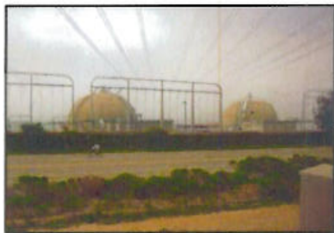
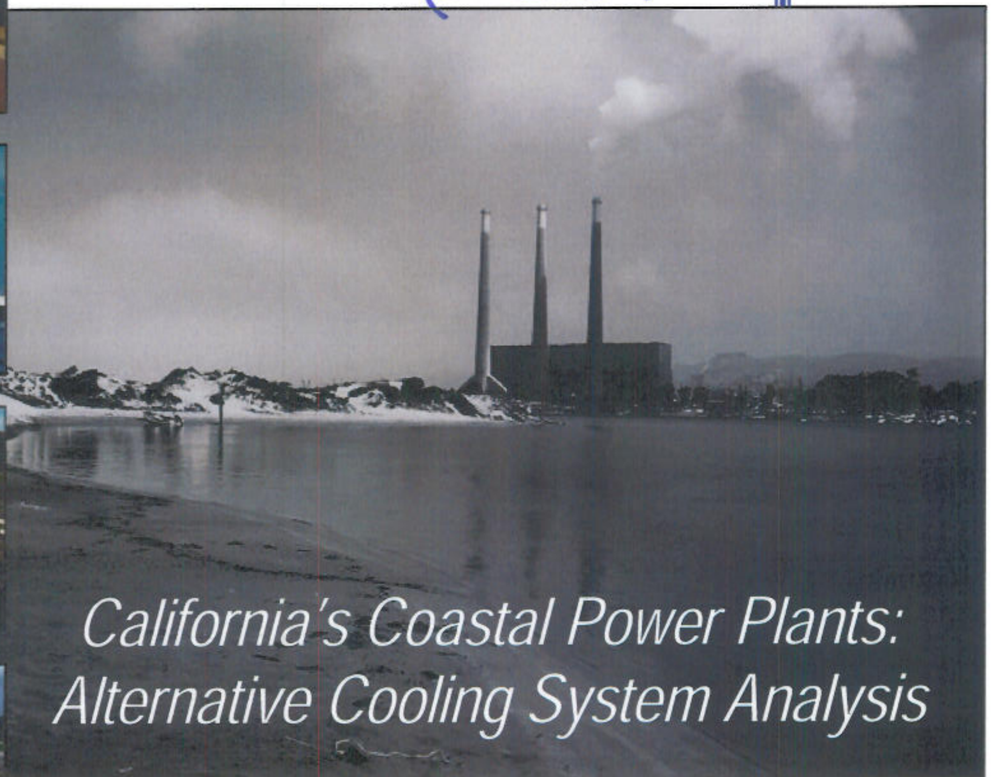
171
(ON WEB)





California's Coastal Power Plants: Alternative Cooling System Analysis

— prepared by —

Tetra Tech, Inc.

Golden, CO

Tim Havey, Project Manager

— prepared for —

California Ocean Protection Council

Oakland, CA

Christine Blackburn, Ph.D., Project Manager

February 2008

complex world | CLEAR SOLUTIONS™

CALIFORNIA'S COASTAL POWER PLANTS: ALTERNATIVE COOLING SYSTEM ANALYSIS

— FINAL REPORT —

— prepared for —

California Ocean Protection Council
Oakland, CA
Christine Blackburn, Ph.D., Project Manager

OCEAN PROTECTION COUNCIL

— prepared by —

Tetra Tech, Inc.
Golden, CO
Tim Havey, Project Manager

February 2008

This report was funded by the California Ocean Protection Council and has benefitted greatly from the many contributions provided by individuals and organizations, including state agency staff, industry representatives, technology vendors and third-party experts. Their input and insight has been critical to the final analysis and is reflected throughout the document.

California Ocean Protection Council
Christine Blackburn, Project Manager
Drew Bohan, Executive Policy Officer
Jon Gurish, Staff Counsel

California Coastal Commission
Tom Luster

State Water Resources Control Board
Dominic Gregorio

California Energy Commission
Jim McKinney
Joe O'Hagan
John Kessler
Caryn Holmes
Matt Layton

Technical review of segments of this report provided by:

- John Maulbetsch, Ph.D., Maulbetsch Consulting
- Bill Powers, P.E., Powers Engineering
- Ron Rimelman, Tetra Tech, Inc.

Representatives of companies whose facilities comprise California's coastal power plants:

- AES Southland, LLC.
- Dynegy, Inc.
- El Segundo Power, LLC.
- Los Angeles Department of Water and Power
- Mirant Delta, LLC.
- Pacific Gas and Electric
- Reliant Energy, Inc.
- Southern California Edison

Technology vendors:

Particular appreciation is extended to Aaron Atherton of GEA Power Cooling, Inc. for providing numerous cooling tower budget estimates and technical specifications for individual facilities in this report.

Also noted for their contributions are:

- Enviroair (on behalf of Marley/SPX Cooling, Inc.)
- Price Brothers Company
- HiTech Piping, Ltd. (on behalf of Reinforced Plastic Systems, Inc.)
- Romatec (on behalf of Mosser Valves)
- Weir Pumps
- Holtec International, Inc.
- Groupe Laperrière & Verreault Inc.

Also recognized are the significant contributions from Hatch, Ltd., under subcontract to Tetra Tech, Inc., in developing cost and engineering estimates for each facility profile. The final report reflects a collaborative effort in these areas between Bernard Bruman, Hatch, Ltd. Project Manager, and the author.

CONTENTS

CHAPTER 3—REGULATORY REVIEW

CHAPTER 6—RETROFIT AND REPOWER EXAMPLES

CHAPTER 7—FACILITY PROFILES

APPENDICES

TABLES

FIGURES

ACRONYMS AND ABBREVIATIONS

ACC	Air-cooled condenser
AFB	Aquatic Filtration Barrier
AGS	Alamitos Generating Station
APCD	Air Pollution Control District
AQMD	Air Quality Management District
ASHRAE	American Society of Heating, Refrigerating and Air-conditioning Engineers
BAAQMD	Bay Area Air Quality Management District
BACT	Best Available Control Technology
BAT	Best Available Technology Economically Achievable
BCDC	Bay Conservation and Development Commission
BHP	Brake horsepower
BPJ	Best Professional Judgment
BTA	Best Technology Available
BTU	British Thermal Unit
CARB	California Air Board
CCA	California Coastal Act
CCC	California Coastal Commission
CCPP	Contra Costa Power Plant
CCR	California Code of Regulations
CCRWQCB	Central Coast Regional Water Quality Control Board
CDFG	California Department of Fish and Game
CDP	Coastal Development Permit
CEC	California Energy Commission
CEMS	Continuous Emission Monitoring System
CEQA	California Environmental Quality Act
CIMIS	California Irrigation Management Information System
CNEL	Community noise equivalent levels
CPUC	California Public Utilities Commission
CTI	Cooling Tower Institute
CTR	California Toxics Rule
Cu-Ni 70-30	Copper-Nickel alloy (70% to 30%)
Cu-Ni 90-10	Copper-Nickel alloy (90% to 10%)
CVRWQCB	Central Valley Regional Water Quality Control Board
CWA	Federal Water Pollution Control Act ("Clean Water Act")
CWC	California Water Code (Porter-Cologne Water Quality Control Act)
CWIS	Cooling Water Intake Structure
DCPP	Diablo Canyon Power Plant
EAP	Energy Action Plan
EIR	Environmental Impact Report
ELG	Effluent Limitation Guideline
EPA	US Environmental Protection Agency

EPCM	Engineering, Procurement, and Construction Management
ERC	Emission Reduction Credit
ESGS	El Segundo Generating Station
ESHA	Environmentally Sensitive Habitat
FPS	Feet per Second
FRP	Fiber Reinforced Plastic
GIS	Gas Insulated Switchgear
gpm	Gallons per Minute
HBGS	Huntington Beach Generating Station
HEI	Heat Exchange Institute
HGS	Harbor Generating Station
HHV	Higher Heating Value
HnGS	Haynes Generating Station
hp	Horsepower
HRSG	Heat Recovery Steam Generator
ICE	Intercontinental Exchange
IM&E	Impingement mortality and entrainment
ITD	Initial temperature difference
kWh	Kilowatt-hour
LA	Load allocation
LADWP	Los Angeles Department of Water and Power
LAER	Lowest achievable emissions rate
LARWQCB	Los Angeles Regional Water Quality Control Board
LCP	Local coastal program
LHV	Lower Heating Value
MBPP	Morro Bay Power Plant
MBUAPCD	Monterey Bay Unified Air Pollution Control District
MCC	Motor Control Center
mgd	Million Gallons per Day
MGS	Mandalay Generating Station
MLPP	Moss Landing Power Plant
MW	Megawatt
MWh	Megawatt-hour
NAAQS	National Ambient Air Quality Standards
NCDC	National Climatic Data Center
NOAA	National Oceanographic and Atmospheric Administration
NO_x	Nitrogen Oxides
NPDES	National Pollutant Discharge Elimination System
NPV	Net present value
NPV_{20}	20-year Net Present Value
NSPS	New Source Performance Standards
NSR	New Source Review
O&M	Operations and Maintenance
OBGS	Ormond Beach Generating Station
OPC	California Ocean Protection Council
PCCP	Prestressed Concrete Cylinder Pipe
PG&E	Pacific Gas and Electric

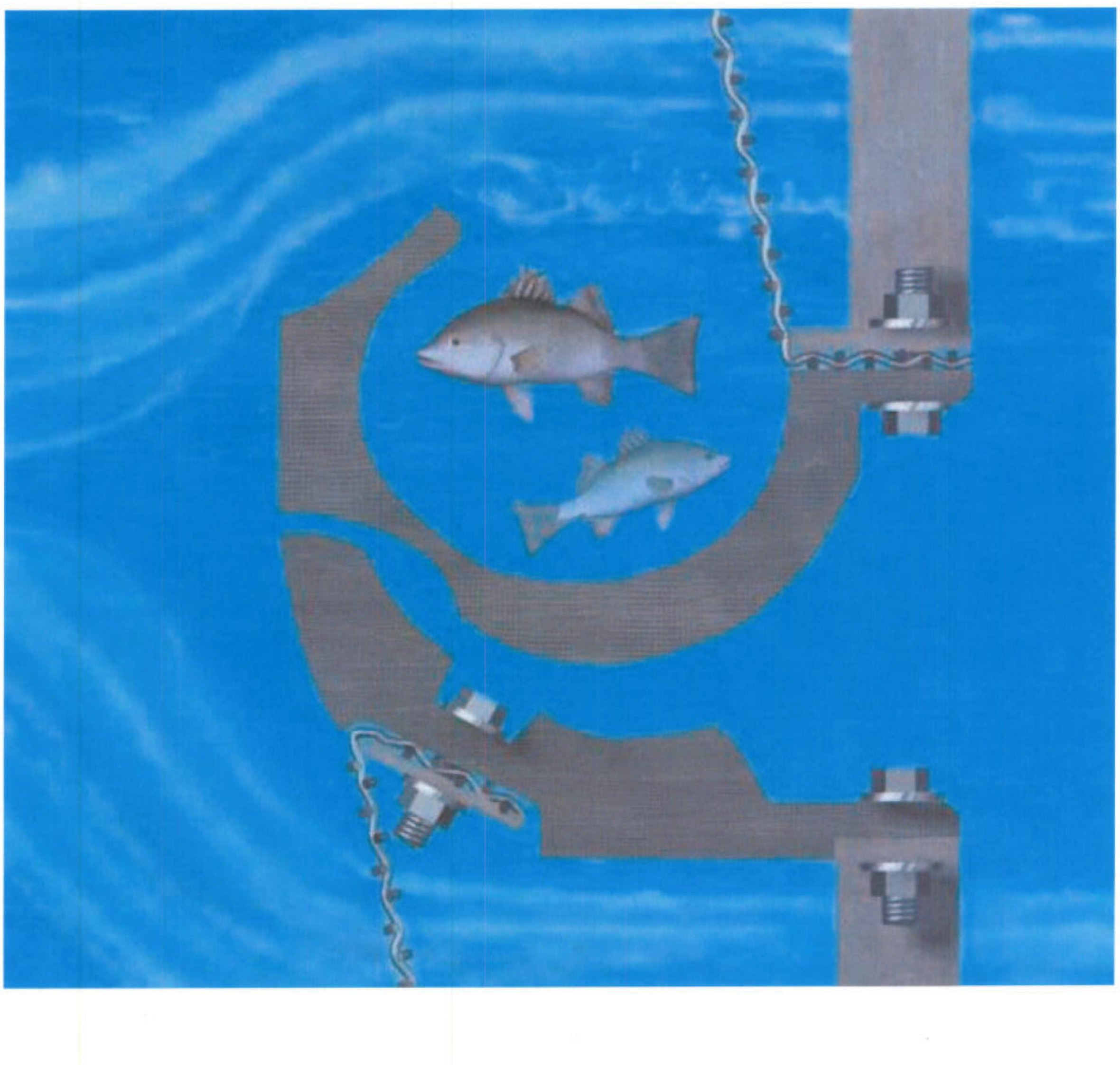
PM_{10}	Particulate Matter 10 microns or less in size
POTW	Publicly Owned Treatment Work
PPP	Pittsburg Power Plant
ppt	Parts per thousand
PWR	Pressurized Water Reactor
RBGS	Redondo Beach Generating Station
RWQCB	Regional Water Quality Control Board
SCAQMD	South Coast Air Quality Management District
SCC	California State Coastal Conservancy
SCCOOS	Southern California Ocean Observing System
SCE	Southern California Edison
SDAPCD	San Diego Air Pollution Control District
SDRWQCB	San Diego Regional Water Quality Control Board
SFBRWQCB	San Francisco Bay Regional Water Quality Control Board
SGS	Scattergood Generating Station
SIP	Policy for Implementation of Toxics Standards for Inland Surface Waters, Enclosed Bays, and Estuaries of California
SLC	California State Lands Commission
SO_2	Sulfur Dioxide
SONGS	San Onofre Nuclear Generating Station
SWRCB	California State Water Resources Control Board
TDS	Total Dissolved Solids
TMDL	Total maximum daily load
VCAPCD	Ventura County Air Pollution Control District
VFD	Variable Frequency Drive
VSP	Variable Speed Pump
WQBEL	Water quality–based effluent limits
ZLD	Zero liquid discharge

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Technical Resource Document for Modified Ristroph Traveling Screens

Model Design and Construction Technology and Technology Installation and Operation Plans

Technical Report



Technical Resource Document for Modified Ristroph Traveling Screens

Model Design and Construction Technology and Technology Installation and Operation Plans

1013308

Final Report, November 2006

EPRI Project Manager
D. Dixon

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

Alden Research Laboratory, Inc.

NOTE

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or e-mail askepri@epri.com.

CITATIONS

This report was prepared by

Alden Research Laboratory, Inc.
30 Shrewsbury Street
Holden, MA 01520

Principal Investigator
J. Black
N. Olken
R. Tuttle

This report describes research sponsored by the Electric Power Research Institute (EPRI).

The report is a corporate document that should be cited in the literature in the following manner:

Technical Resource Document for Modified Ristroph Traveling Screens: Model Design and Construction Technology and Technology Installation and Operation Plans. EPRI, Palo Alto, CA: 2006. 1013308.

REPORT SUMMARY

Power companies planning to use technologies or changes in facility operation to meet the performance standards in the Clean Water Act Phase II § 316(b) Rule are required to submit Technology and Compliance Assessment Information (TCAI) as part of the Comprehensive Demonstration Study (CDS). Two components of the TCAI are the Design and Construction Technology Plan (DCTP) and the Technology Installation and Operation Plan (TIOP). This report is a resource document for power companies developing DCTPs and TIOPs for modified traveling (Ristroph) screens to meet the requirements of the Phase II Rule.

Background

The primary function of the DCTP is to describe the technology proposed to meet the performance standards and estimate its biological effectiveness with the species commonly impinged or entrained at a facility. The TIOP describes how the selected technology will be operated and sets the schedule for its installation. Under the Phase II Rule, the TIOP also allows the establishment of an adaptive management plan, which becomes the standard by which a technology's performance will be evaluated. The adaptive management plan lays out steps to be taken to optimize the performance of the selected technology in the event that results of verification monitoring indicate that the technology is not meeting the performance standards. A facility that is following its adaptive management plan will not be considered out of compliance if the installed technology is not meeting the performance standards.

In the Phase II § 316(b) Rule (FR Vol. 69, No. 131, July 9, 2004), EPA identified the type of information it expects to be developed as part of the DCTP and TIOP but did not give any specific guidance on how to develop that information. This report provides an example of the types of information that could be submitted if a power company chooses to use modified traveling (Ristroph) screens to meet the impingement mortality (IM) reduction standard (80-95% reduction in impingement mortality compared to the calculation baseline).

Objective

To develop a technical resource document for power companies that are submitting DCTPs and TIOPs to support the use of modified traveling (Ristroph) screens to meet the Phase II Rule.

Approach

The project team defined each requirement of the DCTP and TIOP as established by the Phase II Rule and discussed the rationale for its inclusion. For illustrative purposes, the team created a hypothetic facility located on a large freshwater river that is proposing to retrofit modified traveling screens to meet the impingement mortality reduction standard. The team developed DCTP and TIOP sample text for the hypothetical facility such as would be submitted to the Director prior to installation of the modified traveling screens at an actual site.

Results

This document provides an explanation of each requirement in the DCTP and TIOP and provides a rationale for the development of each section. In addition, the document includes a sample text for each section. For illustrative purposes, a DCTP and TIOP are developed for a fictitious power plant. This document can be used by power companies to assist in the development of site-specific DCTPs and TIOPs for the use of modified traveling (Ristroph) screens—a DCTP and a TIOP must be submitted as part of the CDS reporting requirements. With modifications, this resource document could also assist power companies that are proposing to use other technologies to meet the requirements of the Phase II § 316(b) Rule.

EPRI Perspective

This technical resource document will assist power companies by providing a framework for DCTPs and TIOPs that are to be submitted to their permit authorities to satisfy the technology sections of the CDS. By providing a uniform approach and suggesting the appropriate type of information and level of detail, the technical resource document will also help power companies meet the CDS reporting requirements specific to modified traveling (Ristroph) screens.

Keywords

Fish Protection Technologies
Cooling Water Intake Structures
Clean Water Act Section 316(b)
Modified Traveling Screens
Ristroph Screens

EXECUTIVE SUMMARY

1.0 BACKGROUND

The California Ocean Protection Council (OPC), created under the 2004 California Ocean Protection Act, is responsible for facilitating interagency regulatory and oversight efforts related to the protection of California's coastal resources. On April 20, 2006, the OPC adopted a resolution titled *Regarding the Use of Once-Through Cooling Technologies in Coastal Waters* ("2006 Resolution") acknowledging that steam electric power plants that withdraw large, continuous volumes of water can have a significant environmental impact on coastal resources. Further, the resolution urges state agencies to "implement the most protective controls to achieve a 90–95 percent reduction in [impingement and entrainment] impacts" and analyze the costs and constraints involved with the conversion of each once-through cooling system to an alternative technology.

This study evaluates the feasibility of impingement and entrainment control technologies that can meet the 2006 Resolution benchmark in the most cost-effective manner. Although many technologies and operational measures exist that might achieve reductions approaching the benchmark levels, the certainty of their performance at California's coastal facilities cannot be assured without a companion analysis of each location's biological characteristics. Accordingly, this study focuses on those technologies with proven performance data that demonstrate an ability to meet the benchmark reductions, without evaluating biological criteria as well. The most effective technology that can meet these criteria is closed-cycle cooling, commonly referred to as "wet" or "dry" cooling towers.

This study includes an engineering assessment and cost profile for each facility based on retrofitting once-through cooling systems to wet cooling towers. Dry systems were not considered in detail because both wet and dry cooling can meet the 2006 Resolution benchmarks, but dry systems generally present greater technical, logistical and economic constraints. Dry cooling becomes more competitive when considered for repowering projects, where the generating unit undergoes substantial modification or replacement and can more easily be configured to operate with a dry system.

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 with closed-cycle cooling rather than retrofit the existing system. A repowered facility is generally more compatible with closed-cycle technologies, operates more efficiently, emits less CO_2 per kilowatt-hour (kWh), and has a greater potential to increase operating revenues, among other benefits.

This study evaluates the cooling system's redesign only; the role of repowering, which enables consideration of a wider range of cooling options, is not addressed.

2.0 CALIFORNIA'S COASTAL POWER PLANTS

In California, reference is often made to 21 coastal power plants that operate once-through cooling systems. As of the publication of this study, only 18 of these facilities are actively generating power and withdrawing water from marine or estuarine sources. Three facilities—Humboldt Bay, Hunter's Point, and Long Beach—have ceased operations that rely on once-through cooling; Humboldt Bay and Long Beach are in the process of repowering with technologies that do not require cooling water.

The remaining 18 facilities are concentrated along the southern coastline but also extend north to the San Francisco Bay and Sacramento-San Joaquin Delta. These plants are summarized in Table ES-1 and shown in Figure ES-1 and Figure ES-2.

Of these 18 facilities, only 15 are addressed in this study. The Carlsbad Energy Center Project is intended as a replacement for the Encina Power Station using air-cooled combined-cycle units and is currently undergoing certification review by the CEC. The South Bay Replacement Project was pursuing CEC approval for a similar repowering effort at the time this study began, but the project was formally withdrawn from consideration on October 24, 2007 following the Administrative Draft's publication. Potrero Power Plant, with one active generating unit, is likely to close pending the implementation of the San Francisco Energy Reliability Project.

Table ES-1. California Power Plants with Once-Through Cooling

Facility	Source water body	Fuel type	Generating capacity (MW)	Design intake flow (mgd)
Alamitos	Los Cerritos Channel	Natural gas	1,970	1,077
Contra Costa	Sacramento/San Joaquin Delta	Natural gas	680	440
Diablo Canyon	Pacific Ocean	Uranium	2,202	2,500
El Segundo	Santa Monica Bay	Natural gas	670	424
***Encina* [a]**	*Aqua Hedionda Lagoon / Pacific Ocean*	*Natural gas*	*966*	*857*
Harbor	Los Angeles Harbor	Natural gas	462	108
Haynes	Long Beach Marina	Natural gas	1,606	966
Huntington Beach	Pacific Ocean	Natural gas	1,013	516
Mandalay	Channel Islands Harbor	Natural gas	573	253
Morro Bay	Morro Bay Harbor	Natural gas	912	668
Moss Landing	Elkhorn Slough/Moss Landing Harbor	Natural gas	2,484	1,224
Ormond Beach	Pacific Ocean	Natural gas	1,613	688
Pittsburg	Sacramento/San Joaquin Delta	Natural gas	1,370	495
***Potrero* [a]**	*San Francisco Bay*	*Natural gas*	*366*	*226*
Redondo Beach	Santa Monica Bay	Natural gas	1,343	871
San Onofre	Pacific Ocean	Uranium	2,254	2,574
Scattergood	Santa Monica Bay	Natural gas	803	496
***South Bay* [a]**	*San Diego Bay*	*Natural gas*	*706*	*601*

[a] Potrero, South Bay, and Encina are not evaluated in this study.
mgd = million gallons per day.

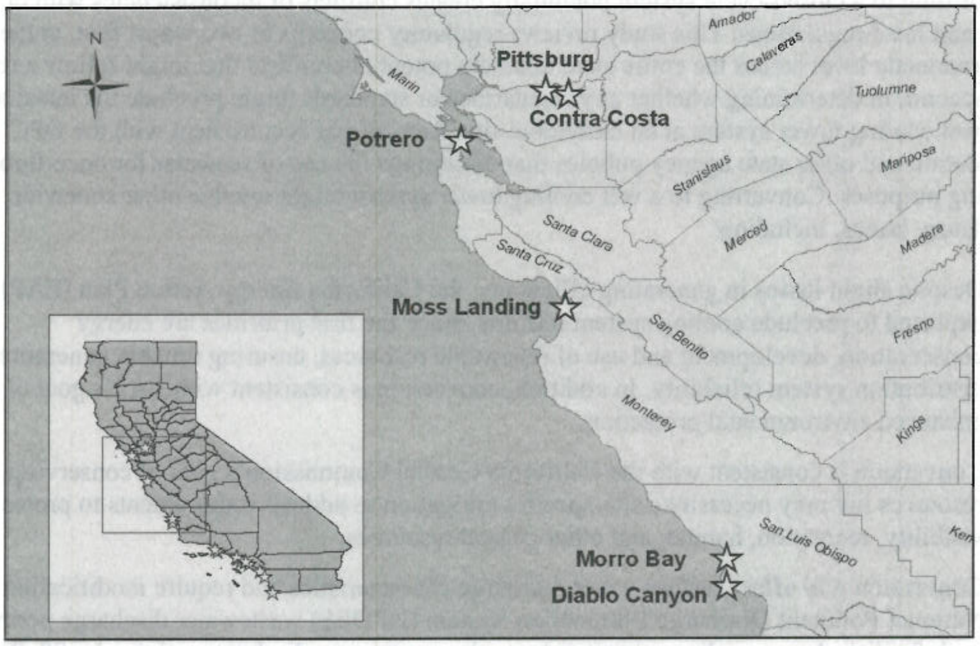


Figure ES-1. North Coast Power Plants

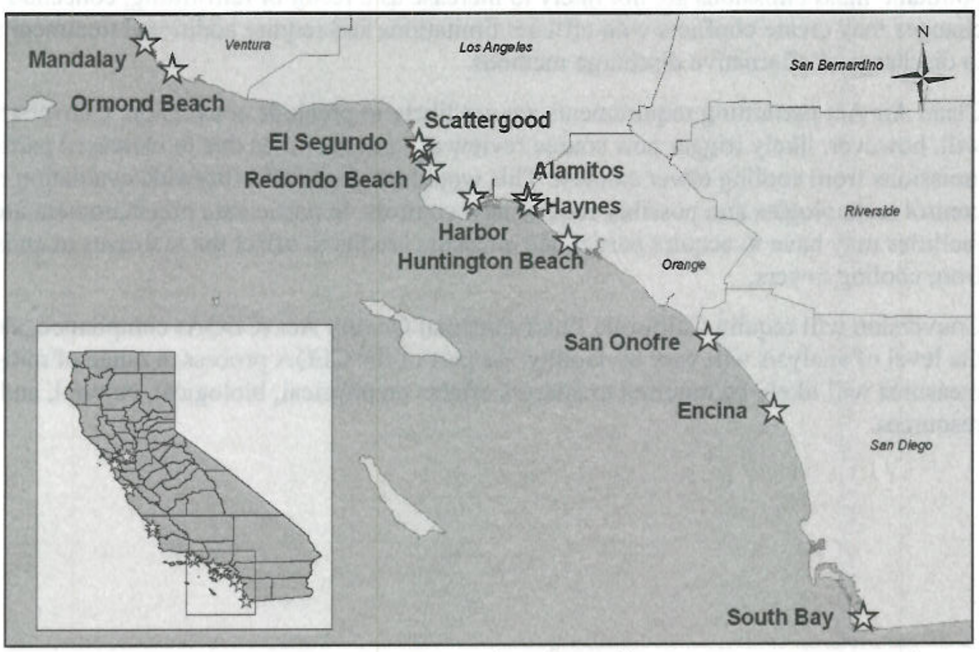


Figure ES-2. South Coast Power Plants

3.0 REGULATORY FRAMEWORK

Retrofitting to a closed-cycle system potentially creates conflicts or inconsistencies with other state and local regulations. This study reviews regulatory concerns in two ways: first, at the programmatic level across the entire state to assess potential conflicts that might follow a retrofit; and second, in determining whether any regulations or standards might preclude the installation of a wet cooling tower system at an individual site. Retrofitting is consistent with the OPC's 2006 Resolution and other state agency policies that discourage the use of seawater for once-through cooling purposes. Converting to a wet cooling tower system might involve other statewide regulatory issues, including:

- Despite slight losses in generating efficiency, the California Energy Action Plan (EAP) is not expected to preclude cooling system retrofits, since the first priorities are energy conservation, development and use of renewable resources, ensuring reliable generation, and distribution system reliability. In addition, conversion is consistent with EAP's goal of enhanced environmental protection.
- Conversion is consistent with the California Coastal Commission's goal of conserving marine resources but may necessitate site-specific mitigation to address requirements to protect visibility, recreation, habitat, and other coastal resources.
- Conversion will affect surface water discharge characteristics and require modification of National Pollutant Discharge Elimination System (NPDES) wastewater discharge permits for each facility. A wet cooling system reduces the wastewater discharge volume by 90–95 percent but may increase the concentrations of some pollutants contained therein. While pollutant mass emissions are not likely to increase as a result of retrofitting, concentration changes may create conflicts with effluent limitations and require additional treatment prior to discharge or alternative discharge methods.
- Clean Air Act permitting requirements are not likely to preclude conversion. Conversions will, however, likely trigger new source review at some facilities due to increased particulate emissions from cooling tower exhaust. This would necessitate facilitywide evaluation of control technologies and possibly require new controls. In particulate nonattainment areas, facilities may have to acquire particulate emission credits to offset the increases in emissions from cooling towers.
- Conversion will require California Environmental Quality Act (CEQA) compliance, although the level of analysis will vary by facility. As part of the CEQA process, a range of mitigation measures will likely be required to address effects on physical, biological, cultural, and social resources.

4.0 EVALUATION OF OTHER TECHNOLOGIES

While the primary focus of this study is retrofitting with wet cooling systems, the study also includes a *limited* review of other technologies that could be used to meet the performance benchmarks included in the 2006 Resolution. Dry cooling systems can effectively eliminate the withdrawal of surface water by using air to condense steam. As noted in Section 1.0, however, dry cooling was not considered in detail in this study because, in a strictly retrofit application, the logistical constraints and total cost will be greater, often significantly so, than a comparable wet cooling system retrofit.

Fine-mesh wedgewire screens were found to be a viable, less costly option for two facilities, although a more detailed, site-specific analysis would need to be completed to confirm their performance at each location. Use of this technology in coastal waters has not been evaluated in detail, although further research into different design configurations may allow for their deployment in coastal waters at some point in the future.

Variable speed pumps/variable frequency drives allow a facility to moderate its cooling water intake flow depending on seasonal and operational conditions. The maximum benefit is typically limited to a 50 percent reduction of impacts (depending on intake flow) but actual reductions will based on the time of year and generating load of the facility. Variable speed pumps are technically feasible at all facilities; any benefit, however, is dependent on the frequency and degree to which flow can be reduced without impacting operations.

A number of plants that withdraw water directly from the Pacific Ocean in southern California have offshore intake structures with velocity caps. These offshore structures may limit impingement and entrainment compared to a conventional onshore intake location, but sufficient biological data were not available to determine site-specific performance. In addition, several state agencies have been hesitant to state conclusively that offshore intake locations are sufficient to meet the best technology available (BTA) standard in Section 316(b) of the Clean Water Act.

Where available, reclaimed water was considered as a potential source of makeup water for wet cooling towers, or, at a few facilities, as a direct replacement for the existing once-through cooling water source. Obtaining reclaimed water requires the construction of transmission pipelines and may require additional treatment prior to use in a cooling tower. These factors are likely to increase the total cost of a wet cooling tower installation. Use of reclaimed water can yield additional benefit such as avoiding conflicts with water discharge limits and reduced air emissions of particulates.

5.0 STUDY FRAMEWORK AND METHODS

This study specifically evaluates the site-specific technical and logistical feasibility and cost of wet cooling towers at 15 of the 18 coastal power plants listed in Table ES-1. 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. This study does not reach any overall conclusions regarding a site-specific feasibility determination, such as that which would be required in a CEQA analysis.

For each facility, a conceptual design of a wet cooling tower system was developed that would meet the minimum identified requirements at each location. This "preferred option" is the design that can reduce impingement and entrainment impacts by 90 percent or more and can comply with site-specific restrictions in the most cost-effective manner.

The preferred option is based on accepted industry standards and practices, as well as best professional judgment when evaluating the following broad criteria:

5.1.1 ENGINEERING CONSTRAINTS

1. **Technical / Logistical.** The availability of sufficient space is the most limiting factor in a wet cooling tower retrofit analysis. As part of this process, a conceptual design of the cooling tower system was developed within the logistical constraints identified at each facility. At most locations, space is available but may require relocation of existing structures. Optimal siting generally places wet cooling towers at a reasonable distance from the generating units to minimize costs. This was not always possible because of land availability and conflicts with other land uses at or immediately adjacent to the site. Other factors, such as integration with the generating unit and conflicts with other facility systems, were also evaluated.

2. **Regulatory / Local Use.** This study evaluated local land use policies and public health and safety requirements that might affect the design or feasibility of wet cooling tower systems. Where necessary to ensure compliance with other regulatory programs, mitigation measures were incorporated into the tower design, e.g., noise and plume abatement.

5.1.2 COST ESTIMATE

Comprehensive cost estimates were based on four categories: (1) initial capital and startup, (2) operations and maintenance, (3) shutdown revenue loss, and (4) energy penalty. In the study, all capital costs were assumed to be amortized over a 20-year period based on an assumed average lifespan for saltwater towers before significant repair or replacement costs are incurred. The basis does not reflect the potential lifespan of the individual facility or generating unit. The results are presented as net present costs and annualized costs (in current dollars) over this 20-year period and include:

1. **Initial capital.** This category addresses all construction and design-related activities required for a wet cooling tower retrofit, including the following:
   - Cooling tower costs. Cooling tower construction costs were obtained from cooling tower vendors based on the conceptual designs.
   - Civil, structural, mechanical, and electrical costs. These costs are associated with the supporting structures and equipment necessary to integrate the cooling towers with the power generating units.
   - Indirect costs. These are other costs associated with cooling tower management, including start-up, permitting, engineering, etc. These costs are not itemized but estimated as 25 percent of all direct costs (cooling tower plus civil, structural, mechanical, and electrical).
   - Condenser modification. This cost is an allowance for a facility to reinforce its condenser in order to accommodate the higher circulating water pressures that can result from converting to wet cooling towers. This cost was estimated at 5 percent of all direct costs.
   - Contingency. This is an allowance for project unknowns, accidents, and delays that often affect complex construction projects. Based on the level of detail available for this study and following professional estimator guidelines, the contingency cost is calculated as 25 percent of all direct, indirect, and condenser modification costs.
2. **Operations and maintenance.** This category reflects the annual cost associated with maintaining wet cooling towers over a 20-year period. Based on information from cooling tower vendors, it is calculated as a fixed amount per gallon per minute of cooling system flow.
3. **Shutdown costs.** This category reflects the lost revenue resulting from a necessary cessation of power generation during the construction and tie-in period. For Diablo Canyon and San Onofre, this is a significant cost component because of their size and high capacity utilization rate. Shutdown losses were also estimated for Haynes and Moss Landing, although the total value is substantially less. At all other facilities, the seasonal or infrequent operation of individual units allows construction and integration to be completed while units are not operational.
4. **Energy penalty.** The energy penalty is based on two components: the increased electrical usage associated with the operation of tower fans and pumps, and the reduced generating efficiency associated with a wet tower retrofit. The manner in which a facility chooses to adapt to these changes will influence the actual cost of the energy penalty. In some cases a facility may opt to absorb the net loss of revenue-generating electricity. Natural gas-fired units may be able to increase the turbine firing rate, or thermal input, to make up some, or all, of the net generating shortfall—in which case the energy penalty cost is the value of the additional fuel that is consumed.

   Nuclear facilities such as Diablo Canyon (Pacific Gas & Electric [PG&E]) and San Onofre (Southern California Edison [SCE]) generally cannot modify thermal inputs to the system because of safety and design constraints. As investor-owned utilities, PG&E and SCE must compensate for the net generating shortfall by purchasing replacement power from other sources or on the open market, the cost of which is often much higher than the nuclear cost of generation

6.0 RESULTS

This study shows that retrofitting existing once-through cooling systems with the preferred wet cooling design could be technically and logistically feasible at 12 of the 15 active coastal power plants (Table ES-2).

Table ES-2. Feasibility Summary

Infeasible	Feasible	
• El Segundo • Ormond Beach • Redondo Beach	• Alamitos • Diablo Canyon • Haynes • Mandalay • Moss Landing • San Onofre	• Contra Costa • Harbor • Huntington Beach • Morro Bay • Pittsburg • Scattergood

Retrofitting to wet cooling towers is not feasible at Redondo Beach because of its immediate proximity to office buildings and residential areas. Compliance with local use requirements would be unlikely.

For two other facilities—El Segundo and Ormond Beach—the preferred option could not be configured to meet the minimum site constraints. At both locations, interference from a wet cooling tower's visible plume with nearby flight operations made it probable that plume-abated towers would be required. An acceptable configuration could not be designed for either location due to limited space availability and potential interference with other major structures. Because the plume abatement requirement could not be confirmed for either facility, the study proceeded with an analysis of conventional cooling towers for El Segundo and Ormond Beach, which are logistically feasible at both sites may face other obstacles.

For other facilities, wet cooling tower retrofits are technically and logistically feasible based on the study's criteria but may have to overcome other impediments. At Diablo Canyon, the constraints of the existing site and the disruption caused by a wet cooling tower retrofit will require both units to be offline for 8 months or more. At San Onofre, a retrofit would require additional regulatory approval because of potential effects on sensitive plant species and the disruption to environmentally sensitive habitats. At Moss Landing and other central coast facilities, particulate emission increases from a wet cooling tower may require the facility to purchase emission reduction credits, which may be costly, if they are available at all.

Table E-3 summarizes 20-year annualized cost estimates for 11 of California's coastal facilities where cooling tower retrofits are considered technically and logistically feasible.[1] Per megawatt-hour costs are presented based on rated capacities and 2006 net output for each generator category. Table ES-4 presents the same costs for each facility.

In sum, the annual cost to retrofit the 11 facilities noted above with wet cooling towers translates to 0.45 cents per kilowatt hour (kWh) based on the facilities' collective generating capacity. Compared with their 2006 generating output, the annual cost translates to 1.13 cents/kWh. If passed entirely to the ratepayer, retrofit costs would represent an increase ranging from 3.5 to 8.7 percent based on the 2006 average end-use retail cost of 12.93 cents/kWh in California.[2]

Table ES-3. Annualized Cost Summary—Generating Sector

Facility category	20-year total annualized cost [a],[b] ($)	Rated capacity (GWh)	Cost per MWh ($/MWh)	2006 net output (GWh)	Cost per MWh ($/MWh)
Nuclear [c]	442,600,000	39,017	11.34	35,603	12.43
Steam turbine [d]	123,400,000	75,257	1.64	8,522	14.48
Combined-cycle [e]	20,600,000	16,557	1.25	7,613	2.72
All facilities	**586,600,000**	**130,831**	**4.48**	**51,738**	**11.34**

[a] 20-year annualized cost of all initial capital and startup costs, operations and maintenance, and energy penalty. Value represents the total annualized cost for all facilities in each category.
[b] Annual costs do not include any revenue loss associated with shutdown during construction. This loss is incurred in the first year of the project but not amortized over the 20-year project life span. Estimates of shutdown losses were developed for the following facilities:
Diablo Canyon: $ 727 million
San Onofre: $ 595 million
Haynes: $ 5 million
Moss Landing: $ 2 million

[c] Diablo Canyon and San Onofre
[d] Alamitos, Contra Costa, El Segundo (Units 3 & 4 only), Haynes (Units 1, 2, 5, & 6 only), Huntington Beach, Mandalay, Moss Landing (Units 6 & 7 only), Pittsburg, and Scattergood.
[e] Harbor, Haynes (Unit 8 only), and Moss Landing (Units 1 & 2 only).
GWh = gigawatt hour
MWh = megawatt hour

[1] Costs for Morro Bay are not included in either table because the analysis was developed based on the repowering project the previous owner (Duke Energy) had proposed for the facility. Cost estimates, therefore, are not directly comparable to the retrofit analyses conducted for the other coastal facilities. Based on a previous analysis prepared by Tetra Tech, Inc. for the Central Coast Regional Water Quality Control Board in 2002 and the general methodology of this study, the updated annual cost for Morro Bay is $9.6 million.
[2] *California Average Retail Price of Electricity to Ultimate Customers—All Sectors (Residential, Commercial Industrial) Year to Date through October 2006.* US Energy Information Agency, 2006.

Table ES-4. Annualized Cost Summary—Facility

Facility	Category [a]	20-year annualized cost [b],[c] ($)	Rated capacity (GWh)	Cost per MWh ($/MWh)	2006 net output (GWh)	Cost per MWh ($/MWh)
Alamitos	ST	25,400,000	17,082	1.49	1,677	15.15
Contra Costa	ST	9,900,000	5,957	1.66	142	69.86
Diablo Canyon	N	233,700,000	19,272	12.13	18,465	12.66
Harbor	CC	2,700,000	2,059	1.36	183	15.28
Haynes [d]	CC	6,000,000	5,037	1.19	2,065	2.91
Haynes [d]	ST	13,900,000	9,145	1.52	2,263	6.14
Huntington Beach	ST	15,400,000	7,709	2.00	1,141	13.50
Mandalay	ST	5,800,000	3,767	1.54	312	18.57
Moss Landing [e]	CC	11,900,000	9,461	1.26	5,364	2.22
Moss Landing [e]	ST	21,700,000	12,299	1.76	1,043	20.81
Pittsburg	ST	12,700,000	12,264	1.04	447	28.40
San Onofre	N	208,900,000	19,745	10.58	17,139	12.19
Scattergood	ST	18,600,000	7,034	2.64	1,497	12.42
All facilities		**586,600,000**	**130,831**	**4.48**	**51,738**	**11.34**

[a] CC = combined-cycle; ST = simple cycle steam turbine (natural gas); N = nuclear-fueled steam turbine

[b] 20-year annualized cost of all initial capital and startup costs, operations and maintenance, and energy penalty.

[c] Annual costs do not include any revenue loss associated with shutdown during construction. This loss is incurred in the first year of the project but not amortized over the 20-year project life span. Estimates of shutdown losses were developed for the following facilities:

Diablo Canyon:	$ 727 million
San Onofre:	$ 595 million
Haynes:	$ 5 million
Moss Landing:	$ 2 million

[d] Haynes operates one combined-cycle unit (Unit 8) and four simple cycle units (Units 1, 2, 5, & 6). Costs are specific for each unit type; facility-wide cost is the sum of both categories.

[e] Moss Landing operates two combined-cycle units (Unit 1 & 2) and two simple cycle units (Units 6 & 7). Costs are specific for each unit type; facility-wide cost is the sum of both categories.

[f] 3-year average output for SONGS.

GWh = gigawatt hour

MWh = megawatt hour