Thermal Electric Power Plant Water Uses; Improvements Promote Sustainability and Increase Profits

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Preface

This paper includes research conducted by LimnoTech sponsored by the Electric Power Research Institute. It represents information extracted from a more comprehensive report entitled "Program on Technology Innovation: An Energy/Water Sustainability Research Program for the Electric Power Industry" (EPRI 2007). Any citations or more in-depth information is best directed to this document.

Background

The electric power industry requires reliable supplies of water for cooling, for flue gas treatment, and for ash handling. Power generators account for about 40% of U.S. freshwater withdrawals (USGS, 2004). Even though this amounts to only about 3% of freshwater consumption, (because most of the water withdrawn is returned) this still represents a significant water resource need. As population grows, so does the demand for electric power and related water. This demand will compete with demands for water used for agricultural, municipal, residential, commercial, and industrial uses. According to a 2003 GAO report, 46 states expect water shortages during the next 10 years under drought conditions (GAO 2003). As competing demands for water increase, the electric power industry will need to develop technologies to improve their water efficiencies, in order to have a sustainable water-energy model.

Water use at individual plants can be significant. Many older plants still use once-through cooling, which heats large volumes of water and then returns those waters with minimal loss to the environment. Table 1 shows typical water withdrawal and consumption values for once-through cooling systems. For newer installations, improved efficiencies have been gained by using cooling towers, recirculating cooling systems, and other technology improvements.

Table 1: Cooling Water Withdrawal and Consumption (Evaporation to the Atmosphere) Rates for Power Plants Using Fossil, Biomass, or Waste as Fuel

Cooling System Type	Water Withdrawal (gal/MWh)	Water Consumption (gal/MWh)
Once Through Cooling	20,000 to 50,000	~300
Cooling Towers	500 to 600	~480

To the credit of the industry, a changing mix of once-through and recirculating cooling systems, in addition to water-conserving improvements, has enabled the electric power industry to reduce its water withdrawals per unit of power generated by a factor of three, from 63,000 gal/MWh in

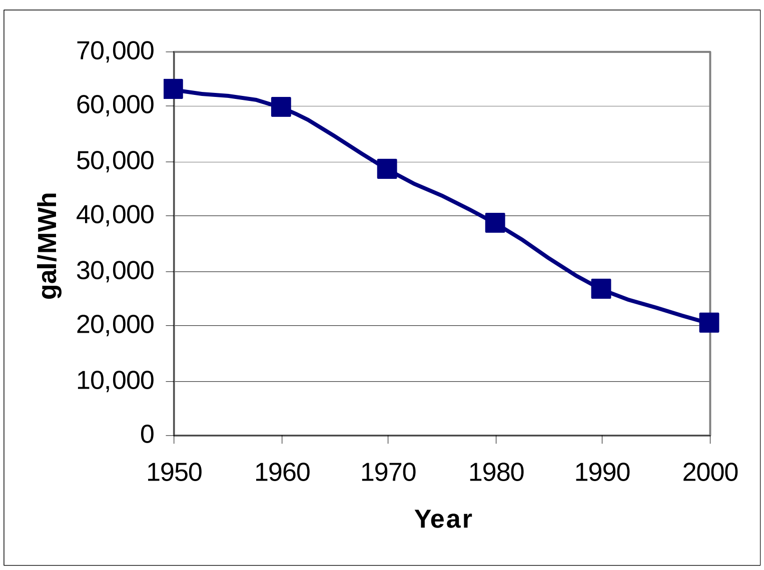
1950 to 21,000 gal/MWh in 2000. Over the same period, the industry has increased its output of electric power by a factor of 15. Therefore, the net result was a 5-fold increase in water withdrawals by the electric power industry. However, all of the increases occurred before 1980: water withdrawals by the industry have actually declined since 1980 . These trends are shown in Table 2 and Figure 1 below.

Table 2: Water Withdrawals, Power Generated, and Improvement in Water Withdrawal Efficiency, 1950 – 2000

	1950	1960	1970	1980	1990	2000
Water Withdrawals (Billion gallons)	14,500	36,500	62,100	77,000	71,000	71,000
Power Generated (Billion MWh)	0.23	0.61	1.28	2.00	2.68	3.45
Water Withdrawal Efficiency (gal/MWh)	63,000	60,000	49,000	39,000	27,000	21,000

Source: USGS 2004; Energy Information Administration 2004

Figure 1: Trend in U.S. Thermoelectric Power Water Withdrawal Efficiency, 1950-2000



The issue of water availability and the choice of cooling technologies is generally a second-tier consideration in planning for new plants or plant expansions. New plants or expansions are primarily dictated by electric power demand forecasts and consideration of where fuel, transmission capacity, and demand are aligned. Hence, a location without sufficient water supply might require significant improvements in water use technology, different cooling technologies, or finding alternative water supplies, such as waste water from municipal sources. Hence the issue of water use efficiency becomes more of an economic issue of how to get a plant operating profitably, rather than an environmental issue of where the most sustainable natural water source is available.

The costs associated with water use are not trivial and can represent a significant economic profit factor for a typical plant. For example shown in Table 3 are the costs associated with acquiring, delivering, and treating/disposing of water used in power production. For a typical plant of say, 350 MW these costs can be on the order of $6 million. Totals in Table 3 are not column sums; rather they represent approximate bounds or total costs combinations encountered at real plant sites.

Table 3: Representative Costs of Acquiring, Transporting, and Treating/Disposing of Water ($/kgal)

Component	Low	Medium	High
Acquire	$ 0.50	$ 1.25	$ 3.00
Deliver	$ 0.13	$ 0.57	$ 1.20
Treat/Dispose	$ 0.22	$ 1.00	$ 4.28
Total	$ 1.00	$ 2.82	$ 4.00

Hydroelectric power accounts for 5-10% of U.S. power generation, with the output depending on water flows generated by precipitation and resulting runoff and snowmelt. For example the 2003 European heat wave demonstrated how susceptible hydro power is to drought conditions, where hydropower generation capacity in France was reduced by about 20%. In combination with a loss of nuclear generation capacity due to heat discharge restrictions, the shortfall in hydropower generation during a time of peak demand was challenging. Although this is a significant issue, it is not addressed in this paper.

This paper addresses the benefits of improving water efficiencies at thermal electric power plants in the areas of water reuse and recovery; use of nontraditional water sources; and use of advanced cooling technologies. This work was supported by the Electric Power Research Institute and is reported on in more detail and covering other related issues in a more lengthy report. (EPRI 2007)

Benefits of Water Reuse and Recovery

Recirculating cooling systems require much lower flows than once-through systems, but consume more water due to evaporation. In addition, water may be consumed by flue gas scrubbing and lost due to cooling tower blowdown. Technology development could reduce losses from each of these processes, as discussed below related to evaporation, blowdown and flue gas scrubbing.

Evaporation

Evaporation represents the largest water loss from recirculating towers, roughly 480 gal/MWh for a coal-fired power plant, and also the greatest opportunity for savings (EPRI 2002). Evaporative losses can be reduced if water vapor can be condensed and returned to the cooling system. Small-scale tests of one technology, which uses cross-currents of ambient air for condensation, show potential to capture 12-30% of evaporative losses when translated into full scale, reducing losses by about 60-140 gal/MWh, with the higher end of this loss range applying to hotter climates (Mortenson 2006.).

This reduction in water losses can be translated into dollar savings at the plant level by assuming a cost of water and a plant capacity. Using the representative midrange value of $2.82/kgal, savings range from $0.17-0.39/MWh. For a typical 350 MW plant operating continuously throughout the year, the savings from reducing evaporation range from $500,000 to $1,200,000, with a midrange value of $870,000. Savings for larger or smaller plants would be roughly proportional to their capacities (EPRI 2004).

Blowdown

As cooling water evaporates from a cooling tower, the concentrations of dissolved and suspended solids increase. To minimize scaling, fouling, and corrosion of the cooling system, these concentrations are reduced by blowdown. Blowdown is the discharge of water from the cooling system, with replacement by fresh intake water. Figure 2 shows the relationship between water losses due to blowdown and cycles of concentration (assuming the typical evaporation rate of 480 gal/MWh cited above). Cycles of concentration describe the proportion by which evaporation increases constituent concentrations. For example, at two cycles of concentration, evaporation doubles constituent concentrations, relative to intake water.

Research to develop cooling system materials that are resistant to scaling, corrosion, and fouling can make it possible to operate at higher solids concentrations, producing significant reductions in blowdown losses. Doubling cycles of concentration from 4 to 8, which exceeds the usual allowable range, could reduce blowdown by about 100 gal/MWh (DeFillippo 2003).

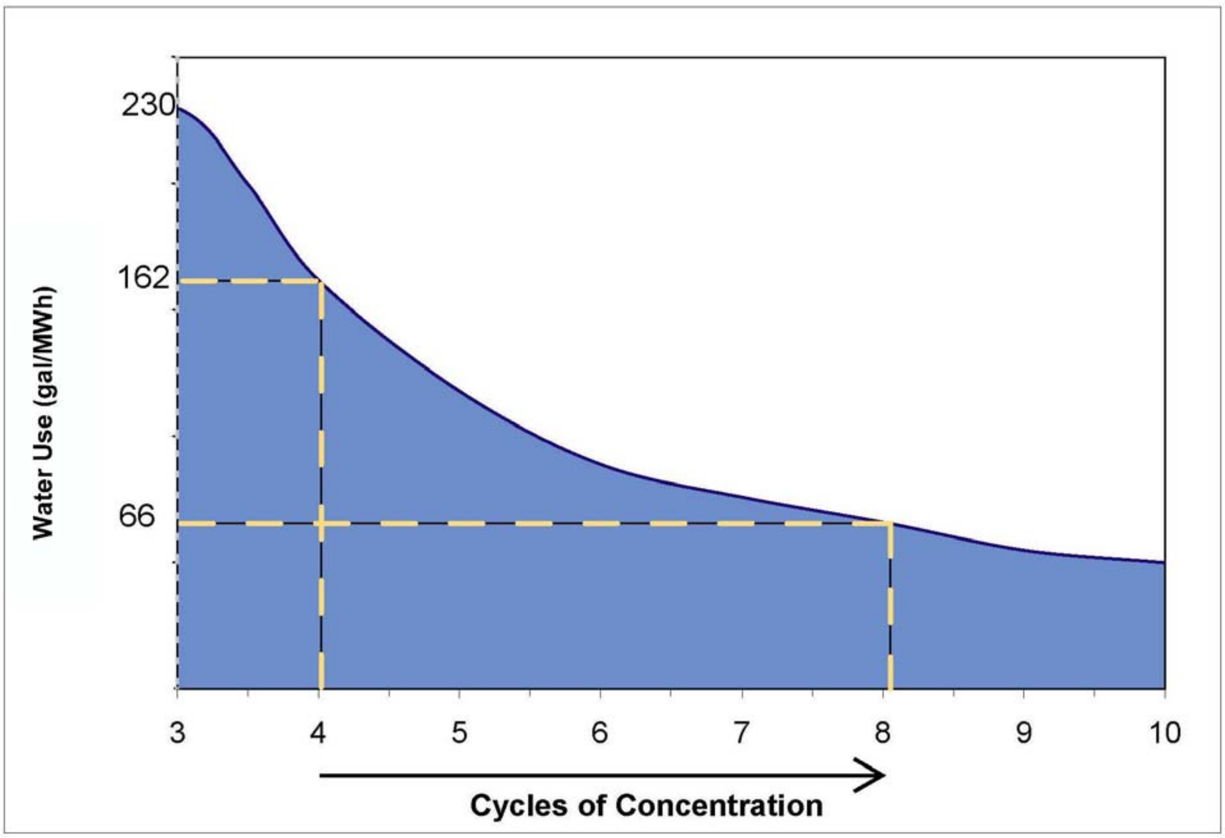
As was done for reductions in evaporative losses, this reduction in water losses can be translated into dollar savings at the plant level by assuming a cost of water and a plant capacity. Using a range of $1-4/kgal, savings range from $0.10-0.40/MWh. For a 350 MW plant operating continuously throughout the year, the potential savings range from about $300,000 to $1,200,000, with a midrange value of $860,000.

Flue Gas Scrubbing

Flue gas desulfurization, or scrubbing, can be accomplished with either dry or wet systems. Plants are likely to increase scrubbing capacity in coming decades to meet tightening air emissions requirements, causing water use for this purpose to increase unless there are conservation measures adopted. Wet scrubbers entrain flue gas in water spray, capturing sulfur dioxide and other pollutants, which are then removed by creating an alkaline slurry. Dry scrubbing injects the alkaline particles directly into the flue gas stream, obviating the need for water, but the more limited contact between reactants in the absence of water results in lower pollutant removal efficiencies.

Research to reduce or recover evaporative losses from flue gas, or to increase the removal efficiency of dry scrubbing, could reduce water use and associated costs. Water requirements for wet scrubbers are about 25 gal/MWh, so this is the amount of water that would be saved at a plant by shifting from wet to dry scrubbing or by capturing all of the evaporation that results from wet scrubbing (National Energy Technology Laboratory, 2006). Using a range of $1-4/kgal, savings range from $0.025-0.10/MWh. For a 350 MW plant operating continuously throughout the year, the potential savings range from shifting from wet to dry scrubbing range from about $75,000 to $300,000, with a midrange value of $220,000.

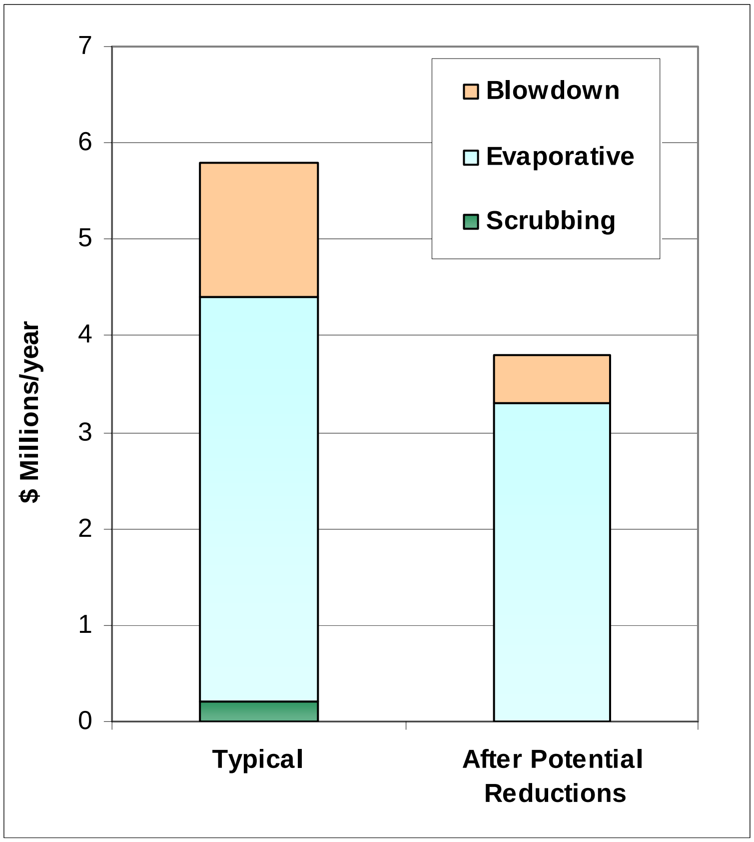
Figure 2: Typical Water Losses from Cooling Towers, at Varying Cycles of Concentration



Combined Savings

If all three loss processes could be reduced as described above for an existing 350 MW coal-fired plant, total annual cost savings would range from $ 875,000 to $2,700,000, depending on climate and the cost of water, with a midrange total of $1,950,000. Figure 3 shows a potential savings, assuming an intermediate cost of $2.82/kgal for water use. Most of the potential savings are from reductions in blowdown and evaporative losses, with the elimination of wet scrubbing contributing a smaller share of savings.

Figure 3: Annual Cost of Water Cooling, 350 MW Coal Burning Plant, Typical and After Potential Reductions



Benefits of Non-Traditional Water Sources

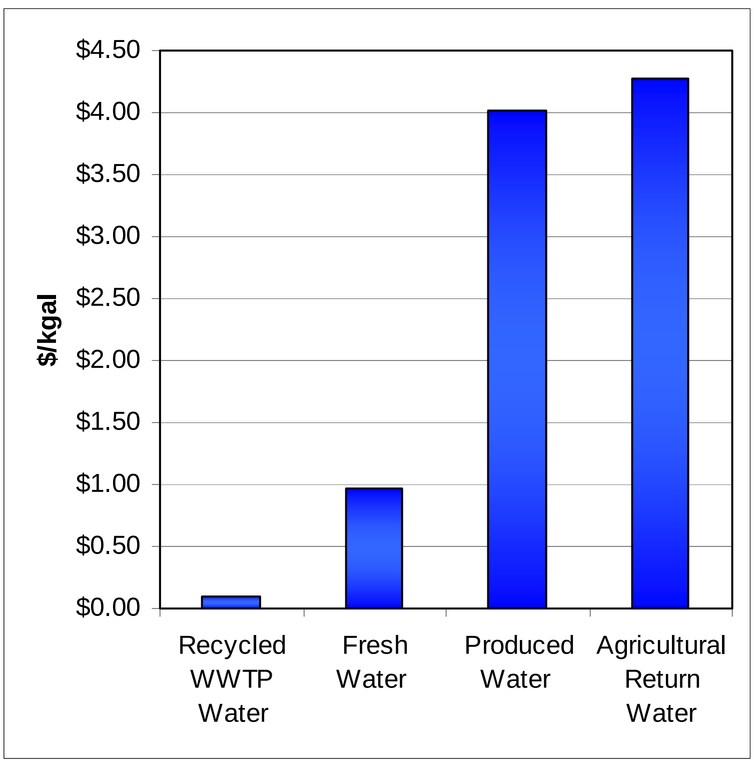
Where clean water is unavailable at a reasonable cost, lower-quality non-traditional water supplies may be good substitutes, as long as depreciation of cooling systems can be minimized by limited pretreatment of intake waters. Potential sources of non-traditional water include treated urban wastewater, stormwater, mine drainage, quarry dewatering, and produced waters from oil and gas operations.

Wastewaters from public treatment works can be a very low-cost water source, at the low end of treatment/disposal costs shown in Table 3, taking advantage of treatment already received. This water source will also increase, because growing populations requiring electric power also generate growing wastewater flows in the same locations. New sewage flows can be expected at a rate exceeding 40 gallons per day per capita, including domestic water use alone, whereas about 16 gallons per day per capita are sufficient for new power generation, assuming current average rates of 33 kWh per day electricity demand per capita and a consumptive use rate for power generation of 480 gal/MWh (Metcalf & Eddy, Inc 1991, California Energy Commission 2003).

In locations where population growth does not provide sufficient new wastewater flows for new power plants, advances in technologies allowing use of degraded waters may also present great opportunities for cost savings. As Figure 4 shows, the cost of treatment required to safely use produced waters can exceed $4/kgal for produced waters and agricultural return waters, in which case it is the largest component of the cost of water. At such a high cost, use of these degraded waters is not often competitive. However, advances in the ability to use degraded waters without extensive pretreatment, such as Spray-Enhanced Dry Cooling could reduce the overall cost of cooling water, making produced water competitive with more traditional groundwater and surface water sources (McGowin 2006).

To roughly estimate the potential saving from advances in use of degraded waters, we can assume a reasonable decrease in the cost of pretreatment, based on the range of current costs. Produced waters from oil and gas exploration and agricultural return waters have treatment costs of $4/kgal or more, according to estimates of DeFilippo, cited by EPRI (EPRI 2004, DeFillippo 2003). The same sources estimate treatment costs for fresh water supplies of about $1/kgal. It is unlikely that research into treatment and/or compatible materials for degraded waters could reduce costs to that level. It is possible, however, that the difference in treatment costs could be significantly reduced, by $0.25-0.75/kgal. For a 350 MW plant operating continuously throughout the year, requiring 480 g/MWh, the savings from reducing costs associated with degraded water sources by $0.25-$0.75/kgal would range from $370,000 to $1,100,000, with a midrange value of $740,000.

Figure 4: Example Water Treatment Costs per 1,000 Gallons for Source Cases [7]



Benefits of Advanced Cooling Technologies

Where water supplies are very limited, cooling with air or a combination of air and water can make it possible to site new facilities. Air- and hybrid cooling technologies exist and are in limited use, but have cost and efficiency disadvantages. There is strong interest in the industry for research to develop improved advanced cooling technologies, and overcome these disadvantages, especially in the southwest.

Full scale air cooling systems are in place and operating in some locations, but they suffer from a "hot weather penalty" of reduced cooling efficiency. Especially in hotter climates, the warmer ambient air that is present during periods of peak air conditioning loads is less effective in condensing steam. This reduces power output per unit of fuel and, for base load facilities, requires costly purchases of imported power to replace lost output.

It is only in the most adverse climates, subject to the highest costs of water, that air cooling is cost-competitive with water cooling. This is illustrated by Figure 5, which shows the relationship between total annualized cooling costs using wet vs. dry cooling for a hypothetical 350 MW coal-burning plant in El Paso, Texas. Cost estimates include both capital and O&M costs, and are based on cooling system designs optimized for this location (EPRI 2004). The figure shows that dry cooling is cost-competitive only for a cost of water exceeding about $3/kgal. Beyond that cost level, dry cooling costs are lower because they are affected very little by the cost of water.

If the hot weather penalty could be reduced through improved design, such as advanced hybrid cooling systems, this would provide substantial savings. Computational fluid dynamics research can assist in this goal by improving understanding of air flow and heat transfer across fin surfaces, under a range of temperature and wind conditions, supporting more efficient designs. The magnitude of potential savings for generators in warmer climates approaches 20% of cooling costs, and can be envisioned by comparing cost schedules for El Paso, a relatively hot location, with Portland, Oregon, which has much less extreme hot weather. Figure 6 shows this difference, which is due entirely to El Paso's hot weather penalty, relative to Portland. Figure 6 shows that there is a hot weather penalty on the order of $1.5 million/year in cooling costs in the warmer southwestern climates, for a 350 MW coal-burning facility. The goal of research into improved air-cooled and/or hybrid technologies would be to reduce costs for a plant of this capacity by a significant fraction of $1.5 million/year. Reductions of 33-66% in the hot weather penalty would result in savings of $500,000 - $1,000,000/year.

Figure 5: Costs of Wet vs. Dry Cooling, Hypothetical 350 MW Coal-Burning Plant, El Paso, Texas

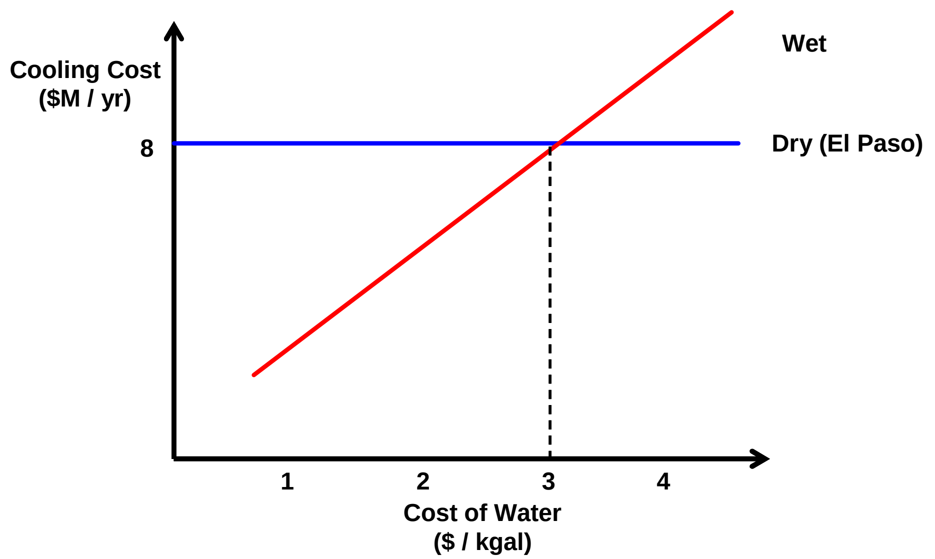
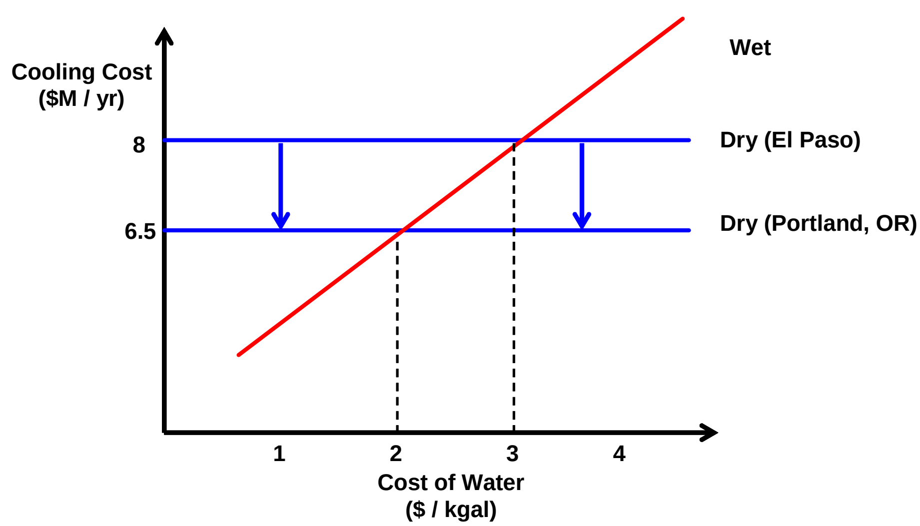


Figure 6: Costs of Wet vs. Dry Cooling, Hypothetical 350 MW Coal-Burning Plant, El Paso, Texas



Summary of Estimated Benefits

Potential cost savings have been estimated above for a series of innovative and emerging technologies. To provide a consistent point of reference, cost savings have been roughly estimated for a 350 MW plant. Table 4 presents the full set of estimates for the 350 MW plant and shows that in each case, the potential savings for a facility of this size for each technology are on the order of hundreds of thousands to millions of dollars per year. Estimated potential annual savings from capture of evaporation, reductions in blowdown, use of degraded waters, and air cooling technologies are all of about the same magnitude, given the approximate nature of the estimates. Potential economic benefits from eliminating water losses from scrubbing are smaller, due to the smaller volume of water lost to scrubbing.

Table 4: Ranges of Potential Savings in Water Costs for 350 MW Power Plant

Research Area	Low	Mid	High
Capture Evaporation	$500,000	$870,000	$1,200,000
Reduce Blow Down	$300,000	$860,000	$1,200,000
Dry Scrubbing	$75,000	$220,000	$300,000
Use of Degraded Waters	$370,000	$740,000	$1,100,000
Air Cooling	$500,000	$750,000	$1,000,000

The estimated savings shown in Table 4 would significantly increase profitability for power generators. Power generation costs for a 350 MW baseload coal-burning facility are about $100-125 million annually, based on a range of levelized cost of $33-41/MWh (Yahoo Finance 2006, Tolley and Jones 2004). With the exception of dry scrubbing, each technology listed in Table 4-1 has the potential to reduce annual production costs by about 1%, increasing the rate of profit by the same percentage. Profit rates for power generators currently average about 7-8% of costs, so the implementation of these technologies, singly or in combination, has the potential to raise profit rates by roughly 1-3 percentage points, increasing profit rates from about 7-8% to about 8-11%, a substantial increase.

Summary and Conclusions

With population and energy demands increasing there is going to be a compelling need for the electric power industry to be more water efficient. As with many business, the environmental aspects of operations and development are not usually a primary consideration. This paper has shown that improved water efficiencies through reuse and recovery, use of non-traditional waters, and improved cooling efficiencies can be effective strategies for the industry to not only conserve increasingly scarce water but also improve the economic line for plant profitability. By considering economics and well as the environment, we have a better chance of achieving a sustainable future for water use in the power industry.

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