1. INTRODUCTION

1.0 BACKGROUND

Steam-powered turbines remain the principal technology used to generate electricity in the United States, accounting for nearly three-quarters of the total annual output. Because a limited amount of electricity can be extracted from steam, a balance of waste heat remains that must be removed from the system to maintain optimal efficiencies. The most basic approach to remove waste heat has been to circulate large volumes of water through a condenser and back to the water body, where the heat is rejected to the surrounding environment. These single-pass, or once-through, systems have been the most commonly used cooling methods because of their relatively low capital and operating costs and, in most cases, their ability to provide the lowest cooling temperature, which enables electricity to be generated more efficiently.

There are currently more than 1,200 steam-generating units using this cooling method in the United States. Together, these units account for 65 percent of the steam electric capacity and maintain the capability of withdrawing up to 177,000 million gallons per day (mgd) from surface water sources, the largest categorical use of surface water. California's coastal power plants alone maintain the capacity to withdraw more than 13,000 mgd.

Although once-through cooling systems continue to predominate, various trends over the last several decades have encouraged the development and implementation of alternative technologies that can reduce or eliminate the adverse impacts associated with once-through cooling. Increased competition for water resources, whether for potable or recreational purposes, has expanded the use of cooling methods that rely on substantially less water (evaporative cooling) or effectively eliminate the use of water altogether (dry cooling). Technological advances such as combined-cycle systems generate electricity more efficiently by capturing waste heat from gas combustion turbines to generate steam, thus requiring less cooling water per megawatt of capacity. Finally, the expanding awareness and general consensus that once-through cooling water systems can have a significant adverse impact on aquatic environments has contributed to increased efforts on the part of state and federal agencies to address these effects through regulatory measures.

2.0 PURPOSE

The California Ocean Protection Council (OPC), created under the 2004 California Ocean Protection Act, is charged with facilitating interagency efforts as they relate to the protection of California's coastal resources. Specifically, the OPC is tasked with the following:

- Coordinating activities of ocean-related state agencies to improve the effectiveness of state efforts to protect ocean resources within existing fiscal limitations.
- Establishing policies to coordinate the collection and sharing of scientific data related to coast and ocean resources between agencies.

- Identifying and recommending to the Legislature changes in law.
- Identifying and recommending changes in federal law and policy to the Governor and Legislature.

On April 20, 2006, the OPC adopted a resolution titled Regarding the Use of Once-through Cooling Technologies in Coastal Waters that acknowledges that power plants with once-through cooling systems, through their high use of coastal waters, can have a significant environmental impact on coastal resources. Further, the resolution urges various state agencies to "implement the most protective controls to achieve a 90–95 percent reduction in impacts" and analyze the costs and constraints involved with the conversion of each once-through cooling system to an alternative technology (OPC 2006). Partner agencies in this effort include the California Coastal Commission (CCC), Bay Conservation and Development Commission (BCDC), California Energy Commission (CEC), State Water Resources Control Board (SWRCB), State Lands Commission (SLC), and California Public Utilities Commission (CPUC).

This study has been undertaken to support the efforts of these agencies in determining whether California's once-through cooling facilities can implement alternative technologies that would allow them to reduce adverse impacts to the level set forth in the OPC resolution. The principal reasons for this study and its focus are twofold.

First, the decision to modernize an existing facility's once-through cooling system requires careful consideration of a broad range of issues, especially when retrofitting to closed-cycle technologies. These technologies can dramatically reduce the adverse effects to California's coastal waters attributed to once-through cooling systems but may create other environmental effects, such as increased greenhouse gas emissions, that could conflict with other regulations. The duration a facility may be offline during construction may strain local grid reliability requirements, especially for large baseload facilities. In addition, the associated costs for some technologies, both initial and long-term, may be significant and may not be economically practical for many of California's aging steam facilities.

Second, previous efforts to quantify the technical feasibility and costs for broad groups of facilities have relied upon models and case studies to develop assumptions that could then be extrapolated based on a common metric. These studies are useful for understanding broader issues and, in some cases, may be an acceptable method for estimating facility-level costs, but often underestimate or ignore important factors that heavily influence a technology's design, feasibility, and cost at a particular location. This effort attempts to more accurately account for the unique conditions and requirements at each of California's coastal facilities and quantify their impact on the overall evaluation.

It is important to note that the conclusions reached by this study are driven by the baseline assessment of technical and logistical feasibility; that is, could a closed-cycle cooling system be installed at each facility and at what cost. They do not constitute a final determination of what is "feasible" at any individual facility under the California Environmental Quality Act (CEQA), which is defined as "capable of being accomplished…taking into account social, environmental, economic and technological factors." It is the OPC's intention that this study will be used as an important component of the state's efforts to address cooling water impacts and provide the necessary information to formulate broader conclusions about the overall feasibility of alternative cooling systems.

References to feasibility in this study are limited to technical and logistical considerations, except as noted. Additional information describing the steps used in this evaluation is contained in Section 4.0 of this chapter.

3.0 ONCE-THROUGH COOLING IMPACTS

Assessing adverse impacts due to cooling water withdrawals is a complex undertaking, one that requires detailed information about the facility in question and the ecology of its source water. Many site-specific factors influence the level of impact a once-through system may have; for example, two systems operating identically, but in different locations, may have very different effects on their surroundings. While there may be variability from one facility to another, the consensus among regulatory agencies at both the state and federal levels is that once-through systems contribute to the degradation of aquatic life in their respective ecosystems. In its 2005 report, the CEC concluded once-through cooling systems were "partly responsible for ocean degradation" and contributed to declining fisheries and impaired coastal habitats through the intake of large volumes of water and the discharge of elevated-temperature wastewater (CEC 2005).

Most facilities that obtain cooling water from surface water sources use some method of primary screening to prevent large objects from being drawn through the cooling system, where they may clog or damage sensitive equipment. These screens typically have mesh panels with slot sizes ranging from 3/8 inch to 1 inch and are rotated periodically or removed to clean off any debris, including aquatic organisms.

3.1 IMPINGEMENT

Impingement occurs when organisms are trapped against the screen as a result of the force of the intake water and are unable to escape. Impinged organisms may asphyxiate if the force of the oncoming water prevents their gills from operating normally. Starvation or mortality from fatigue may result if organisms are held against the screen for prolonged periods. Even those organisms that are able to escape may suffer physical injuries, such as descaling, that make them more susceptible to death or predation. Impingement does not, however, always result in the death of the organism. Hardier species, particularly larger ones in their adult phases, are sometimes capable of withstanding the stresses of impingement. Modifications to screening systems may enable the capture and release of organisms before mortality or significant injury can occur.

Susceptibility to impingement is dependent on many factors, not the least of which is the target species and its inherent ability to out swim the current induced by the intake system or its ability to withstand any physical injury that may occur from interaction with the screens. Survival, or avoidance of impingement altogether, is also influenced by the life stage and general health of the target organism. Environmental factors, such as relative areas of light and dark in the vicinity of the intake structure, may also contribute to an increased rate of impingement by triggering behavioral responses. Changes in temperature beyond the optimal range for some species may induce lethargy and impair the organism's ability to avoid or escape from the intake structure. In some cases, these behavioral responses can be exploited to prevent organisms from being impinged, although they are highly species specific and limited in their application.

EPA, in its development of national regulations addressing impingement and entrainment impacts, considered an "impingeable" organism to be one that is free swimming and larger than 3/8 inch in size (USEPA 2002). This generally applies to organisms that are juveniles or, in certain species, adults.

3.2 ENTRAINMENT

Entrainment is the action of drawing smaller objects through the entire cooling water system, including the pumps and condenser tubes, and discharging them along with the cooling water and other plant wastes. Organisms susceptible to entrainment through cooling water systems are among the most fragile in the aquatic community because of their relatively small size (less than 3/8 inch) and life stage (typically fish eggs and larvae). Planktonic organisms such as these cannot independently escape the influence of an intake system and are instead reliant upon screening mechanisms or other methods to prevent their intake.

Organisms that find themselves entrained through a power plant cooling system will be subjected to dramatic changes in pressures as they pass through the pump and condenser. Water temperatures will rapidly increase by 10 to 25° F, or more, and decrease upon discharge and mixing with the receiving water. Physical injury may occur from the interaction with mechanical equipment and the shearing forces of pumps. Chemicals used to control biofouling in the system, such as chlorine, further complicate the ability of organisms to survive entrainment until they are discharged back to the water body.

There is some disagreement within the stakeholder community over the ability of certain organisms to survive entrainment and maintain their long-term viability. Limited data are available that can reliably demonstrate the survival of entrained organisms in relation to the number entrained overall. For this reason, EPA assumed 100 percent mortality for entrained organisms during the development of regulations addressing cooling water impacts (USEPA 2004). Accordingly, the preferred method to reduce the adverse effects of entrainment is to prevent the interaction of susceptible organisms and the cooling system altogether. This can be accomplished in one of two ways: the use of a barrier technology with pores small enough to exclude entrainable organisms, or by reducing the volume of water withdrawn by the facility.

3.3 COASTAL POWER PLANTS IN CALIFORNIA

There are currently 18 large steam electric power plants in California that use once-through systems. Most of these facilities are concentrated in southern California and withdraw cooling water directly from the Pacific Ocean or nearby estuaries. Together, these facilities are permitted to withdraw more than 13,000 mgd from California's coastal waters and discharge the same volume back to the source water at an elevated temperature. Many of the generating units at these stations were first placed into service decades ago; the average age of coastal fossil fuel units in California is 40 years. In part because of their age and lower efficiency, these units are dispatched less frequently than newer, more efficient stations and may only be operational for a few weeks or months of the year. General information about California's coastal facilities is summarized in Table 1-1. The general location of each facility is shown in Figure 1-1 and 1-2.

Table 1-1. California Coastal Facilities

Facility name (Location)	Design flow (mgd)	Water body type	Unit	In-service year	2001–2006 capacity utilization (%)	Dependable capacity (MW)
Alamitos Generating Station (Long Beach)	1,077	Estuary	1	1956	6.7	175
			2	1957	8.7	175
			3	1961	27.7	326
			4	1962	20.8	324
			5	1969	27.4	485
			6	1966	22.2	485
Contra Costa Power Plant (Antioch)	440	Estuary	6	1964	16.4	340
			7	1964	23.1	340
Diablo Canyon Power Plant (Avila Beach)	2,500	Ocean	1	1985	89.0	1,103
			2	1986	89.3	1,099
El Segundo Generating Station (El Segundo)	424	Ocean	3	1964	19.4	335
			4	1965	24.8	335
Encina Power Station (Carlsbad)	857	Ocean	1	1954	18.7	107
			2	1956	21.0	104
			3	1958	25.1	110
			4	1973	36.0	300
			5	1978	33.0	330
Harbor Generating Station (Los Angeles)	108	Enclosed bay / harbor	CC	1994	20.5	227
Haynes Generating Station (Long Beach)	966	Estuary	1	1962	20.5 [a]	1,606 [a]
			2	1963		
			5	1966		
			6	1967		
			8	2005		
Huntington Beach Generating Station (Huntington Beach)	516	Ocean	1	1958	31.5	215
			2	1958	31.0	215
			3	2002	9.6	225
			4	2003	8.5	225
Mandalay Generating Station (Oxnard)	253	Enclosed bay / harbor	1	1959	20.6	218
			2	1959	23.4	218
Morro Bay Power Plant (Morro Bay)	552	Estuary	3	1962	18.8	300
			4	1963	18.8	300
Moss Landing Power Plant (Moss Landing)	1,224	Enclosed bay / harbor	1	2002	41.1	540
			2	2002	41.4	540
			6	1967	19.7	702
			7	1968	24.2	702
Ormond Beach Generating Station (Oxnard)	688	Ocean	1	1971	16.3	806
			2	1973	17.7	806

Facility name (Location)	Design flow (mgd)	Water body type	Unit	In-service year	2001–2006 capacity utilization (%)	Dependable capacity (MW)
Pittsburg Power Plant (Pittsburg)	495	Estuary	5	1960	23.7	325
			6	1961	21.0	325
			7	1972	23.5	720
Potrero Power Plant (San Francisco)	226	Estuary	3	1956	38.1	207
Redondo Beach Generating Station (Redondo Beach)	871	Ocean	5	1954	4.9	179
			6	1957	5.6	175
			7	1967	22.2	493
			8	1967	19.6	496
San Onofre Nuclear Generating Station (San Clemente)	2,574	Ocean	2	1983	86.8	1,127
			3	1984	79.4	1,127
Scattergood Generating Station (Los Angeles)	496	Ocean	1	1958	22.1 [a]	803 [a]
			2	1959		
			3	1974		
South Bay Power Plant (Chula Vista)	532	Estuary	1	1960	39.8	136
			2	1962	38.7	136
			3	1964	27.9	210
			4	1971	6.8	214

[a] Facility-wide totals. Unit-level data unavailable.

Figure 1-1. North Coast Power Plants

Figure 1-2. South Coast Power Plants

4.0 FRAMEWORK

This study evaluates the logistical, regulatory, and economic factors that arise when a facility modifies its cooling water system by implementing technology-based measures designed to achieve the OPC performance benchmark. Previous attempts to quantify the cost and complexity associated with retrofitting an existing cooling water system have been based on broad assumptions and extrapolated from models or case studies. Because the circumstances and operating limitations can vary widely from facility to facility, this approach can have the effect of underestimating or overestimating the true costs and logistical considerations of an actual retrofit scenario.

This report moves beyond a model-based approach by using facility-specific data to develop comprehensive cost and engineering profiles that are unique to each of California's affected facilities. It is not, however, intended to be exhaustive in terms of the many obstacles that may exist and the different technology configurations that can be evaluated, nor can it be considered a substitute for the more rigorous engineering assessment that would be conducted prior to the implementation of one of the evaluated options. Instead, the intent is to establish a more precise understanding of the engineering options and associated costs of a once-through cooling system retrofit, and the factors that influence those costs, in order to assist state agencies in the regulatory development process as it moves forward.

4.1 TECHNOLOGY EVALUATION

The technologies considered for this study are limited to those with a proven capability to achieve measurable and consistent reductions of impingement mortality or entrainment (IM&E), or both. These reductions are generally independent of the biological makeup of the affected water body and can be evaluated based on quantifiable physical and logistical criteria.

The exclusion of any technology from detailed evaluation in this study does not correspond to a determination of the potential effectiveness it may have in achieving comparable IM&E reductions. Individual facility conditions may allow for deployment of an alternate technology, but an assessment of its effectiveness cannot be made without the rigorous biological analysis that must complement the logistical evaluation of the local environment. Some of these technologies are discussed further in Chapter 2.

Taking into account only physical and logistical factors, this study evaluates each facility with respect to technologies that can achieve a 90–95 percent reduction of IM&E impacts as discussed in the 2006 OPC resolution. Dry cooling technologies were not considered for this study because of the numerous difficulties associated with their use in a purely retrofit application (see Chapter 4). Thus, this study primarily focuses on the technical and logistical considerations associated with retrofitting an existing once-through system with wet cooling towers (evaporative cooling).

For a particular facility and technology, the determination of feasibility was based on the technology's ability to satisfy the following general criteria as they apply to that facility:

1. *Logistical Feasibility.* Are there physical constraints or other logistical considerations that would preclude its successful use at the particular location? Examples include lack of sufficient space or incompatibility with the configuration of the existing facility or its cooling water system.
2. *Operational Feasibility*. Would the technology conflict with the facility's design criteria and operating limits? In some cases, retrofitting to closed-cycle cooling may raise turbine backpressures to unacceptable levels and place undue strain on turbine and condenser equipment. Variable speed pumps can reduce intake volume from 30 to 40 percent and achieve a similar reduction of IM&E impacts, but this benefit cannot be realized unless operating conditions allow reduced circulating water flows. If the periods in which variable speed pumps operate at their maximum capacity overlap with seasonal spawning or migration times, any potential benefits may be negated.
3. *Local Use Restrictions.* Are there local planning and zoning ordinances, such as those that relate to building height, noise, or public safety, that would affect the design or configuration of the technology so as to preclude its use? If so, can the technology be configured differently to avoid conflict?
4. *Aesthetic and Environmental Restrictions.* What impacts will the operation of the technology have on the surrounding environment? Are there state or federal regulations that restrict activities to protect public beneficial uses or endangered or threatened species? Will the facility be able to comply with new and revised regulatory requirements that address issues such as increased air emissions and altered wastewater discharges?

The first two criteria (logistical and operational feasibility) are the most critical for consideration in this study; a technology's inability to meet either is considered a "fatal flaw" for that particular facility and precluded any further evaluation. The second two criteria were primarily used to guide the selected technology's design and configuration at each location. In some cases, local use or environmental restrictions would preclude a technology's deployment at a particular location analysis despite the ability, from a logistical perspective, to install and operate that technology at a particular location.

For the wet cooling tower retrofit analysis, these criteria were used to develop a "preferred option" for each facility based on the minimum identified requirements and assumptions used in this study (see Chapter 5). Feasibility determinations are based on the preferred option's ability to satisfy these requirements.

At Redondo Beach Generating Station, for example, sufficient space exists to accommodate wet cooling towers, but the proximity to office buildings and residential areas, and the general approach to development taken by the city of Redondo Beach, creates a regulatory and zoning scenario in which compliance with public health, noise and aesthetic restrictions is highly unlikely. Thus, this study concludes that wet cooling towers are infeasible at this location; a detailed analysis is not developed.

In some cases, the preferred option is based on best professional judgment and the presumed requirements at a particular location in lieu of definitive guidelines. The proximity of El Segundo Generating Station and Ormond Beach Generating Station to airport facilities (Los Angeles International and Pt. Mugu Naval Air Station, respectively) would seem to require plume abatement technologies to avoid interference with flight operations, but no specific mandate could be confirmed. The preferred option (plume-abated towers) for each facility requires a larger available area than would be required for conventional (non plume-abated) towers, but because space is limited at each location, cannot be configured to meet the design criteria.

This study considers wet cooling tower retrofits at El Segundo and Ormond Beach to be infeasible because the preferred option is unavailable, although the discussion chapters for each facility do include an engineering and cost analysis based on conventional towers. This is provided because it could not be determined whether the appropriate regulatory agency would absolutely require the preferred option.

4.2 RETROFIT VS. REPOWER

In the context of this study, the term *retrofit* describes the conversion of an existing cooling water system to incorporate a new technology (or technologies) designed to reduce IM&E impacts to the benchmark levels set forth in the OPC resolution. Elements that may be modified or replaced as part of a retrofit include the intake screens, circulating water pumps and piping, and intake location, in addition to the new technology itself. Unless specifically required, upgrades to or replacements of power generation components (mainly boilers and turbines) were not considered as long as the installation of the new technology would not result in a detrimental effect on the ability of these components to function within their original design tolerances.

By contrast, the term *repower* as it applies in this context is a more comprehensive overhaul to a steam-generating unit. Repowering typically involves the replacement of, or substantial upgrade to, the principal generating components—specifically the boiler, turbine, and condenser. These improvements often involve the installation of more modern and efficient equipment, such as combustion turbines and heat recovery steam generators (HRSGs). When viewed in conjunction with a broader repowering project, the options to retrofit the cooling water system with a desirable technology become more numerous and more economically practical. Elements that may have been problematic in a retrofit scenario can be addressed more readily when they are considered as part of the initial design. This study does not evaluate alternative cooling system technology options as they might apply to a repowering project because the decision to repower a particular unit is driven, in part, by external factors, such as market conditions, corporate strategy, and contractual obligations, which are beyond the scope of this report.

Repowering is of particular interest in California, where many of the coastal power plants are 30 to 40 years old, or more, and are likely to be replaced with more efficient technologies in the coming years. Economically, it may be more practical to repower an existing facility rather than retrofit the existing cooling system. A repowered facility is generally more compatible with closed-cycle cooling technologies, operates more efficiently, emits less CO_2 per kWh, and has a greater potential to increase operating revenues, among other benefits. Figure 1-3 shows the relative CO_2 emissions from an average retrofitted unit and a new combined cycle unit.[1] Figure 1-4 shows the difference in fuel-cost-to-gross-revenue ratio for the same facilities.

Examples of repowering projects and cooling system retrofits are discussed in Chapter 6.

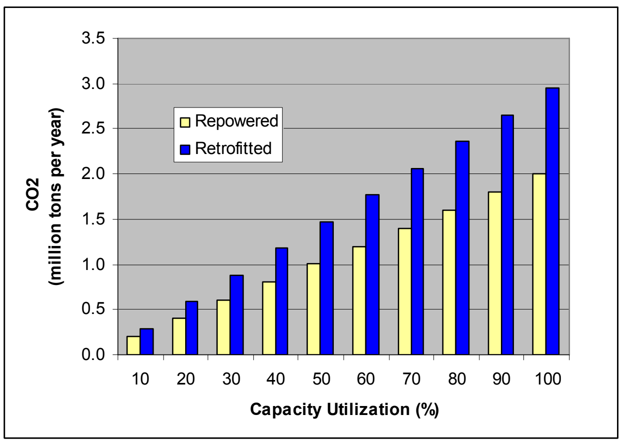

Figure 1-3. Annual CO_2 Emissions

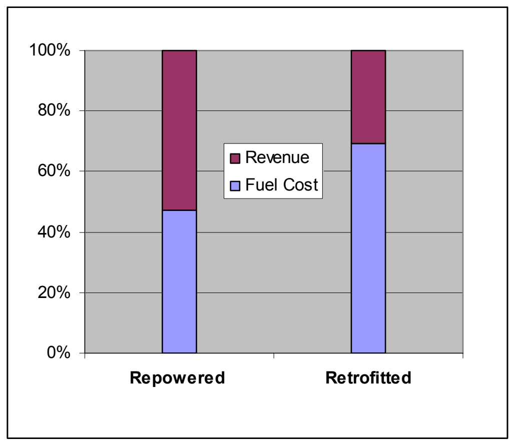

Figure 1-4. Fuel Cost to Revenue Ratio

[1] Each unit with a generating capacity of 575 MW. Heat rates: 10,000 BTU/kWh (retrofitted); 6,800 BTU/kWh (repowered).

5.0 COST EVALUATION

Using the OPC resolution as the performance benchmark for a selected technology, this study evaluates the cost of potential retrofit options on a "most practical/least costly" basis. Essentially, this approach assesses the options available to a facility that allow it to achieve the benchmark at the lowest reasonable cost, while at the same time acknowledging other technology options or configurations that may enable a facility to exceed the benchmark reduction levels, but at a higher cost. The OPC recognizes that site-specific considerations or other regulatory concerns may make these additional measures equally, or more, desirable than the lowest-cost option.

Comprehensive cost estimates for this study are unique for each location and based on specific data provided by the facility. In some cases, the data, given its level of detail and usefulness, limited the development of a more precise estimate and may not fully reflect the design parameters of the facility. Capital costs are developed for each facility based on budgetary quotes provided by vendors that supply the various technologies to power plants throughout the country. Annual costs for operations and maintenance (O&M) are calculated based on the approximate life span of the selected technology, vendor information, and best professional judgment (BPJ).

Energy penalty costs, those that result from the changes to the overall efficiency of a facility, are developed based on the design specifications provided by each facility. The methodology used to develop the design configuration and estimate the cost of installing wet cooling towers is discussed in detail in Chapter 5.

6.0 REPORT ORGANIZATION

Following this introduction, this report is organized into the following sections:

- Chapter 2: Discussion of various background elements that are fundamental to understanding the broader implications of retrofitting a once-through cooling system, including the regulatory history of Clean Water Act Section 316(b); previous retrofit analyses; the performance and design of closed-cycle cooling systems, including wet and dry cooling towers; and other IM&E technologies.
- Chapter 3: Discussion of the overall regulatory environment beyond measures that specifically address impacts associated with once-through cooling water withdrawals (the scope of changes that result from adopting wet cooling towers may impact a facility's ability to comply with other regulations, such as air emission standards, modified water discharge limitations, and local use restrictions)
- Chapter 4: Discussion of closed-cycle cooling systems
- Chapter 5: Assumptions and methodology used to develop the conceptual design and cost estimate for a wet cooling tower retrofit at each facility
- Chapter 6: Examples of facilities that have retrofitted or repowered their existing systems
- Chapter 7.A – 7.O: Individual facility analyses
- Appendices

7.0 REFERENCES

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