can include boiler blowdown, treated sanitary waste, floor drains, laboratory drains, demineralizer regeneration waste and metal cleaning waste, among others, are significantly diluted when combined with the vastly larger volume of cooling water. Reducing the cooling water-related discharge volume, by as much as 95 percent, may alter the characteristics of the final discharge by increasing pollutant concentrations and possibly triggering concerns over whole effluent toxicity, but will also reduce any thermal discharge impacts

3.6.1 PRIORITY POLLUTANTS

For marine dischargers currently regulated under the Ocean Plan or for facilities discharging to inland waters, estuaries or enclosed bays and regulated under a Basin Plan, the California Toxics Rule and the State Implementation Plan (SIP), new dilution models will likely need to be developed. If sufficient dilution is not available, additional treatment or alternative discharge methods may be required, such as the incorporation of submerged diffusers to reduce the thermal and high salinity plumes. For all facilities, cooling tower blowdown wastes are regulated by federal Effluent Limitation Guidelines (ELGs) for Steam Electric Facilities.

EPA promulgated the current ELGs for the steam electric point source category in 1982. At the time, chromium and zinc compounds were commonly used maintenance chemicals to control corrosion and fouling in cooling towers. EPA retained a numeric effluent limitation for these pollutants out of concern that acceptable alternatives were not widely available. To address the possibility that priority pollutants, including chromium and zinc, may be present in cooling tower blowdown as a result of background concentrations or air deposition, EPA stated that cooling tower blowdown ELGs are “applicable only to pollutants that are present in cooling tower blowdown as a result of cooling tower maintenance chemicals” (USEPA 1982). At the discretion of the permitting authority, compliance may be demonstrated through routine monitoring or through mass-balance calculations that show tower maintenance chemicals do not contribute to pollutant levels above the ELGs.[2]

Technology advances and regulatory restrictions enacted since 1982 have largely eliminated the need to use chromium and zinc compounds as cooling tower maintenance chemicals. Furthermore, acceptable substitutes are more widely available and more effective when coupled with corrosion-resistant materials such as FRP, titanium, or stainless steel, which are the preferred design materials for saltwater applications. Despite these changes, ELGs remain an NPDES component and would require a retrofitted facility to demonstrate its compliance.

The concentrating effect of wet cooling towers on some pollutants is more likely to cause conflicts with water quality-based effluent limitations (WQBELs) when background concentrations in the makeup or receiving water are already elevated, or facility-specific load Commission has found that, with respect to the discharge of metals from cooling tower blowdown, "these discharges have not been found to be a problem at operating nuclear power plants with cooling-tower-based heat dissipation systems" and characterized the potential impact as "small or insignificant" (NRC 2003).

3.6.2 THERMAL DISCHARGES

A significant benefit of wet cooling system retrofits, in addition to reduced impingement and entrainment, is the reduced impact on the receiving water resulting from elevated temperature waste discharges. California's coastal facilities, many of which are 40 years or older, are currently regulated for thermal discharge under the California Thermal Plan as existing sources for elevated temperature wastes. Permitted discharge temperatures are based on criteria that seek to protect designated beneficial uses and areas of special biological concern, and range as high as 100ºF in some cases. Thermal plumes can extend long distances from the discharge point and have far-reaching effects on the receiving water. Wet cooling towers, in addition to dramatically reducing the discharge volume and thermal plume, can be configured to discharge blowdown directly from the tower's cold water basin, with a discharge temperature that more closely approximates the receiving water.

[2] Discussions with EPA staff confirmed this interpretation. (Personal communication between Tim Havey, Tetra Tech and Ron Jordan, US EPA. January 24, 2008.)

4.0 DRY COOLING SYSTEMS

Dry cooling systems are so named because the removal of heat from the steam cycle is accomplished through sensible heat transfer (convection and radiation) rather than through latent heat transfer (evaporation) that is characteristic of wet cooling systems. By relying solely on sensible heat transfer, dry cooling systems eliminate the need for a continuous supply of cooling water to the condenser, thus reducing many of the environmental concerns associated with once-through or wet cooling systems—such as adverse impact on aquatic ecosystems, consumptive use of water resources, and plume or drift emissions.

The use of dry cooling systems at steam electric power plants began largely as an alternative to once-through or wet cooling systems in areas where water resources were limited, but their application has expanded over the years in response to other environmental concerns related to the withdrawal and discharge of large volumes of cooling water. While many of the existing applications of dry cooling in the United States are limited to smaller capacity facilities (<150 MW), larger projects are increasing in frequency as regulatory and market pressures minimize some of the disadvantages usually associated with these types of systems. In California, Otay Mesa (510 MW), Sutter (540 MW), and Gateway (530 MW) are examples of larger applications of dry cooled units that have been built, or are underway, in the last decade (CEC 2007b). South Bay Power Plant, Encina Power Station and El Segundo Generating Station (Units 1 and 2), have each proposed to repower units at their facilities and convert the existing once-through cooling systems to dry cooling.[3]

4.1 TYPES OF DRY COOLING SYSTEMS

Dry cooling systems can be broadly categorized as either direct or indirect. Direct systems, also know as air-cooled condensers (ACC), feed the turbine exhaust steam through sealed ducts directly to a fin tube array where air is drawn across and heat is rejected to the surrounding atmosphere, much like a radiator in a car. The tubes are often arranged in an A-frame configuration with a fan drawing air from below (Figure 4–6). The condensed steam is collected in a sump and returned to the boiler for reuse in the turbine. At no point during the cycle is there any contact between the between the outside air and the steam or condensate.

[3] The South Bay project was withdrawn from consideration in October 2007.

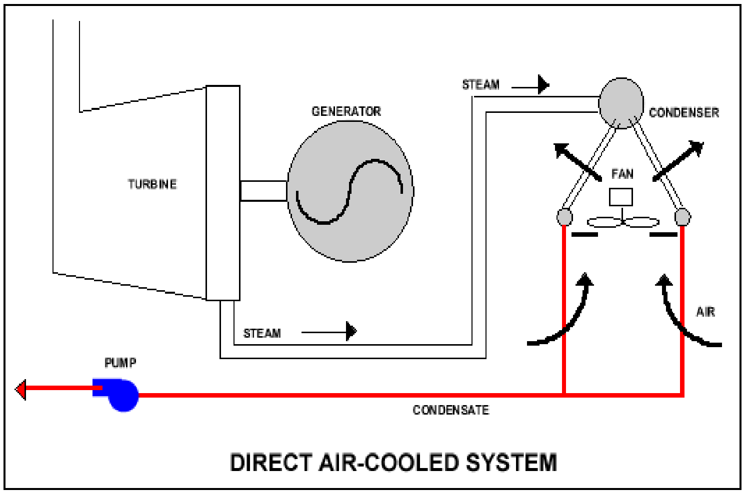

Figure 4–6. Air Cooled Condenser ("Direct Dry")

Indirect dry cooled systems incorporate a surface condenser as an intermediate step between the turbine exhaust and cooling tower. Heat is transferred from the turbine exhaust to the circulating water (or other medium) in the condenser and dispersed to the atmosphere through a fin tube array in a tower, much like the operation of a wet cooling tower. The difference is that, like the ACC, the condenser circulating water is not exposed to the outside air and instead runs in a continuous loop from the turbine to the tower (Figure 4–7).

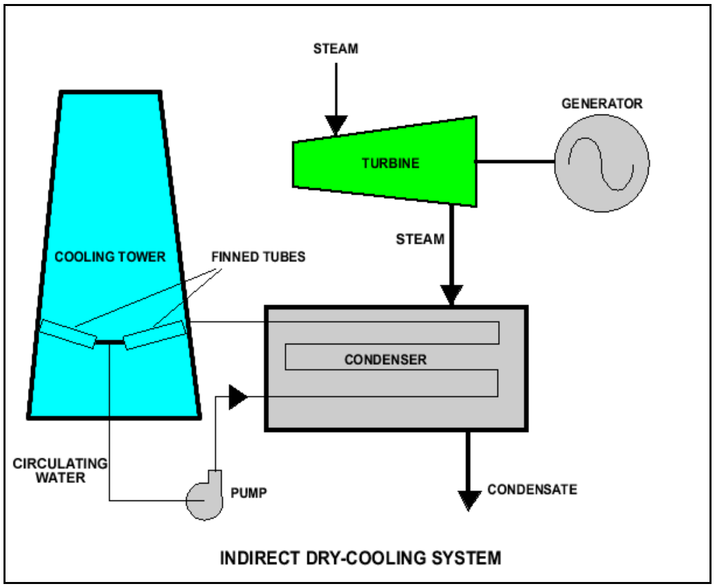

Figure 4–7. Indirect Dry Cooling

The principal disadvantage of an indirect dry cooling system stems from the use of a two-step process to reject heat. The added thermal resistance from the surface condenser reduces the overall heat transfer efficiency of the system. In order to achieve a comparable level of cooling, an indirect system will require a much larger cooling surface area, at increased capital and operational cost, than would be expected for a similar ACC system (Tawney 2003). An indirect system's larger demand for circulating air can be achieved most economically through the use of natural draft towers, which do not require fans. A mechanical draft configuration would require a significant number of fans owing to the increased size of the system and consequently draw a larger percentage of the unit's electrical output for their operation. Without the use of natural draft towers, Heller systems provide no cost advantage over an ACC. At the facilities evaluated in this study, natural draft towers are not considered a viable option, whether for wet or dry systems, due to the concerns over seismic stability and permitting obstacles that would be encountered in sensitive coastal areas.

4.2 DRY COOLING CONSIDERATIONS FOR RETROFIT APPLICATIONS

The decision to adopt a dry cooling system as opposed to a wet or once-through system is fundamentally driven by the relative impacts each system type will have on facility performance weighed against any significant environmental considerations. The overall efficiency of a steam electric generating unit is primarily based on the efficiency with which it can generate electricity from the heat input to the turbine. In a retrofit scenario where a once-through cooling system is replaced with closed-cycle cooling, a dry system will result in less efficient operation than a wet system because of its lower capacity to reject heat from the system.[4] This will increase the heat rate at which the unit generates electricity.

Many units in this study are old (40+ years) and relatively inefficient compared to newer combined cycle units. These inefficiencies contribute to their low capacity utilization levels in recent years as utilities are driven to purchase electricity from more efficient producers. . In addition, the initial capital and operational costs are greater, often significantly so, for dry systems when constructed as part of a new facility (Maulbetsch 2002) and can be expected to be as high or higher in a retrofit application.

Studies conducted by Argonne National Laboratory (ANL 2002) and others have reached largely the same conclusions with regard to cost and feasibility for dry cooling systems as retrofit options and in greater detail than can be presented here.

[4] Assuming a retrofit without substantial modification to condensers or turbines.

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