Powers Engineering

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Subject: Comments on February 2002 CEC/EPRI Document – *"Comparison of Alternate Cooling Technologies for California Power Plants - Economic, Environmental, and Other Tradeoffs"*

Dear Kent:

I did not become aware of the California Energy Commission/Electric Power Research Institute (CEC/EPRI) document, *"Comparison of Alternate Cooling Technologies for California Power Plants - Economic, Environmental, and Other Tradeoffs,"* until very late in the report finalization phase, and as a result did not have an opportunity to comment on the draft. Dr. John Maulbetsch, author of the CEC/EPRI report, and I have communicated over the past year on a variety of technical and cost issues related to wet and dry cooling systems for power plants. John mentioned to me recently that he is now working on a similar nationwide cooling alternatives evaluation under contract to EPRI. I would like to offer my comments on the February 2002 document at this time so that my comments can be considered in the developmental phase of the national EPRI evaluation.

My comments follow the order of the February 2002 report.

Report Abstract

The approximate price range for a turnkey Douglas Fir conventional wet tower on a 500 MW combined cycle power plant was estimated by Marley Cooling Technologies at $8 to $10 million dollars during research I conducted for a 2002 New Mexico combined-cycle power plant case study. The results of the New Mexico case study are provided in Attachment A. The installed cost of a turnkey plume abatement wet tower was estimated by Marley at $11 to $14 million. These cost estimates assumed non-union labor is used. An air-cooled condenser (ACC) for the same site, capable of maintaining steam turbine MW output at "typical year hottest temperature" was quoted at $21 to $24 million depending on whether union labor is utilized. The installed capital cost ratio of a low cost Douglas Fir conventional wet tower to ACC in the 2002 case study, approximately 1.0 to 2.5, is consistent with the cost ratio prepared by the EPA[1] as part of the *Cooling Water Intake Structures – Section 316(b)* rulemaking procedure. The EPA analysis indicates essentially no difference between the installed capital cost of a plume abatement wet tower and an ACC.

[1] Cooling Water Intake Structures – Section 316(b), Economic and Engineering Analyses of the Proposed Section 316(b) New Facility Rule, Appendix A, *Detailed Information on Technologies and the Development of Unit Costs*, August 2000, pg. AppA-14.

All inland California power plants must pay a fee for the freshwater, groundwater, or reclaimed water consumed by the power plant cooling system. Often the water supply is delivered over significant distances by a pipeline installed by the project developer. Virtually all of the utility power plants permitted California in the last ten years are equipped with zero liquid discharge (ZLD) systems. The large capital costs of these water and wastewater systems, and the high parasitic loads associated with operating these systems, are an integral part of a wet cooling system. Including these costs in a wet versus dry comparison typically has a dramatic effect on the relative cost of the two options. The February 2002 CEC/EPRI report includes a total of $100,000 for water delivery and wastewater treatment infrastructure. The $100,000 estimate assumes water of acceptable quality can be accessed from a source immediately adjacent to the power plant, and that there is essentially no cost associated with discharging large volumes of brine from the cooling tower. These assumptions are not correct for California power plants.

Table 3-2. ACCs in Use or Planned

The estimate of ACCs in use or planned, approximately 4,000 MW, appears to be at least a factor of three low, based on a review of the 2001 project lists of the three principal providers of ACCs to the power indusdtry. These vendors are GEA Power Cooling Systems, Hamon Dry Cooling, and Marley Cooling Technologies, Inc. (Balcke-Durr).

Figures 5-3 to 5-6. Cost Ratios Between Wet and Dry Cooling

I agree with the statement on pg. 5-5 that:

> *Busbar production cost: includes all the costs of generating electricity and the plants being compared (since the cooling system costs are a small fraction of the total plant capital, operating, and fuel costs, these ratios are normally close to unity, even when the total cooling system cost ratios are 3 to 5 or higher)*

However, this conclusion is based on obsolete 1970s data presented in Figures 5-3 through 5-6 that accentuate the difference in busbar electricity cost between wet and dry cooling systems. Figures 5-3 through 5-6 require more explanation. Why are nine comparisons included in Figure 5-3, eight in Figures 5-4 and 5-5, and only four in Figure 5-6? The eight comparisons in Figures 5-4 and 5-5 are not the same eight comparisons. What could arguably be called the most important figure of the four is Figure 5-6, "Busbar Power Cost Ratio." Why does Figure 5-6 only include four comparisons? It would appear that several comparisons that may have busbar power cost ratios closest to unity, specifically UEC1, UEC2, UEC3, DTECH, and possibly GE, are not included in Figure 5-6. This leads the reader to assume that the busbar power cost ratios presented in Figure 5-6 are represented of all the data sources cited when they appear to represent a subset that tends to accentuate the busbar power cost delta between the two cooling options.

Table 5-4. Capital Cost Elements for Wet System System Equipment

My discussions with cooling tower vendors and subsystem suppliers, such as suppliers of water circulation pumps, pump motors, electrical hardware and interconnects, water supply, and water

treatment systems, indicate that the cost of wet tower subsystems are considerably higher than those obtained using the factors in Table 5-4. Steam turbine cost is also directly affected by the choice of cooling system, as turbines designed for the higher backpressure associated with ACCs are less costly. For example:

- The cold water basin can be 30 to 50 percent of the tower cost, depending on site-specific conditions.
- The circulating water system can cost from 50 to almost 100 percent of the cost of the cooling tower. Cooling tower vendors such as Marley do not specify or cost out the circulating water pump(s), pump motor(s), or electrical systems associated with the cooling tower.
- Water supply intake structure (pumping hardware and pipeline) can dwarf the cost of the wet tower. 16- to 20-inch pipelines cost in the range of $0.75 to $1 million per mile.
- Wastewater treatment hardware can be far more expensive than the wet tower cost. The approximate installed cost for a ZLD system on a 500 MW plant is $10 million.
- The cost of a steam turbine for 500 MW dry-cooled plant is approximately $2 million less due to the shorter last stage bucket used (allows higher backpressure operation).[2]

Also, the document addresses conventional wet towers only. Cost data for plume abatement wet towers should be included in the report. A number of California power plants use plume abatement cooling towers. It is important to discuss the rationale for using plume abatement wet towers. The EPA estimates that the capital cost of plume abatement cooling towers and ACCs is essentially the same. My estimate based on research performed for the 2002 New Mexico case study is that the capital cost of a plume abatement tower is approximately 60 percent the cost of an ACC. Plume abatement towers are now commonly specified for plant sites near California urban areas or major roadways. Plume abatement towers have significantly higher capital and operating costs than conventional wet towers.

Table 5-5. Capital Cost Breakdown for Wet Cooling System Equipment at California Central Valley Location, "Low First Cost" Design

The cost estimate shown in this table appears to be a factor of two low, even for a "low first cost" design, <u>without considering</u> the cost of water supply structure or wastewater treatment for cooling tower blowdown. Please see the EPA evaluation[3] and the references for cost estimates cited in the case studies in Attachment A.

According to the California Energy Commission,[4] approximately 70 percent of the last 20 to 30 inland powerplants permitted in California use ZLD systems take cooling tower brine to solid directly. The ZLD system is capable of recycling 98 percent of the cooling tower wastewater and eliminates wastewater discharges. There is also one case, Blythe Energy, that sends concentrated brine to evaporation ponds. Two plants located in western Kern County use direct injection into a saline aquifer to dispose of cooling tower brine. These plants are located in the middle of a major oil production area.

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[2] Telephone conversation with Chuck Jones, GE Power Systems, July 26, 2002.
[3] Ibid
[4] Telephone conversation with Dick Anderson, California Energy Commission, January 22, 2003.

As noted, a ZLD systems typically add approximately $10 million to a 500 MW combined-cycle plant and add 1,500 to 2,000 kw of continuous parasitic load. According to the author of a March/April 2001 Power Magazine article on ZLD systems, approximately 50 percent of all new power plants in the U.S. are ZLD plants.[5]

Figure 5-17. Capital Cost vs. ITD for Air-Cooled Condenser

The typical ITD specified by ACC vendors is in the 40 to 45 ^{o}F range. Vendors are reluctant to quote a system with an ITD less than 35 ^{o}F, primarily because the rapidly increasing ACC capital costs result in incrementally smaller increases in system efficiency. The only rationale for going below an ITD of 35 ^{o}F would be if extraordinarily high fuel costs were anticipated over the life of the project. For example, the lowest competitive bid ITD that GEA Power Cooling Systems has bid to date is 38 ^{o}F. The typical ITD design is usually capable of maintaining rated steam turbine output at "typical year" hottest 1-hour temperature. No steam turbine MW output derate will occur with an adequately sized ACC, although additional fuel will needed to account for the more pronounced ACC efficiency loss at high ambient temperature.

An ACC designed for an ITD of 35 ^{o}F will always be able to maintain rated steam turbine output at less than 8-inches Hg backpressure at any site in the U.S. Therefore the economic issue with a properly sized ACC is the additional fuel cost to produce the power, not lost power sales. As explained below, it is not reasonable to assume chronically high fuel costs, given that natural gas prices consistently above approximately $4/MMBtu would provide the economic incentive to construct as many liquified natural gas (LNG) regasification terminals as necessary to compete in the marketplace and stabilize natural gas prices.

I recommend that the curve in Figure 5-17 begin at an ITD of 35 ^{o}F to avoid giving the impression to the reader that an ITD of 35 ^{o}F is "typical." The current ITD endpoints in Figure 5-17 are 20 ^{o}F, highest capital cost, and 55 ^{o}F, lowest capital cost. An ITD of 35 ^{o}F represents a realistic practical limit on ACC capital cost.

I also recommend that the curve in Figure 5-17 end at an ITD of 70 or 75 ^{o}F. A backpressure of 8-inches Hg equates to a condenser temperature of 152 ^{o}F. At coastal California sites, where ambient temperature almost never exceeds 80 ^{o}F, an ACC designed with an ITD of 70 ^{o}F could maintain steam turbine power output across the entire ambient temperature range at the site. If inexpensive fuel is readily available, for example from an onsite gas field, the power plant operator may opt to build the smallest ACC that permits full steam turbine output across the ambient temperature range at the site and accept a lower overall plant thermal efficiency.

Table 5-11. Lost Energy from Heat Rate Penalty

"Lost energy" can be either a combination of steam turbine power reduction at high ambient temperature and loss in efficiency, or loss in efficiency alone. The report needs to be explicit about this distinction. Project developers are rightfully concerned about losing MW output on hot days when the price of

[5] Telephone conversation with Bill Heins, Ionics RCC, October 2001.

power is generally highest. A properly designed ACC will not limit steam turbine MW output even on hottest days. Additional fuel will have to be consumed to maintain steam turbine output, though steam turbine output will be maintained.

The ACC efficiency penalty is limited to the annual cost of the additional fuel consumed, assuming a properly sized ACC. The CEC has estimated an average cost of natural gas over the next ten years of approximately $3.50/MMBtu. This is an appropriate value to use as a fuel cost in wet versus dry cost comparisons, regardless of temporary natural gas price spikes or pessimistic predictions regarding domestic natural gas availability. Why? LNG imports. According to an energy industry newsletter,[6] most LNG project developers expect LNG to be competitive with domestic natural gas at prices in the range of $3.25/MMBtu to $3.50/MMBtu.

Table 5-14. Lost Energy from Heat Rate Penalty

The maximum cost of electricity that is appropriate to use in this table is $50/Mw-hr minus the fuel cost associated with this busbar cost. Fuel is a major component of busbar power cost at a combined-cycle power plant, and is simply a passthrough cost for the power producer. The Western Governor's Association estimates that even at a natural gas fuel cost of nearly $5/MMBtu the cost of electricity production is less than $44/Mw-hr.[7] The use of power prices only reached during the California power "crisis" of 2000-2001 as representative prices exaggerates the cost impact of any overall heat rate penalty. We have to presume that the deregulated power industry will eventually deliver on the promise of more competitive electricity rates. A $50/Mw-hr ceiling assumes an average fuel cost of approximately $5/MMBtu and a profit of 15 percent. $50/Mw-hr is a reasonable ceiling. $30/Mw-hr is a reasonable floor, given the low end of the spot market price since the summer of 2001 has been significantly less than $30/Mw-hr.

Chapter 6. Environmental Impacts

Water Resources

Virtually all inland California power plants using wet cooling pay considerable sums for the water evaporated in the cooling tower. Virtually all inland plants have also invested considerable sums in cooling tower wastewaster treatment and disposal systems. None of these costs are addressed in the body of the report or in the Water Resources section of Chapter 6. Please see the case studies in Attachment A to assess the potential impact of these costs on the comparative cost of wet and dry cooling.

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[6] W. McNamara, *Offshore LNG Projects Increase*, online Energy Info Source, http://www.energyinfosource.com/commentary/article.cfm?article_ID=751

[7] Western Governor's Association, *Conceptual Plans for Electricity Transmission in the West*, August 2001, pg. 40.

Noise and Visual Impacts

The three most controversial issues surrounding choice of cooling systems at California power plants are noise, visual impacts, and particulate emissions (from the wet tower). The report does address the effect of optimizing the ACC for low noise operation is the following statement:

> *In the case of the Crockett Co-Generation Plant (see Appendix C), the plant is located on the outskirts of the town of Crockett in a mixed commercial/residential area with private homes located across the street to the south. On the northern boundary are the Carquinez Straits of the San Francisco Bay, a recreational and commercial boating area. Site-specific noise limits of 50 dB at the nearest residence and at a distance of 300 ft into the Bay were imposed and met with no difficulty through the use of Alpina low-noise fans.*

A similar optimization discussion on ACC height would be very helpful for the reader as well. ACC vendors provide standard ACC heights of 100 to 120 feet. These ACC heights are completely acceptable in areas with no people where visual impacts are not an issue. However, ACC height can be optimized to 70 feet or potentially less if minimum height is a critical design criterion. For example, the ACC at Crockett Cogen is only 70 feet high, although it is sitting atop a 50-foot high building. The overall height of the ACC designed for the 540 MW Otay Mesa Project, located on the outskirts of San Diego, is just under 76 feet in height.

Conventional wet towers are approximately 45 feet in height, but emit very visible vapor plumes that can be hundreds of feet high. Plume abatement towers are approximately 65 feet high, and emit vapor plumes of up to 40 feet in height on humid days. All of these height and visual resource issues need to be understood for the reader to grasp the visual impacts of the wet and dry options available.

State Regulations – Air Toxics and Particulate Emissions from Wet Towers

It should be noted that reclaimed water may be high in ammonia and that, given a typical cooling tower pH of approximately 8, considerable amounts of ammonia may be stripped in the wet tower. Ammonia is a listed air toxic compound in California and a major constituent of ammonium nitrate, one of the principal secondary "particulate less than 2.5 microns in diameter" ($PM_{2.5}$) compounds formed in the atmosphere.

Note of Caution – Use of GTPro™ to Develop Wet vs. Dry Cooling Comparisons

I used GTPro™ to compare the performance and cost of wet and dry cooling options for a proposed combined-cycle plant in September 2002. GTPro™ is not a convenient tool to use for this purpose. Many default assumptions must be overridden to develop a useful comparative picture of wet and dry performance and cost. GTPro™ inevitably will indicate both an ACC performance and power output penalty, even when the ACC if fully capable of maintaining rated steam turbine output across the ambient temperature range at a site. Costs for wet cooling tower subsystems, such as pumps, pump motors, motor starters, electrical wiring, etc., are not included in the price shown for the wet tower. Rather these costs are group by function, such as pumps, motors, starters, that include the entire plant-wide cost for that functional group of devices. The bottom line is that combined-cycle power plant

software such GTPro™ requires a relatively high degree of customization and user knowledge to produce useful comparisons of wet and dry cooling system performance and cost.

Please feel free to give me a call at (619) 295-2072 if you have any questions about my comments on the February 2002 CEC/EPRI report, *"Comparison of Alternate Cooling Technologies for California Power Plants - Economic, Environmental, and Other Tradeoffs."*

Best regards,

Bill Powers, P.E.

cc: Dr. John Maulbetsch/Maulbetsch Consulting
Matt Layton/CEC
Joe O'Hagan/CEC

Attachment A: Dry vs. Wet Cooling Cost Case Study, Luna Plant, New Mexico

A comprehensive wet cooling versus dry cooling case studies were prepared as a component of a "water conservation and power plants" white paper by a coalition group of New Mexico state agencies and environmental organizations prepared for the New Mexico Water and Natural Resources Interim Committee in September 2002. The white paper was submitted on October 1, 2002 to the Interim Committee. The case studies are based on an actual plant under construction, the 600 MW Duke Energy Luna Plant in Deming, New Mexico. Construction is about 40 percent complete and has been temporarily suspended. The white paper contains two case studies that compare a minimum cost conventional wet tower with an air-cooled condenser (ACC) for a moderately duct fired 500 MW basecase and a heavily duct fired 600 MW case. Two additional case studies were also prepared that compare a plume abatement wet tower to an ACC for the 500 MW and 600 MW scenarios. The plume abatement wet tower case studies were not included in the white paper principally to avoid "information overload." The plume abatement wet tower case studies are included in this attachment.

The Luna Plant is a natural gas fired, combined-cycle power plant. Case Study 1 assumes a plant with moderate duct firing to provide a rated power output of 500 MW. This is the most common mid-sized combined-cycle power plant configuration on a national scale. Case Study 2 assumes a plant similar in all respects to Case Study 1 except that heavy duct firing is incorporated to achieve a peak plant output of 600 MW. All of this additional power comes from the steam turbine cycle, resulting in a steam turbine and cooling system that are approximately 60 percent larger than in Case Study 1. This is the actual configuration of the Duke Energy Luna Plant in Deming. In both Case Study 1 and Case Study 2, dry cooling is more cost-effective than wet cooling under the site-specific conditions of the Deming site. It is important to note that oversizing the steam cycle to provide additional peak MW capacity results in an overall plant efficiency penalty of nearly one percent compared to a combined-cycle plant that does not incorporate duct firing. The cost-effectiveness of air cooling was more pronounced when compared to a plume abatement wet tower in Case Study 3 and Case Study 4.

The dry cooling versus wet cooling cost comparison results are summarized in Table A-1 below.

Table A-1. La Luna Plant Dry Cooling vs. Wet Cooling Case Study Cost Comparison Results

Case Study	Plant Capacity (MW)	Description	Annualized Cost of Dry Cooling ($MM/yr)	Annualized Cost of Wet Cooling ($MM/yr)
1	500	low cost conventional Douglas Fir wet tower vs. ACC	3.1	4.4
2	500	plume abatement wet tower vs.ACC	3.1	4.6
3	600	low cost conventional Douglas Fir wet tower vs. ACC	4.6	5.4
4	600	plume abatement wet tower vs.ACC	4.6	5.7

The Luna Project is unusual in the sense that it includes two independent water supply pipelines to the plant. This was done because the facility will be using both reclaimed water and groundwater, and there is insufficient reclaimed water to supply the cooling needs of the plant. Primary water supply will be groundwater from a wellfield 12 miles from the plant. Secondary water supply will be reclaimed water from the Deming wastewater treatment (WWT) plant, which Duke will upgrade to supply 1.0 Mgd of reclaimed water to plant. The pipeline from the WWT plant is sized to carry all water needed by the

plant in case the primary water supply pipeline is temporarily out of service for whatever reason. Emergency water to meet the plant's needs will be drawn from the City of Deming's water supply. The total capital cost of the WWT plant upgrade and 6-mile pipeline from the WWT to the plant is $12MM.

Initial feedback for industry on the case studies was that even though two independent water sources and pipelines may in fact be the situation at La Luna, it is not representative of most plants using water for cooling and therefore is not representative of "hypothetical typical" wet system costs. In response to this observation, the $12MM reclaimed water plant upgrade and 6-mile reclaimed water pipeline were deleted from the wet system costs. The effect of deleting this $12MM capital cost from the wet cooling system on the dry versus wet cooling cost comparison is shown in the Table A-2 below:

Table A-2. La Luna Plant "Hypothetical Typical" Dry Cooling vs. Wet Cooling Case Study Cost Comparison Results – Reclaimed Water Plant Upgrade and Pipeline Deleted

Case Study	Plant Capacity (MW)	Description	Annualized Cost of Dry Cooling ($MM/yr)	Annualized Cost of Wet Cooling ($MM/yr)
1	500	low cost conventional Douglas Fir wet tower vs. ACC	3.1	3.4
2	500	plume abatement wet tower vs.ACC	3.1	3.6
3	600	low cost conventional Douglas Fir wet tower vs. ACC	4.6	4.5
4	600	plume abatement wet tower vs.ACC	4.6	4.7

Summary

Dry cooling is considerably less expensive on an annualized cost basis than wet cooling, either conventional or plume abatement wet cooling, under the site-specific conditions at the Luna Plant for both the 500 MW and 600 MW cases (Table A-1). Dry cooling is less expensive on an annualized basis than wet cooling, either conventional or plume abatement wet cooling, under "hypothetical representative" conditions at the Luna Plant for the 500 MW case (Table A-2). The annualized cost of dry cooling and wet cooling are essentially the same, for both conventional or plume abatement wet cooling, for the "hypothetical representative" 600 MW case.

Case Study 1

Moderate Duct Fire 500 MW Gas-Fired CC Plant, Deming, NM
Conventional Wet Tower and Air-Cooled Condenser

I. Combined-Cycle Power Plant Assumptions	
Total MW output	Moderate duct fire S207FA configuration, 500 MW rating. 340 MW from two GE Frame 7FA gas turbines, 160 MW from one GE D11 steam turbine. Steam turbine capable of maintaining rated output up to 8" Hg backpressure.
Fuel	Natural gas
Peak temperature	105 ^{o}F (Deming, NM weather station historical data)
Plant capacity factor	0.7 (high for merchant plants per Power Magazine feature article, August 2002 issue)
II. Dry Cooling (Air Cooled Condenser) System Description	
Steam turbine used with ACC	GE Power Systems D11 with 33.5" last stage bucket to tolerate up to 8" Hg backpressure. (Chuck Jones, GE Power Systems, July 2002)
ACC design	30 cells, 34 ft. diameter fans, 200 hp each (149 kw). Designed for 7" Hg backpressure at 105 ^{o}F, can maintain 160 MW steam turbine rating at essentially all site temperatures. Assuming conventional fans, low noise fans not required at site. (GEA PCS, August 2002)
Annual dry cooling efficiency reduction	1.5% (CEC estimate for 510 MW air cooled Sutter Plant north of Sacramento, 106 ^{o}F peak summer temperature)
III. Wet Cooling System Description	
Steam turbine used with wet tower	GE Power Systems D11 with 40" last stage bucket to tolerate up to 5" Hg backpressure. (Chuck Jones, GE Power Systems, July 2002)
Cooling tower and surface condenser (all from Marley Cooling Tower Co.)	1a. 7-cell conventional wet tower, 48' by 54' cells 1b. 7 wet tower fans, 200 hp each (1,400 hp total) 1c. Fan electrical installation ($100/hp) 2a. Circulating water pumps designed for 120,000 gpm, 30' pump head (total of 1,300 hp pump power estimated by Powers Engineering) 2b. Water circulation piping 3. Cold water basin 4. Surface condenser 5. Piping from surface condenser to cooling tower 6. Cost of major wet tower rebuilds over 30-year lifetime
Groundwater rights	4,000 acre-ft/yr needed for continuous plant operation. 1.6 acre-ft/yr extraction allowable for industrial use under NM regulations. Purchase of 2,500 acres of agricultural land necessary. $2,000/acre is market rate. (Deming, NM city manager)
Groundwater wells and wellfield	500 ft. depth to groundwater. Assume 2,500 gpm pumping rate against 600 ft. total head to deliver to plant. (Big Sandy, AZ permit application)
Water pipeline from wells to plant	12-mile long, 20" diameter pipeline from Red Mountains to plant site. (Sempra Energy 500 MW Palomar permit application, CA: $0.8MM/mile)
Reclaimed water supply	Upgrade to Deming WWT to provide up to 1.0 Mgd of reclaimed water to plant site for use in cooling system. (Deming, NM Headlight Newspaper 8-17-02 article)
Water pipeline from WWT to plant	6-mile long, 20" diameter pipeline from Deming WWT to plant site. Pipeline capable of supplying full 3.6 Mgd plant water demand under emergency conditions. (Deming city manager, August 2002)
Cooling tower water recycle softener/RO system	Plant is zero liquid discharge. 500 gpm cooling tower blowdown is separated to recycle water and concentrated brine in water softener/RO system. Concentrated brine is sent to evaporation ponds. (Ionics RCC August 2002 e-mail, Sept. 2002 call)
Brine evaporation ponds	Receive concentrated brine. Convert to solid residue in lined outdoor evaporation ponds. (520 MW Blythe Energy Project permit application, CA)

IV. Combined-Cycle Power Plant Assumptions	
Total MW output	500 MW rating
Fuel	Natural gas
Peak temperature	105 ^{o}F
Plant capacity factor	0.7
V. Dry Cooling (Air Cooled Condenser) System - Installed Cost	
Steam turbine used with ACC	Basecase turbine, see cost impact under wet cooling system installed cost.
30-cell ACC design	$21MM with non-union labor, $24MM with union labor. (GEA PCS, August 2002)
VI. Wet Cooling System – Installed Cost	
Steam turbine used with wet tower	+2MM over basecase. (Chuck Jones, GE Power Systems, July 2002)
Cooling tower and surface condenser (all from Marley Cooling Tower Co.)	1a. $2MM 1b. included in 1a. 1c. $0.2MM 2a. $3MM 2b. $0.2MM 3. $1MM ($50/ft^2 per Marley, cold water basin dimensions 48' x 378') 4. $3MM ($3.4MM cited in 520 MW Blythe Energy Project application, CA) 5. $0.2MM 6. $1MM $11MM Total installed wet tower/condenser package
Groundwater rights	$5MM ($2,000/acre x 2,500 acres)
Groundwater wells and wellfield	$1MM (Big Sandy, AZ permit application, $1.2MM estimated for wells/wellfield for 720 MW plant)
Water pipeline from Red Mountain wells to plant	$9MM (12 miles x $0.8MM/mile)
Reclaimed water plant upgrade	$7MM (Deming, NM Headlight Newspaper 8-17-02 article)
Water pipeline from WWT to plant	$5MM (6 miles x $0.8MM/mile)
Cooling tower water recycle softener/RO system	$6MM ($8 MM installed cost – Dave Ciszewski, Ionics RCC, 09-12-02 phone interview. 860 gpm system needed for 600 MW actual site case. (use "0.6 power law" to scale down to 500 MW basecase)
Brine evaporation ponds	$3MM (520 MW Blythe Energy Project permit application, CA, $3.2MM estimated for evaporation ponds)

Total installed ACC cost (union labor): **$24MM** Amortized cost (30 yr, 7%): **$1.9MM/yr**

Total installed wet cooling system cost: **$49MM** Amortized cost (30 yr, 7%): **$3.9MM/yr**

VII. Combined-Cycle Power Plant Assumptions	
Total MW output	500 MW rating
Fuel	Natural gas
Peak temperature	105 ^{o}F
Plant capacity factor	0.7
VIII. Dry Cooling (Air Cooled Condenser) System – O&M Cost	
Steam turbine used with ACC	Basecase turbine, see cost impact under wet cooling system installed cost.
ACC fans	4,500 kw
Fuel penalty	$1,000,000/yr (assumed fuel cost is $21/MW-hr, equivalent to gas price of $3/MMBtu)
Steam turbine MW output loss	None.
IX. Wet Cooling System – O&M Cost	
Steam turbine used with wet tower	Same for both cases.
Cooling tower and surface condenser (all from Marley Cooling Tower Co.)	1a. included in 1b. 1b. 1,000 kw 1c. NA 2a. 1,000 kw 2b – 6. Unknown Annual tower maintenance: $40,000/yr Water treatment chemicals: $350,000/yr (Blythe, CA permit application) Routine labor O&M for wet towers and auxiliaries: unknown
Groundwater rights	NA
Groundwater wells and wellfield	400 kw
Water pipeline from Red Mountain wells to plant	Included in groundwater pumping parasitic load.
Reclaimed water plant upgrade	NA (O&M will be responsibility of Deming WWT Department)
Water pipeline from WWT to plant	Included in groundwater pumping parasitic load. (total water flow will be split between groundwater pumps and WWT lift station pump when reclaimed water is in use)
Cooling tower water recycle softener/RO system	2,000 kw Operating labor, 2 hr/shift, assume $40/hr loaded labor rate: $60,000/yr (Estimates provided by Ionics RCC, 08-28-02, confirmed by Ionics RCC on 09-12-02)
Brine evaporation ponds	Unknown

ACC O&M Cost Summary:	Wet Cooling System O&M Cost Summary:
Parasitic load: 4,500 kw Fuel penalty: $1,000,000/yr Operating labor: basecase	Parasitic load: 4,400 kw Fuel penalty: basecase Chemicals: $350,000 yr Operating labor: $100,000/yr

I. Dry vs. Wet Cost Comparison at Site-Specific Deming, NM Conditions

Assumptions:

1. Parasitic loads are roughly equal, assume no difference in parasitic load between options.
2. ACC option can maintain steam turbine rated output at all site temperatures, although additional fuel is required to maintain this output (1.5% annual thermal efficiency reduction).
3. A dry-cooled plant would require raw water and produce wastewater discharge, at a rate 2 to 4 percent that of wet-cooled plant. Raw water infrastructure must be built by Duke Energy from nearest City of Deming existing water line (3/4 mile away) to supply up to 200 acre-ft/yr to plant. Not-to-exceed budget for this project is $120,000. This equates to $10,000/yr at 30-year, 7%. A two-mile wastewater discharge line to nearest city tie-in will be provided by City of Deming. Average cost of raw water supplied by city is $1.20/Mgal. Maximum raw water fees are $80,000/yr. Average cost of 200 acre-ft/yr wastewater discharge is estimated at $1,500/yr, although an typical Southwestern urban wastewater discharge fee of $2/Mgal will be assumed to be conservative. Maximum wastewater discharge fees are $130,000/yr. Total water/wastewater cost associated with the dry system is $220,000/yr.

ACC Cost Summary:		**Wet Cooling System Cost Summary:**	
Amortized cost:	$1,900,000/yr	Amortized cost:	$3,900,000/yr
Fuel penalty:	$1,000,000/yr	Fuel penalty:	basecase
Operating labor:	basecase	Chemicals:	$350,000/yr
Water/wastewater:	$ 220,000/yr	Operating labor:	$100,000/yr

Total annual ACC cost: **$3,100,000/yr** Total annual wet system cost: **$4,400,000/yr**

II. Dry vs. Wet Cost Comparison with Hypothetical "Representative" Water Supply System

The Duke Energy Luna Project in Deming, NM is unusual in the sense that it includes two independent water supply pipelines to the plant. This was done because the facility will be using both reclaimed water and groundwater, and there is insufficient reclaimed water to supply the cooling needs of the plant. Primary water supply will be groundwater from a wellfield 12 miles from the plant. Secondary water supply will be reclaimed water from the Deming wastewater treatment (WWT) plant, which Duke will upgrade to supply 1.0 Mgd of reclaimed water to plant. The pipeline from the WWT plant is sized to carry all water needed by the plant in case the primary water supply pipeline is temporarily out of service for whatever reason. Emergency water to meet the plant's needs will be drawn from the City of Deming's water supply. The total capital cost of the WWT plant upgrade and 6-mile pipeline from the WWT to the plant is $12MM. Deleting this $12MM capital cost from the wet cooling system reduces the annualized wet system cost as shown in the table below:

ACC Cost Summary:		**"Representative" Wet Cooling System Cost Summary:**	
Amortized cost:	$1,900,000/yr	Amortized cost:	$3,000,000/yr
Fuel penalty:	$1,000,000/yr	Fuel penalty:	basecase
Operating labor:	basecase	Chemicals:	$350,000/yr
Water/wastewater:	$ 220,000/yr	Operating labor:	$100,000/yr

Total annual ACC cost: **$3,100,000/yr** Total annual wet system cost: **$3,400,000/yr**

Case Study 2

Moderate Duct Fire 500 MW Gas-Fired CC Plant, Deming, NM
Plume Abatement Wet Tower and Air-Cooled Condenser

X. Combined-Cycle Power Plant Assumptions	
Total MW output	Moderate duct fire S207FA configuration, 500 MW rating. 340 MW from two GE Frame 7FA gas turbines, 160 MW from one GE D11 steam turbine. Steam turbine capable of maintaining rated output up to 8" Hg backpressure.
Fuel	Natural gas
Peak temperature	105 ^{o}F (Deming, NM weather station historical data)
Plant capacity factor	0.7 (high for merchant plants per Power Magazine feature article, August 2002 issue)
XI. Dry Cooling (Air Cooled Condenser) System Description	
Steam turbine used with ACC	GE Power Systems D11 with 33.5" last stage bucket to tolerate up to 8" Hg backpressure. (Chuck Jones, GE Power Systems, July 2002)
ACC design	30 cells, 34 ft. diameter fans, 200 hp each (149 kw). Designed for 7" Hg backpressure at 105 ^{o}F, can maintain 160 MW steam turbine rating at essentially all site temperatures. Assuming conventional fans, low noise fans not required at site. (GEA PCS, August 2002)
Annual dry cooling efficiency reduction	1.5% (CEC estimate for 510 MW air cooled Sutter Plant north of Sacramento, 106 ^{o}F peak summer temperature)
XII. Wet Cooling System Description – Plume Abatement Wet Tower	
Steam turbine used with wet tower	GE Power Systems D11 with 40" last stage bucket to tolerate up to 5" Hg backpressure. (Chuck Jones, GE Power Systems, July 2002)
Cooling tower and surface condenser (all from Marley Cooling Tower Co.)	1a. 6-cell plume abatement wet tower, 54' by 60' cells 1b. 6 wet tower fans, 250 hp each (1,500 hp total) 1c. Fan electrical installation ($100/hp) 2a. Circulating water pumps designed for 120,000 gpm, 55' pump head (total of 2,400 hp pump power estimated by Powers Engineering) 2b. Water circulation piping 3. Cold water basin 4. Surface condenser 5. Piping from surface condenser to cooling tower 6. Cost of major wet tower rebuilds over 30-year lifetime
Groundwater rights	4,000 acre-ft/yr needed for continuous plant operation. 1.6 acre-ft/yr extraction allowable for industrial use under NM regulations. Purchase of 2,500 acres of agricultural land necessary. $2,000/acre is market rate. (Deming, NM city manager)
Groundwater wells and wellfield	500 ft. depth to groundwater. Assume 2,500 gpm pumping rate against 600 ft. total head to deliver to plant. (Big Sandy, AZ permit application)
Water pipeline from wells to plant	12-mile long, 20" diameter pipeline from Red Mountains to plant site. (Sempra Energy 500 MW Palomar permit application, CA: $0.8MM/mile)
Reclaimed water supply	Upgrade to Deming WWT to provide up to 1.0 Mgd of reclaimed water to plant site for use in cooling system. (Deming, NM Headlight Newspaper 8-17-02 article)
Water pipeline from WWT to plant	6-mile long, 20" diameter pipeline from Deming WWT to plant site. Pipeline capable of supplying full 3.6 Mgd plant water demand under emergency conditions. (Deming city manager, August 2002)
Cooling tower water recycle softener/RO system	Plant is zero liquid discharge. 500 gpm cooling tower blowdown is separated to recycle water and concentrated brine in water softener/RO system. Concentrated brine is sent to evaporation ponds. (Ionics RCC August 2002 e-mail, Sept. 2002 call)
Brine evaporation ponds	Receive concentrated brine. Convert to solid residue in lined outdoor evaporation ponds. (520 MW Blythe Energy Project permit application, CA)

XIII. Combined-Cycle Power Plant Assumptions	
Total MW output	500 MW rating
Fuel	Natural gas
Peak temperature	105 ^{o}F
Plant capacity factor	0.7
XIV. Dry Cooling (Air Cooled Condenser) System - Installed Cost	
Steam turbine used with ACC	Basecase turbine, see cost impact under wet cooling system installed cost.
30-cell ACC design	$21MM with non-union labor, $24MM with union labor. (GEA PCS, August 2002)
XV. Wet Cooling System – Installed Cost	
Steam turbine used with wet tower	+2MM over basecase. (Chuck Jones, GE Power Systems, July 2002)
Cooling tower and surface condenser (all from Marley Cooling Tower Co.)	1a. $4MM 1b. included in 1a. 1c. $0.2MM 2a. $3MM 2b. $0.2MM 3. $1MM ($50/ft^2 per Marley, cold water basin dimensions 48' x 378') 4. $3MM ($3.4MM cited in 520 MW Blythe Energy Project application, CA) 5. $0.2MM 6. $1MM $13MM Total installed wet tower/condenser package
Groundwater rights	$5MM ($2,000/acre x 2,500 acres)
Groundwater wells and wellfield	$1MM (Big Sandy, AZ permit application, $1.2MM estimated for wells/wellfield for 720 MW plant)
Water pipeline from Red Mountain wells to plant	$9MM (12 miles x $0.8MM/mile)
Reclaimed water plant upgrade	$7MM (Deming, NM Headlight Newspaper 8-17-02 article)
Water pipeline from WWT to plant	$5MM (6 miles x $0.8MM/mile)
Cooling tower water recycle softener/RO system	$6MM ($8 MM installed cost – Dave Ciszewski, Ionics RCC, 09-12-02 phone interview. 860 gpm system needed for 600 MW actual site case. (use "0.6 power law" to scale down to 500 MW basecase)
Brine evaporation ponds	$3MM (520 MW Blythe Energy Project permit application, CA, $3.2MM estimated for evaporation ponds)

Total installed ACC cost (union labor): **$24MM** Amortized cost (30 yr, 7%): **$1.9MM/yr**

Total installed wet cooling system cost: **$51MM** Amortized cost (30 yr, 7%): **$4.1MM/yr**

XVI. Combined-Cycle Power Plant Assumptions	
Total MW output	500 MW rating
Fuel	Natural gas
Peak temperature	105 ^{o}F
Plant capacity factor	0.7
XVII. Dry Cooling (Air Cooled Condenser) System – O&M Cost	
Steam turbine used with ACC	Basecase turbine, see cost impact under wet cooling system installed cost.
ACC fans	4,500 kw
Fuel penalty	$1,000,000/yr (assumed fuel cost is $21/MW-hr, equivalent to gas price of $3/MMBtu)
Steam turbine MW output loss	None.
XVIII. Wet Cooling System – O&M Cost	
Steam turbine used with wet tower	Same for both cases.
Cooling tower and surface condenser (all from Marley Cooling Tower Co.)	1a. included in 1b. 1b. 1,100 kw 1c. NA 2a. 1,800 kw 2b – 6. Unknown Annual tower maintenance: $50,000/yr Water treatment chemicals: $350,000/yr (Blythe, CA permit application) Routine labor O&M for wet towers and auxiliaries: unknown
Groundwater rights	NA
Groundwater wells and wellfield	400 kw
Water pipeline from Red Mountain wells to plant	Included in groundwater pumping parasitic load.
Reclaimed water plant upgrade	NA (O&M will be responsibility of Deming WWT Department)
Water pipeline from WWT to plant	Included in groundwater pumping parasitic load. (total water flow will be split between groundwater pumps and WWT lift station pump when reclaimed water is in use)
Cooling tower water recycle softener/RO system	2,000 kw Operating labor, 2 hr/shift, assume $40/hr loaded labor rate: $60,000/yr (Estimates provided by Ionics RCC, 08-28-02, confirmed by Ionics RCC on 09-12-02)
Brine evaporation ponds	Unknown

ACC O&M Cost Summary:	Plume Abated Wet Cooling System O&M Cost Summary:
Parasitic load: 4,500 kw Fuel penalty: $1,000,000/yr Operating labor: basecase	Parasitic load: 5,300 kw Fuel penalty: basecase Chemicals: $350,000 yr Operating labor: $140,000/yr

I. Dry vs. Wet Cost Comparison at Site-Specific Deming, NM Conditions

Assumptions:

1. The plume abatement wet system has a higher parasitic load by 800 kw compared to ACC (5,300 kw vs. 4,500 kw). Multiply reasonable net revenue on power sold of $0.005/kw-hr (net profit after subtracting out fuel cost and fixed costs), or $5/MW-hr, to calculate lost profit due to parasitic load, assuming spot wholesale electricity price in $30/MW-hr to $40/MW-hr range.
2. ACC option can maintain steam turbine rated output at all site temperatures, although additional fuel is required to maintain this output (1.5% annual thermal efficiency reduction).
3. A dry-cooled plant would require raw water and produce wastewater discharge, at a rate 2 to 4 percent that of wet-cooled plant. Raw water infrastructure must be built by Duke Energy from nearest City of Deming existing water line (3/4 mile away) to supply up to 200 acre-ft/yr to plant. Not-to-exceed budget for this project is $120,000. This equates to $10,000/yr at 30-year, 7%. A two-mile wastewater discharge line to nearest city tie-in will be provided by City of Deming. Average cost of raw water supplied by city is $1.20/Mgal. Maximum raw water fees are $80,000/yr. Average cost of 200 acre-ft/yr wastewater discharge is estimated at $1,500/yr, although an typical Southwestern urban wastewater discharge fee of $2/Mgal will be assumed to be conservative. Maximum wastewater discharge fees are $130,000/yr. Total water/wastewater cost associated with the dry system is $220,000/yr.

ACC Cost Summary:		**Wet Cooling System Cost Summary:**	
Amortized cost:	$1,900,000/yr	Amortized cost:	$4,100,000/yr
Fuel penalty:	$1,000,000/yr	Fuel penalty:	basecase
Operating labor:	basecase	Chemicals:	$350,000/yr
Water/wastewater:	$ 220,000/yr	Operating labor:	$140,000/yr
		Parasitic load:	$25,000/yr

Total annual ACC cost: **$3,100,000/yr** Total annual wet system cost: **$4,600,000/yr**

II. Dry vs. Wet Cost Comparison with Hypothetical "Representative" Water Supply System

The Duke Energy Luna Project in Deming, NM is unusual in the sense that it includes two independent water supply pipelines to the plant. This was done because the facility will be using both reclaimed water and groundwater, and there is insufficient reclaimed water to supply the cooling needs of the plant. Primary water supply will be groundwater from a wellfield 12 miles from the plant. Secondary water supply will be reclaimed water from the Deming wastewater treatment (WWT) plant, which Duke will upgrade to supply 1.0 Mgd of reclaimed water to plant. The pipeline from the WWT plant is sized to carry all water needed by the plant in case the primary water supply pipeline is temporarily out of service for whatever reason. Emergency water to meet the plant's needs will be drawn from the City of Deming's water supply. The total capital cost of the WWT plant upgrade and 6-mile pipeline from the WWT to the plant is $12MM. Deleting this $12MM capital cost from the wet cooling system reduces the annualized wet system cost as shown in the table below:

ACC Cost Summary:		**Plume Abatement Wet Cooling System Cost Summary:**	
Amortized cost:	$1,900,000/yr	Amortized cost:	$3,100,000/yr
Fuel penalty:	$1,000,000/yr	Fuel penalty:	basecase
Operating labor:	basecase	Chemicals:	$350,000/yr
Water/wastewater:	$ 220,000/yr	Operating labor:	$140,000/yr
		Parasitic load:	$25,000/yr

Total annual ACC cost: **$3,100,000/yr** Total annual wet system cost: **$3,600,000/yr**

Case Study 3

Heavy Duct Fired 600 MW Gas-Fired CC Plant, Deming, NM
Conventional Wet Tower and Air-Cooled Condenser

XIX. Combined-Cycle Power Plant Assumptions	
Total MW output	Heavy duct fire S207FA configuration, 600 MW rating. 340 MW from two GE Frame 7FA gas turbines, 260 MW from one GE D11 steam turbine. Steam turbine capable of maintaining rated output up to 8" Hg backpressure.
Fuel	Natural gas
Peak temperature	105 ^{o}F (Deming, NM weather station historical data)
Plant capacity factor	0.7 (high for merchant plants per Power Magazine feature article, August 2002 issue)
XX. Dry Cooling (Air Cooled Condenser) System Description	
Steam turbine used with ACC	GE Power Systems D11 with 33.5" last stage bucket to tolerate up to 8" Hg backpressure. (Chuck Jones, GE Power Systems, July 2002)
ACC design	50 cells, 34 ft. diameter fans, 200 hp each (149 kw). Designed for 7" Hg backpressure at 105 ^{o}F, can maintain 260 MW steam turbine rating at essentially all site temperatures. Assuming conventional fans, low noise fans not required at site. (GEA PCS, August 2002)
Annual dry cooling efficiency reduction	1.5% (CEC estimate for 510 MW air cooled Sutter Plant north of Sacramento, 106 ^{o}F peak summer temperature)
XXI. Wet Cooling System Description	
Steam turbine used with wet tower	GE Power Systems D11 with 40" last stage bucket to tolerate up to 5" Hg backpressure. (Chuck Jones, GE Power Systems, July 2002)
Cooling tower and surface condenser (all from Marley Cooling Tower Co.)	1a. 11-cell conventional wet tower, 48' by 54' cells 1b. 11 wet tower fans, 200 hp each (2,200 hp total) 1c. Fan electrical installation ($100/hp) 2a. Circulating water pumps designed for 190,000 gpm, 30' pump head (total of 2,100 hp pump power estimated by Powers Engineering) 2b. Water circulation piping 3. Cold water basin 4. Surface condenser 5. Piping from surface condenser to cooling tower 6. Cost of major wet tower rebuilds over 30-year lifetime
Groundwater rights	6,500 acre-ft/yr needed for continuous plant operation. 1.6 acre-ft/yr extraction allowable for industrial use under NM regulations. Purchase of 4,000 acres of agricultural land necessary. $2,000/acre is market rate. (Deming, NM city manager)
Groundwater wells and wellfield	500 ft. depth to groundwater. Assume 4,000 gpm pumping rate against 600 ft. total head to deliver to plant. (Big Sandy, AZ permit application)
Water pipeline from wells to plant	12-mile long, 24" diameter pipeline from Red Mountains to plant site. (Sempra Energy 500 MW Palomar permit application, CA: $0.8MM/mile)
Reclaimed water supply	Upgrade to Deming WWT to provide up to 1.0 Mgd of reclaimed water to plant site for use in cooling system. (Deming, NM Headlight Newspaper 8-17-02 article)
Water pipeline from WWT to plant	6-mile long, 24" diameter pipeline from Deming WWT to plant site. Pipeline capable of supplying full 5.8 Mgd plant water demand under emergency conditions. (Deming city manager, August 2002)
Cooling tower water recycle softener/RO system	Plant is zero liquid discharge. 860 gpm cooling tower blowdown is separated to recycle water and concentrated brine in water softener/reverse osmosis system. 80 gpm concentrated brine is sent to evaporation ponds. (Ionics RCC 8/02 and 9/02)
Brine evaporation ponds	Receive concentrated brine. Convert to solid residue in lined outdoor evaporation ponds. (520 MW Blythe Energy Project permit application, CA)

XXII. Combined-Cycle Power Plant Assumptions	
Total MW output	600 MW rating
Fuel	Natural gas
Peak temperature	105 ^{o}F
Plant capacity factor	0.7
XXIII. Dry Cooling (Air Cooled Condenser) System - Installed Cost	
Steam turbine used with ACC	Basecase turbine, see cost impact under wet cooling system installed cost.
50-cell ACC design	$35MM with non-union labor, $40MM with union labor. (GEA PCS, August 2002)
XXIV. Wet Cooling System – Installed Cost	
Steam turbine used with wet tower	+2MM over basecase. (Chuck Jones, GE Power Systems, July 2002)
Cooling tower and surface condenser (all from Marley Cooling Tower Co.)	1a. $3MM (use "0.6 power law" to scale from 500 MW basecase. 1.3 multiplier) 1b. included in 1a. 1c. $0.3MM 2a. $4MM (use "0.6 power law" to scale from 500 MW basecase. 1.3 multiplier) 2b. $0.3MM 3. $2MM ($50/ft^2 cold water basin, 11 cells, 54' x 600' basin dimensions) 4. $4MM (use "0.6 power law" to scale from 500 MW basecase. 1.3 multiplier) 5. $0.3MM 6. $1MM $15MM Total installed wet tower/condenser package
Groundwater rights	$8MM ($2,000/acre x 4,000 acres)
Groundwater wells and wellfield	$1MM (Big Sandy, AZ permit application, $1.2MM estimated for wells/wellfield for 720 MW plant)
Water pipeline from Red Mountain wells to plant	$9MM (12 miles x $0.8MM/mile, assume change from 20" to 24" pipe does not impact price significantly)
Reclaimed water plant upgrade	$7MM (Deming, NM Headlight Newspaper 8-17-02 article)
Water pipeline from WWT to plant	$5MM (6 miles x $0.8MM/mile, assume change from 20" to 24" pipe does not impact price significantly)
Cooling tower water recycle softener/RO system	$8MM ($8 MM installed cost – Dave Ciszewski, Ionics RCC, 09-12-02 phone interview. 860 gpm system needed for 600 MW actual site case. (use "0.6 power law" to scale down to 500 MW basecase)
Brine evaporation ponds	$4MM (520 MW Blythe Energy Project permit application, CA, $3.2MM estimated for evaporation ponds, use "0.6 power law" to scale from 500 MW basecase.)

Total installed ACC cost (union labor): **$40MM** Amortized cost (30 yr, 7%): **$3.2MM/yr**

Total installed wet cooling system cost: **$59MM** Amortized cost (30 yr, 7%): **$4.7MM/yr**

XXV. Combined-Cycle Power Plant Assumptions	
Total MW output	600 MW rating
Fuel	Natural gas
Peak temperature	105 ^{o}F
Plant capacity factor	0.7
XXVI. Dry Cooling (Air Cooled Condenser) System – O&M Cost	
Steam turbine used with ACC	Basecase turbine, see cost impact under wet cooling system installed cost.
ACC fans	7,450 kw
Fuel penalty	$1,200,000/yr (assumed fuel cost is $21/MW-hr, equivalent to gas price of $3/MMBtu)
Steam turbine MW output loss	None.
XXVII. Wet Cooling System – O&M Cost	
Steam turbine used with wet tower	Same for both cases.
Cooling tower and surface condenser (all from Marley Cooling Tower Co.)	1a. included in 1b. 1b. 1,600 kw 1c. NA 2a. 1,600 kw 2b – 6. Unknown Annual tower maintenance: $60,000/yr Water treatment chemicals: $550,000/yr (linear scale-up from 500 MW case) Routine labor O&M for wet towers and auxiliaries: unknown
Groundwater rights	NA
Groundwater wells and wellfield	600 kw
Water pipeline from Red Mountain wells to plant	Included in groundwater pumping parasitic load.
Reclaimed water plant upgrade	NA (O&M will be responsibility of Deming WWT Department)
Water pipeline from WWT to plant	Included in groundwater pumping parasitic load. (total water flow will be split between groundwater pumps and WWT lift station pump when reclaimed water is in use)
Cooling tower water recycle softener/RO system	3,600 kw (09-12-02 Ionics RCC phone interview) Operating labor, 3 hr/shift, assume $40/hr loaded labor rate: $130,000/yr
Brine evaporation ponds	Unknown

ACC O&M Cost Summary:	**Wet Cooling System O&M Cost Summary:**
Parasitic load: 7,450 kw Fuel penalty: $1,200,000/yr Operating labor: basecase	Parasitic load: 7,400 kw Fuel penalty: basecase Chemicals: $550,000 yr Operating labor: $190,000/yr

I. Dry vs. Wet Cost Comparison at Site-Specific Deming, NM Conditions

Assumptions:

1. Parasitic loads are roughly equal, assume no difference in parasitic load between options.
2. ACC option can maintain steam turbine rated output at all site temperatures, although additional fuel is required to maintain this output (1.5% annual thermal efficiency reduction).
3. A dry-cooled plant would require raw water and produce wastewater discharge, at a rate 2 to 4 percent that of wet-cooled plant. Raw water infrastructure must be built by Duke Energy from nearest City of Deming existing water line (3/4 mile away) to supply up to 200 acre-ft/yr to plant. Not-to-exceed budget for this project is $120,000. This equates to $10,000/yr at 30-year, 7%. A two-mile wastewater discharge line to nearest city tie-in will be provided by City of Deming. Average cost of raw water supplied by city is $1.20/Mgal. Maximum raw water fees are $80,000/yr. Average cost of 200 acre-ft/yr wastewater discharge is estimated at $1,500/yr, although an typical Southwestern urban wastewater discharge fee of $2/Mgal will be assumed to be conservative. Maximum wastewater discharge fees are $130,000/yr. Total water/wastewater cost associated with the dry system is $220,000/yr.

ACC Cost Summary:		**Wet Cooling System Cost Summary:**	
Amortized cost:	$3,200,000/yr	Amortized cost:	$4,700,000/yr
Fuel penalty:	$1,200,000/yr	Fuel penalty:	basecase
Operating labor:	basecase	Chemicals:	$550,000/yr
Water/wastewater:	$ 220,000/yr	Operating labor:	$190,000/yr

Total annual ACC cost: **$4,600,000/yr** Total annual wet system cost: **$5,400,000/yr**

II. Dry vs. Wet Cost Comparison with Hypothetical "Representative" Water Supply System

The Duke Energy Luna Project in Deming, NM is unusual in the sense that it includes two independent water supply pipelines to the plant. This was done because the facility will be using both reclaimed water and groundwater, and there is insufficient reclaimed water to supply the cooling needs of the plant. Primary water supply will be groundwater from a wellfield 12 miles from the plant. Secondary water supply will be reclaimed water from the Deming wastewater treatment (WWT) plant, which Duke will upgrade to supply 1.0 Mgd of reclaimed water to plant. The pipeline from the WWT plant is sized to carry all water needed by the plant in case the primary water supply pipeline is temporarily out of service for whatever reason. Emergency water to meet the plant's needs will be drawn from the City of Deming's water supply. The total capital cost of the WWT plant upgrade and 6-mile pipeline from the WWT to the plant is $12MM. Deleting this $12MM capital cost from the wet cooling system reduces the annualized wet system cost as shown in the table below:

ACC Cost Summary:		**"Representative" Wet Cooling System Cost Summary:**	
Amortized cost:	$3,200,000/yr	Amortized cost:	$3,800,000/yr
Fuel penalty:	$1,200,000/yr	Fuel penalty:	basecase
Operating labor:	basecase	Chemicals:	$550,000/yr
Water/wastewater:	$ 220,000/yr	Operating labor:	$190,000/yr

Total annual ACC cost: **$4,600,000/yr** Total annual wet system cost: **$4,500,000/yr**

Case Study 4

Heavy Duct Fired 600 MW Gas-Fired CC Plant, Deming, NM
Plume Abatement Wet Tower and Air-Cooled Condenser

XXVIII. Combined-Cycle Power Plant Assumptions	
Total MW output	Heavy duct fire S207FA configuration, 600 MW rating. 340 MW from two GE Frame 7FA gas turbines, 260 MW from one GE D11 steam turbine. Steam turbine capable of maintaining rated output up to 8" Hg backpressure.
Fuel	Natural gas
Peak temperature	105 ^{o}F (Deming, NM weather station historical data)
Plant capacity factor	0.7 (high for merchant plants per Power Magazine feature article, August 2002 issue)
XXIX. Dry Cooling (Air Cooled Condenser) System Description	
Steam turbine used with ACC	GE Power Systems D11 with 33.5" last stage bucket to tolerate up to 8" Hg backpressure. (Chuck Jones, GE Power Systems, July 2002)
ACC design	50 cells, 34 ft. diameter fans, 200 hp each (149 kw). Designed for 7" Hg backpressure at 105 ^{o}F, can maintain 260 MW steam turbine rating at essentially all site temperatures. Assuming conventional fans, low noise fans not required at site. (GEA PCS, August 2002)
Annual dry cooling efficiency reduction	1.5% (CEC estimate for 510 MW air cooled Sutter Plant north of Sacramento, 106 ^{o}F peak summer temperature)
XXX. Wet Cooling System Description	
Steam turbine used with wet tower	GE Power Systems D11 with 40" last stage bucket to tolerate up to 5" Hg backpressure. (Chuck Jones, GE Power Systems, July 2002)
Cooling tower and surface condenser (all from Marley Cooling Tower Co.)	1a. 10-cell plume abatement wet tower, 54' by 60' cells 1b. 10 wet tower fans, 250 hp each (2,500 hp total) 1c. Fan electrical installation ($100/hp) 2a. Circulating water pumps designed for 190,000 gpm, 55' pump head (total of 3,800 hp pump power estimated by Powers Engineering) 2b. Water circulation piping 3. Cold water basin 4. Surface condenser 5. Piping from surface condenser to cooling tower 6. Cost of major wet tower rebuilds over 30-year lifetime
Groundwater rights	6,500 acre-ft/yr needed for continuous plant operation. 1.6 acre-ft/yr extraction allowable for industrial use under NM regulations. Purchase of 4,000 acres of agricultural land necessary. $2,000/acre is market rate. (Deming, NM city manager)
Groundwater wells and wellfield	500 ft. depth to groundwater. Assume 4,000 gpm pumping rate against 600 ft. total head to deliver to plant. (Big Sandy, AZ permit application)
Water pipeline from wells to plant	12-mile long, 24" diameter pipeline from Red Mountains to plant site. (Sempra Energy 500 MW Palomar permit application, CA: $0.8MM/mile)
Reclaimed water supply	Upgrade to Deming WWT to provide up to 1.0 Mgd of reclaimed water to plant site for use in cooling system. (Deming, NM Headlight Newspaper 8-17-02 article)
Water pipeline from WWT to plant	6-mile long, 24" diameter pipeline from Deming WWT to plant site. Pipeline capable of supplying full 5.8 Mgd plant water demand under emergency conditions. (Deming city manager, August 2002)
Cooling tower water recycle softener/RO system	Plant is zero liquid discharge. 860 gpm cooling tower blowdown is separated to recycle water and concentrated brine in water softener/reverse osmosis system. 80 gpm concentrated brine is sent to evaporation ponds. (Ionics RCC 8/02 and 9/02)
Brine evaporation ponds	Receive concentrated brine. Convert to solid residue in lined outdoor evaporation ponds. (520 MW Blythe Energy Project permit application, CA)

XXXI. Combined-Cycle Power Plant Assumptions	
Total MW output	600 MW rating
Fuel	Natural gas
Peak temperature	105 ^{o}F
Plant capacity factor	0.7
XXXII. Dry Cooling (Air Cooled Condenser) System - Installed Cost	
Steam turbine used with ACC	Basecase turbine, see cost impact under wet cooling system installed cost.
50-cell ACC design	$35MM with non-union labor, $40MM with union labor. (GEA PCS, August 2002)
XXXIII. Wet Cooling System – Installed Cost	
Steam turbine used with wet tower	+2MM over basecase. (Chuck Jones, GE Power Systems, July 2002)
Cooling tower and surface condenser (all from Marley Cooling Tower Co. Marley confirmed scaling factor approach is accurate)	1a. $5MM (use "0.6 power law" to scale from 500 MW basecase. 1.3 multiplier) 1b. included in 1a. 1c. $0.3MM 2a. $4MM (use "0.6 power law" to scale from 500 MW basecase. 1.3 multiplier) 2b. $0.3MM 3. $2MM ($50/ft^2 cold water basin, 54' x 600' basin dimensions) 4. $4MM (use "0.6 power law" to scale from 500 MW basecase. 1.3 multiplier) 5. $0.3MM 6. $1MM $17MM Total installed wet tower/condenser package
Groundwater rights	$8MM ($2,000/acre x 4,000 acres)
Groundwater wells and wellfield	$1MM (Big Sandy, AZ permit application, $1.2MM estimated for wells/wellfield for 720 MW plant)
Water pipeline from Red Mountain wells to plant	$9MM (12 miles x $0.8MM/mile, assume change from 20" to 24" pipe does not impact price significantly)
Reclaimed water plant upgrade	$7MM (Deming, NM Headlight Newspaper 8-17-02 article)
Water pipeline from WWT to plant	$5MM (6 miles x $0.8MM/mile, assume change from 20" to 24" pipe does not impact price significantly)
Cooling tower water recycle softener/RO system	$8MM ($8 MM installed cost – Dave Ciszewski, Ionics RCC, 09-12-02 phone interview. 860 gpm system needed for 600 MW actual site case. (use "0.6 power law" to scale down to 500 MW basecase)
Brine evaporation ponds	$4MM (520 MW Blythe Energy Project permit application, CA, $3.2MM estimated for evaporation ponds, use "0.6 power law" to scale from 500 MW basecase.)

Total installed ACC cost (union labor): **$40MM** Amortized cost (30 yr, 7%): **$3.2MM/yr**

Total installed wet cooling system cost: **$61MM** Amortized cost (30 yr, 7%): **$4.9MM/yr**

XXXIV. Combined-Cycle Power Plant Assumptions	
Total MW output	600 MW rating
Fuel	Natural gas
Peak temperature	105 ^{o}F
Plant capacity factor	0.7
XXXV. Dry Cooling (Air Cooled Condenser) System – O&M Cost	
Steam turbine used with ACC	Basecase turbine, see cost impact under wet cooling system installed cost.
ACC fans	7,450 kw
Fuel penalty	$1,200,000/yr (assumed fuel cost is $21/MW-hr, equivalent to gas price of $3/MMBtu)
Steam turbine MW output loss	None.
XXXVI. Wet Cooling System – O&M Cost	
Steam turbine used with wet tower	Same for both cases.
Cooling tower and surface condenser (all from Marley Cooling Tower Co.)	1a. included in 1b. 1b. 1,900 kw 1c. NA 2a. 2,800 kw 2b – 6. Unknown Annual tower maintenance: $80,000/yr Water treatment chemicals: $550,000/yr (linear scale-up from 500 MW case) Routine labor O&M for wet towers and auxiliaries: unknown
Groundwater rights	NA
Groundwater wells and wellfield	600 kw
Water pipeline from Red Mountain wells to plant	Included in groundwater pumping parasitic load.
Reclaimed water plant upgrade	NA (O&M will be responsibility of Deming WWT Department)
Water pipeline from WWT to plant	Included in groundwater pumping parasitic load. (total water flow will be split between groundwater pumps and WWT lift station pump when reclaimed water is in use)
Cooling tower water recycle softener/RO system	3,600 kw (09-12-02 Ionics RCC phone interview) Operating labor, 3 hr/shift, assume $40/hr loaded labor rate: $130,000/yr
Brine evaporation ponds	Unknown

ACC O&M Cost Summary:	Wet Cooling System O&M Cost Summary:
Parasitic load: 7,450 kw Fuel penalty: $1,200,000/yr Operating labor: basecase	Parasitic load: 8,900 kw Fuel penalty: basecase Chemicals: $550,000 yr Operating labor: $210,000/yr

I. Dry vs. Wet Cost Comparison at Site-Specific Deming, NM Conditions

Assumptions:

1. The plume abatement wet system has a higher parasitic load by 1,850 kw compared to ACC (9,300 kw vs. 7,450 kw). Multiply reasonable net revenue on power sold of $0.005/kw-hr (net profit after subtracting out fuel cost and fixed costs), or $5/MW-hr, to calculate lost profit due to parasitic load, assuming spot wholesale electricity price in $30/MW-hr to $40/MW-hr range.
2. ACC option can maintain steam turbine rated output at all site temperatures, although additional fuel is required to maintain this output (1.5% annual thermal efficiency reduction).
3. A dry-cooled plant would require raw water and produce wastewater discharge, at a rate 2 to 4 percent that of wet-cooled plant. Raw water infrastructure must be built by Duke Energy from nearest City of Deming existing water line (3/4 mile away) to supply up to 200 acre-ft/yr to plant. Not-to-exceed budget for this project is $120,000. This equates to $10,000/yr at 30-year, 7%. A two-mile wastewater discharge line to nearest city tie-in will be provided by City of Deming. Average cost of raw water supplied by city is $1.20/Mgal. Maximum raw water fees are $80,000/yr. Average cost of 200 acre-ft/yr wastewater discharge is estimated at $1,500/yr, although an typical Southwestern urban wastewater discharge fee of $2/Mgal will be assumed to be conservative. Maximum wastewater discharge fees are $130,000/yr. Total water/wastewater cost associated with the dry system is $220,000/yr.

ACC Cost Summary:		**Wet Cooling System Cost Summary:**	
Amortized cost:	$3,200,000/yr	Amortized cost:	$4,900,000/yr
Fuel penalty:	$1,200,000/yr	Fuel penalty:	basecase
Operating labor:	basecase	Chemicals:	$550,000/yr
Water/wastewater:	$ 220,000/yr	Operating labor:	$210,000/yr
		Parasitic load:	$40,000/yr

Total annual ACC cost: **$4,600,000/yr** Total annual wet system cost: **$5,700,000/yr**

II. Dry vs. Wet Cost Comparison with Hypothetical "Representative" Water Supply System

The Duke Energy Luna Project in Deming, NM is unusual in the sense that it includes two independent water supply pipelines to the plant. This was done because the facility will be using both reclaimed water and groundwater, and there is insufficient reclaimed water to supply the cooling needs of the plant. Primary water supply will be groundwater from a wellfield 12 miles from the plant. Secondary water supply will be reclaimed water from the Deming wastewater treatment (WWT) plant, which Duke will upgrade to supply 1.0 Mgd of reclaimed water to plant. The pipeline from the WWT plant is sized to carry all water needed by the plant in case the primary water supply pipeline is temporarily out of service for whatever reason. Emergency water to meet the plant's needs will be drawn from the City of Deming's water supply. The total capital cost of the WWT plant upgrade and 6-mile pipeline from the WWT to the plant is $12MM. Deleting this $12MM capital cost from the wet cooling system reduces the annualized wet system cost as shown in the table below:

ACC Cost Summary:		**"Representative" Wet Cooling System Cost Summary:**	
Amortized cost:	$3,200,000/yr	Amortized cost:	$3,900,000/yr
Fuel penalty:	$1,200,000/yr	Fuel penalty:	basecase
Operating labor:	basecase	Chemicals:	$550,000/yr
Water/wastewater:	$ 220,000/yr	Operating labor:	$210,000/yr
		Parasitic load:	$40,000/yr

Total annual ACC cost: **$4,600,000/yr** Total annual wet system cost: **$4,700,000/yr**