NATIONAL ENERGY TECHNOLOGY LABORATORY

DOE/NETL's Innovations for Existing Plants Water-Energy R&D Program Goals & Evaluation Methodology

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Presentation Outline

- Development of water-energy R&D goal
- Proposed methodology to measure progress toward achievement of goal

Attributes of the Goal Statement

- **Target date**
  - Short term
  - Long term
- **Performance targets**
  - Percentage reduction in freshwater use
- **Cost targets**
  - Percentage cost reduction compared to current “state-of-the-art” technology
  - Achieve specific levelized cost
    - Cost per freshwater conservation - $/gallon

IEP Water-Energy R&D Goals

Short-term goal

- Technologies ready for commercial demonstration by ***2015***
- Reduce freshwater withdrawal and consumption by ***50%*** or greater
- Levelized cost of less than ***$3.90*** per thousand gallons freshwater conserved

Long-term goal

- Technologies ready for commercial demonstration by ***2020***
- Reduce freshwater withdrawal and consumption by ***70%*** or greater
- Levelized cost of less than ***$2.60*** per thousand gallons freshwater conserved

IEP Water-Energy R&D Goal Statement

The short-term goal for the IEP water-energy R&D activity is to have technologies ready for commercial demonstration by 2015 that, ***when used alone or in combination***, can reduce freshwater withdrawal and consumption by 50% or greater ***for thermoelectric power plants equipped with wet recirculating cooling technology*** at a levelized cost of less than $3.90 per thousand gallons freshwater conserved.

The long-term goal is to have technologies ready for commercial demonstration by 2020 that, when used in combination, can reduce freshwater withdrawal and consumption by 70% or greater at a levelized cost of less than $2.60 per thousand gallons freshwater conserved.

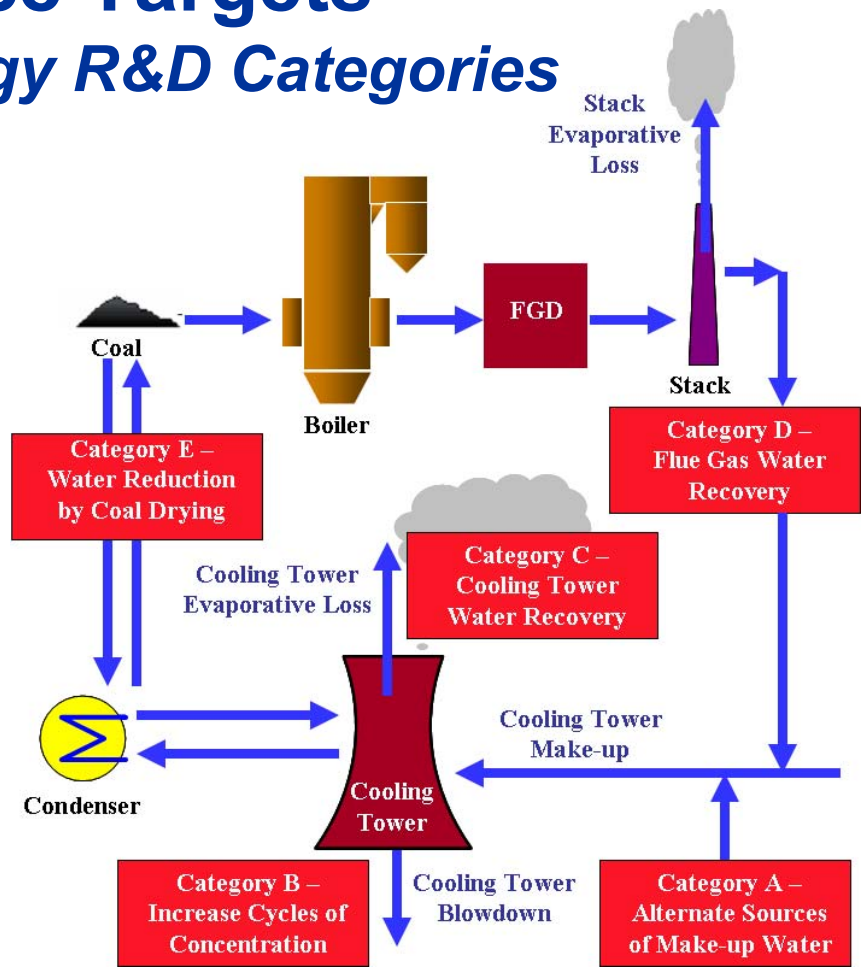
Target Dates

- **Short term goal - *2015***
  - *Maintain current technology development schedule*
- **Long term goal - *2020***
  - *Provide five additional years for technology enhancements*

Performance Targets

Current Water-Energy R&D Categories

- **Category A** – non-traditional water source used to supplement freshwater for cooling water makeup
- **Category B** – increase cycles of concentration (COC) to reduce blowdown, and consequently reduce cooling water makeup
- **Category C** – reduce cooling tower evaporation loss
- **Category D** – reclaim water from combustion flue gas
- **Category E** – utilize waste energy derived from recirculating cooling water to reduce cooling tower evaporative loss



The estimated percentage reduction in freshwater withdrawal and consumption for the five technology categories ranges from 5% to almost 30%. However, by combining technology categories, up to almost 60% reductions are possible for both withdrawal and consumption.

Performance Targets

Technology Category - Individual and Combination

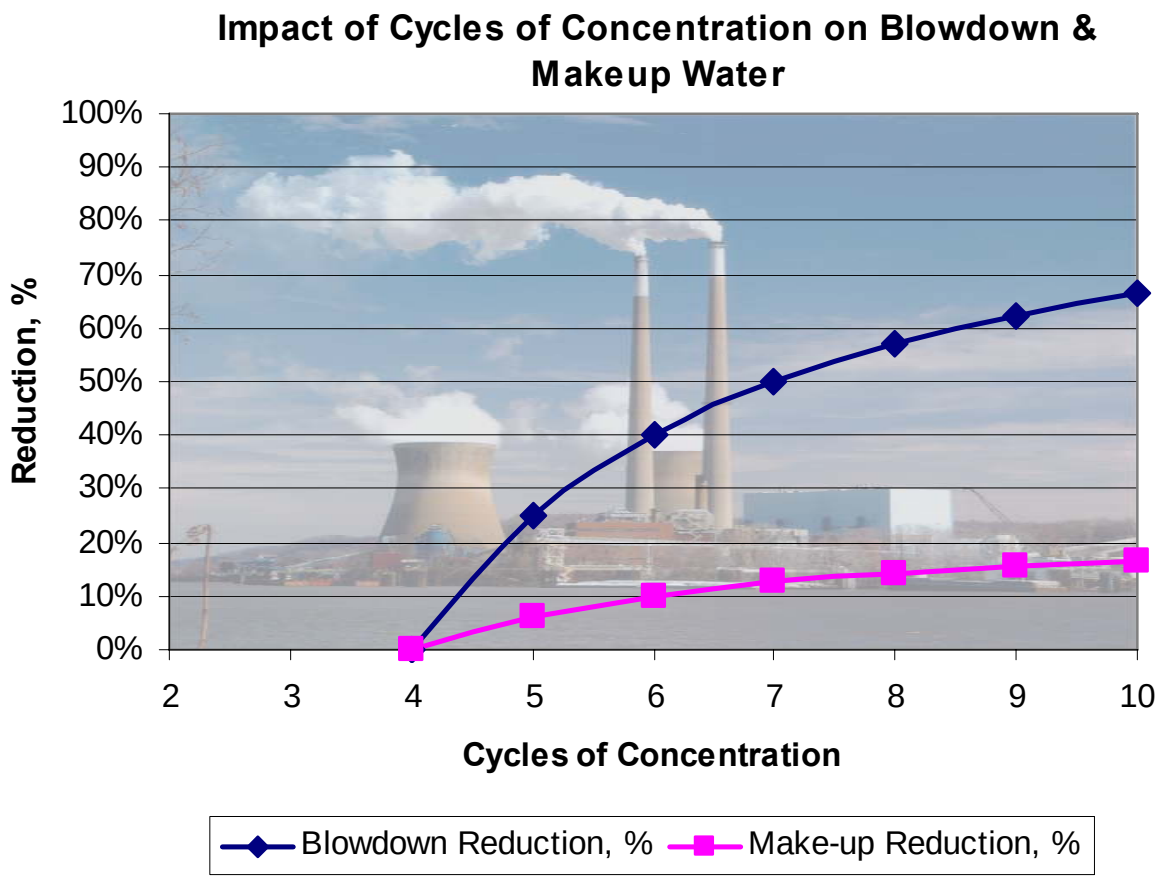
Technology Category Combination	Freshwater Withdrawal Reduction, %	Freshwater Consumption Reduction, %
A	27.0%	27.0%
B	11.1%	0.0%
C	20.0%	20.0%
D	3.8%	3.8%
E	5.6%	5.6%
AB	38.1%	30.4%
AC	47.0%	47.0%
BC	28.9%	20.0%
ABC	55.9%	50.4%
ABDE	46.9%	40.3%
ACDE	55.3%	55.3%
BCDE	36.7%	28.8%
ABCDE	63.7%	59.1%

Based on this analysis, it was recommended that the short-term performance goal be stated as a 50% reduction in water withdrawal and consumption and the long-term goal a 70% reduction.

Source: *NETL internal study*, July 2006.

Performance Targets

Cooling Water System Flow Relationships



- **Make-Up = Evaporation + Blowdown + Drift**
- **Blowdown = Evaporation/(COC – 1) – Drift**

  where: COC = cycles of concentration

  assume drift = 0

Cost Targets

Cost Comparison of Wet and Dry Cooling Water Systems for a Reference 500 MW Coal-Fired Power Plant

Cost Component	Wet Cooling (2006$)	Direct Dry Cooling (2006$)	Delta
Equipment Capital Cost			
Capital cost, $/kW	78	168	90
Total capital requirement, Million $	38.8	83.8	45
First year carrying charge, (1,000 $/yr)	6,601	14,251	7,650
Annual Operation & Maintenance Cost (x1,000)			
Maintenance	388	838	450
Water treatment	844	0	-844
Auxiliary power	1,051	2,102	1,051
Lost capacity penalty	0	1,183	1,183
Total annual O&M	2,284	4,124	1,840
Total First Year Costs			
$/yr (x1,000)	8,885	18,375	9,490
COE, mills/kWh	2.54	5.24	2.71
$/1000 gallon water conserved	NA	NA	6.37
Levelized Annual Cost (Constant $)			
$/yr (x1000)	7,332	15,022	7,690
COE, mills/kWh	2.09	4.29	2.19
$/1000 gal water conserved	NA	NA	5.16
Levelized Annual Cost (Current $)			
$/yr (x1000)	8,958	18,328	9,371
COE, mills/kWh	2.56	5.23	2.67
$/1000 gal water conserved	NA	NA	6.29

Step 1: Dry & Wet Cooling Cost
dry @ 4.29 mills/kWh
wet @ 2.09 mills/kWh

Step 2: Dry vs. Wet Δ Cost
4.29 – 2.09 = Δ 2.19 mills/kWh

Step 3: Wet Cooling Water Use
425 gal/MWh

Step 4: Dry Cool Effectiveness
2.19 mills/kWh / 425 gal/MWh
= 5.16 $/kgal conserved

Cost Targets

Cost Effectiveness of Dry Cooling

- **Dry cooling levelized cost @ $5.16 per 1,000 gallons freshwater conserved (2006 constant dollar basis)**
- **Short term goal**
  - Cost effectiveness of R&D technologies equivalent to approx. 75% of dry cooling ($3.90 per 1,000 gallons)
- **Long term goal**
  - Cost effectiveness of R&D technologies equivalent to approx. 50% of dry cooling ($2.60 per 1,000 gallons)

Technology Evaluation Methodology

- ***How to measure progress in achieving DOE/NETL's cost & performance goals?***
  - Calculate levelized cost in terms of dollars per thousand gallons freshwater conserved
  - Compare project cost to NETL cost goal
- ***Need consistent cost methodology for use by all NETL contractors***
- ***Economic assumptions should be equal to those used to establish NETL cost goal***
- ***NETL will provide contractors an economic evaluation guideline and cost estimating spreadsheet model to assure consistency***

Reference Plant Data Sheet

Subcritical PC Boiler Plant Performance Summary @ 100 Percent Load (Table 7-1)	
554.4	Gross power, MW
33.8	Auxilary load, MW
520.6	Net Power, MW
35.4	Net efficiency, % (HHV)
9,638	Net heat rate, Btu/kWh (HHV)
2,335	Condenser cooling duty, 10^6 Btu/h

Reference: DOE/NETL report entitled "Power Plant Water Usage and Loss Study“ , Revised May 2007

Reference Plant Data Sheet (cont'd)

Cooling System Assumptions (Table 1-5)	
System type: Closed recirculating system with evaporative mechanical draft cooling towers	
89	Design dry bulb max. ambient temperature, °F
75	Design wet bulb max. ambient temperature, °F
5	Cooling tower approach, °F
25	Cooling tower range, °F
80	Cold circulating water temperature to condenser, °F
105	Hot circulating water temperature from condenser, °F
4	Circulating water cycles of concentration
0.001	Cooling tower drift (% of CW flow rate)

Subcritical PC Boiler Water Balance Around Cooling Water System (Table 7-8)	
3,891	Cooling tower evaporation, gpm
1,297	Cooling tower blowdown, gpm
5,188	Cooling tower make-up, gpm

Circulating Water Flow Rate Calculation (NETL estimate)	
1.0	Specific heat of water, Btu/lb-F
8.33	Density of water, lb/gal
186,875	Circulating water flow rate, gpm

Reference: DOE/NETL report entitled "Power Plant Water Usage and Loss Study" , Revised May 2007

Input Value Sheet

General Information	
Lead Company	XYZ Company
Principle Investigator	John Doe
NETL Project Manager	Jane Smith
NETL Project #	XXXXXXXX
NETL Water-Energy R&D Category	Category A - Non-Traditional Water
Description of Water Technology	Beta Cooling Technology
Test Site	Alpha Power Company's Beta Power Plant Unit 2
Date Prepared	December 30, 2008

Reference Plant Operating Assumptions	Value	Assumptions/Comments
Plant capacity, MW net	521	From reference plant data sheet.
Net plant heat rate, Btu/kWh	9,638	From reference plant data sheet.
Average plant capacity factor	80%	Assume 80% per NETL Guidelines, Sec.6.3
Cooling tower evaporation, gpm	3,891	From reference plant data sheet.
Cooling tower blowdown, gpm	1,297	From reference plant data sheet.
Cooling tower make-up, gpm	5,188	From reference plant data sheet.
Cycles of concentration	4	From reference plant data sheet.

Input Value Sheet (cont'd)

Water Technology Performance Assumptions & Calculations		All performance values should be based on plant operation at full load.
Reduction in cooling tower freshwater make-up, %	20.0%	Estimate percent reduction in freshwater make-up using water technology for Category A, C, D, E, or F project.
Cycles of concentration	4.0	Estimate COC after application of water technology for Category B project.
Cooling tower freshwater evaporation, gpm	3,113	Calculated value.
Cooling tower freshwater blowdown, gpm	1,038	Calculated value.
Cooling tower freshwater make-up, gpm	4,150	Calculated value.
Reduction in cooling tower freshwater make-up, gpm	1,038	Calculated value.
Reduction in cooling tower freshwater make-up, gallons per year	436,290,048	Calculated value based on average plant capacity factor.
Water Technology Cost Assumptions		
Costs expressed in year dollars	2008	All costs should be escalated to this year dollars for consisteny.
Process capital cost, $	1,000,000	Include costs for all material, equipment, direct and indirect labor, and freight & taxes.
Technology royalty fee, $	0	Estimate fee if necessary.
Special maintenance, $	100,000	Estimate cost of non-routine special maintenance requirements.
Special maintenance frequency, hours	16,000	Estimate operating hours between special maintenance activities.
Primary additive	Additive XX	Identify name and type of additive.
Primary additive cost & feedrate metric	$/lb & lb/hr	Select either $/lb & lb/hr or $/gal & gal/hr.
Primary additive unit cost, $/lb or $/gal	$1.00	Estimate delivered price.
Primary additive feed rate, lb/hr or gal/hr	50	Estimate feed rate at full load. Make sure units are consistent with unit price.
Secondary additive	Additive YY	Identify name and type of additive.
Secondary additive cost & feedrate metric	$/gal & gal/hr	Select either $/lb & lb/hr or $/gal & gal/hr.
Secondary additive unit cost, $/lb or $/gal	$2.00	Estimate delivered price.
Secondary reagent/additive feed rate, lb/hr or gal/hr	10	Estimate feed rate at full load. Make sure units are consistent with unit price.
Increase in flue gas duct pressure drop, in H_2O	0.00	Estimate pressure drop at full load.
Auxiliary electric power consumption, kW	100	Estimate consumption rate at full load.
Process water consumption, gallon/hr	20	Estimate consumption rate at full load.
Process steam consumption, lb/hr	100	Estimate consumption rate at full load.
Service air consumption, cfm	100	Estimate consumption rate at full load.
Waste by-product production, lb/hr	20	Estimate production rate at full load.
No. operators per shift	0.5	Estimate additonal operating personnel per shift. (Fractional entry is acceptable.)

Cost Calculation Sheet

XYZ Company			
Beta Cooling Technology			
Plant Operating Assumptions	**Value**	**Factors**	**Assumptions/Comments**
Plant capacity, MW	521		From input sheet.
Net plant heat rate, Btu/kWh	9,638		From input sheet.
Average plant capacity factor	80%		From input sheet.
Cooling tower water make-up, gpm	5,188		From input sheet.
Reduction in cooling tower freshwater make-up, gpm	1,038		From input sheet.
Costs expressed in year dollars	2008		From input sheet.
Capital Cost			
Process capital cost (PCC)	1,000,000		From input sheet.
Process capital cost w/ retrofit factor	1,000,000	1.00	Retrofit difficulty factor assumed 1.00 per NETL estimate.
Technology royalty fee	0		From input sheet.
General facilities, %	100,000	10%	Assume 10% of PCC per EPRI TAG.
Engineering & construction management fees,%	100,000	10%	Assume 10% of PCC per NETL Guidelines, Sec. 7.1.1.
Process contingency, %	50,000	5%	Assume 5% of PCC per NETL Guidelines Table 6 AACE standards for commercial technology or modifications to commercial technology status.
Project contingency,%	150,000	15%	Assume 15% of PCC per NETL Guidelines Table 7 AACE standards for project control design stage.
Total plant cost (TPC), $	1,400,000		
Total capital requirement, $/kW	2.69		
Total first year capital carrying charge, $/yr	289,800		Calculated using 1st year current $ carrying charge rate from economic factors worksheet.

Cost Calculation Sheet (cont'd)

Fixed O&M Cost			
Operating labor, $/yr	219,000		Calculation based on estimated operating labor per shift at $50/man-hr.
Routine maintenance, $/yr	30,800	2.2%	Assume 2.2% of TPC per NETL Guidelines, Sec. 7.2.1.
Special maintenance, $/yr	43,800		Calculation based on special maintenance cost and frequency from input sheet.
Supervisory/clerical, $/yr	69,396		Assume 30% of operating labor and 12% maintenance costs per NETL Guidelines, Sec. 7.2.1.
Total fixed O&M cost, $/yr	362,996		
Total fixed O&M cost, $/kW-yr	0.70		
Variable O&M Cost			Calculate annual variable costs using plant capacity factor.
Primary additive, $/yr	350,400		Calculation based on estimated unit cost and feed rate.
Secondary additive, $/yr	140,160		Calculation based on estimated unit cost and feed rate.
Additional fan power, $/yr	0		Auxiliary power unit cost per calculation on misc. factor worksheet.
Auxiliary power, $/yr	21,024		Auxiliary power unit cost per calculation on misc. factor worksheet.
Process water, $/yr	316		Process water unit cost per calculation on misc. factor worksheet.
Process steam, $/yr	1,939		Steam unit cost per calculation on misc. factor worksheet.
Service air, $/yr	3,268		Service air unit cost per calculation on misc. factor worksheet.
Waste disposal, $/yr	1,402		Waste disposal unit cost per calculation on misc. factor worksheet.
Total Variable O&M Cost, $/yr	518,509		
Total Variable O&M Cost, mills/kWh	0.14		

Cost Calculation Sheet (cont'd)

Total First Year Costs	
$/year	1,171,305
Increase COE, mill/kWh	0.32
$/kgal freshwater make-up conserved	2.68
Levelized Annual Cost (Constant $)	
$/year	1,063,505
Increase COE, mill/kWh	0.29
$/kgal freshwater make-up conserved	2.44
Levelized Annual Cost (Current $)	
$/year	1,324,061
Increase COE, mill/kWh	0.36
$/kgal freshwater make-up conserved	3.03

Questions?

To Find Out More About NETL's Water-Energy R&D:

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the ENERGY lab

Where energy challenges converge and energy solutions emerge

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- TECHNOLOGIES
  - Oil & Natural Gas Supply
  - Coal & Power Systems
    - Clean Coal Demonstrations
    - Innovations for Existing Plants
    - Gasification
    - Turbines
    - Fuel Cells
    - FutureGen
    - Advanced Research
    - Contacts
  - Carbon Sequestration
  - Hydrogen & Clean Fuels
  - Technology Transfer
- ENERGY ANALYSES
- SOLICITATIONS & BUSINESS
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Home > Technologies > Coal & Power Systems > *Innovations for Existing Plants*

Coal and Power Systems
Innovations for Existing Plants

- On July 29, 2008, DOE announced the selection of 10 projects under Funding Opportunity Announcement DE-PS26-08NT00233 entitled "Research and Development of Advanced Technologies and Concepts for Minimization of Freshwater Withdrawal and Consumption in Coal-Based Thermoelectric Power Plants." Project awards are anticipated to be made later this year.
- On July 31, 2008, DOE announced the selection of 15 projects under Funding Opportunity Announcement DE-PS26-08NT00134 entitled "Carbon Dioxide Capture and Separation Technology Development For Application To Existing Pulverized Coal-Fired Power Plants. Project awards are anticipated to be made later this year.

Welcome to the Innovations for Existing Plants homepage. The The Innovations for Existing Plants (IEP) Program is an integral part of NETL's Coal and Power Systems RD&D portfolio. Coal is a vital energy resource in the United States, providing approximately half of the electricity supply to the country. Through the IEP Program we are striving to sustain the strategic role of coal in the nation's energy mix by maintaining its integrity as an affordable and environmentally sound natural resource. Our program mission is to

- CO_2 Emissions Control
- Water-Energy Interface
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http://www.netl.doe.gov/technologies/coalpower/ewr/index.html

EXTRA SLIDES

Cost Targets

Economic Assumptions

Economic Assumptions	Reference: NETL Guidelines, Sec. 7.3	
Year dollars	2006	Per study requirements
Project life, yrs	20	
Book life, yrs	20	
Tax life, yrs	20	
Federal and state income tax rate, %	38%	
Tax depreciation method	ACRS	Accelerated cost recovery system - 150% DB
Investment tax credit	0.0%	
Construction interest rate	11.2%	Not used in calculations.
Inflation rate, %	3.0%	
Non-fuel escalation rate, %	0.0%	Not used in calculations.

Financial Structure	Reference: NETL Guidelines, Table 9 - low risk projects				
Type of Security	% of Total	Current $ Cost, %	Current $ Return, %	Constant $ Cost, %	Constant $ Return, %
Debt	80.0%	9.0%	7.2%	5.8%	4.7%
Preferred stock	0.0%	3.0%	0.0%	0.0%	0.0%
Common stock	20.0%	20.0%	4.0%	16.5%	3.3%
Discount rate			11.2%		8.0%

Levelization Factors:	**Current $**	**Constant $**
Levelization factor for O&M	1.253	1.000
1st year carrying charge factor	20.7%	17.0%
20-yr levelized factor for capital	15.7%	13.0%

Cost Targets

Cost and Performance Assumptions

Cost & Performance Assumptions:	Value	Reference
Annual escalation rate, %	3.0%	
Plant capacity, MW	500	
Capacity factor, %	80%	
Wet tower capital cost, $/kW (2002$)	69	(1)
Capital cost adder for dry tower	90	(3)
Fixed maintenance as % capital cost, %	1.0%	(1)
Water treatment, $/kW-yr (2002$)	1.5	(1)
Aux. power as % plant capacity (Wet)	1.0%	(2)
Aux. power as % plant capacity (Dry)	2.0%	(2)
Lost capacity penalty, % (Dry)	1.0%	(2)
Energy cost, $/kWh	0.030	(1)
Water evaporation @ full load, gal/MWh	425	(4)

References:

(1) "An Investigation of Site-Specific Considerations for Retrofitting Recirculating Cooling Towers at Existing Power Plants - A Four-Site Case Study", May 2002, Parsons report for DOE/NETL

(2) EPRI August 2004 report #1005358 titled "Comparison of Alternate Cooling Technologies for U.S. Power Plants: Economic, Environmental, and Other Tradeoffs"

(3) Capital cost adder for dry cooling system based on average dry vs. wet delta capital cost from two references:

Burns & McDonnell evaluation for Sempra Energy, November 2002 - 76 $/kW adder (dry @ 172 $/kW vs. wet @ 96 $/kW)

EPRI August 2004 (see reference 2) - 99 $/kW adder (dry @ 135 $/kW vs. wet @ 36 $/kW)

(4) "Power Plant Water Usage and Loss Study", May 2007, Parsons report for DOE/NETL.
Average of 449 gal/MWh for subcritical PC and 402 gal/MWh for supercritical PC plant.