Department of Energy/Office of Fossil Energy's Power Plant Water Management R&D Program

Thomas J. Feeley, III[1], Lindsay Green[2], James T. Murphy[2],
Jeffrey Hoffmann[1], and Barbara A. Carney[1]

[1.] U.S. Department of Energy, National Energy Technology Laboratory
[2.] Science Applications International Corporation

INTRODUCTION

Coal-fired power plants utilize significant quantities of both coal and water for generating electrical energy. For example, a 500 MW power plant burns approximately 250 tons per hour of coal while using over 12 million gallons per hour of water for cooling and other process requirements[a]. The United States Geological Survey (USGS) estimates that thermoelectric generation[b] accounts for approximately 136,000 million gallons per day (MGD) of freshwater withdrawals[c], ranking only slightly behind agricultural irrigation as the largest source of freshwater withdrawals in the United States.[1] As U.S. population and associated economic development continues to expand, the demand for electricity will increase. The Energy Information Administration's (EIA) latest forecast estimates U.S. coal-fired generating capacity will grow from approximately 305 GW in 2003 to 389 GW in 2025.[2] As such, coal-fired power plants may increasingly compete for freshwater with other sectors such as domestic, commercial, agricultural, industrial, and in-stream use – particularly in regions of the country with limited freshwater supplies. In addition, current and future water-related environmental regulations and requirements will also challenge the operation of existing power plants and the permitting of new thermoelectric generation projects.

In response to these challenges to national energy sustainability and security, the Department of Energy/Office of Fossil Energy's National Energy Technology Laboratory (DOE/NETL) has initiated an integrated research and development (R&D) effort under its Innovations for Existing Plants (IEP) program directed at technologies and concepts to reduce the amount of freshwater used by power plants and to minimize any potential impacts of plant operations on water quality. This paper provides background information on the relationship between water and thermoelectric power generation and describes the R&D activities currently being sponsored by DOE/NETL's IEP program to address current and future water-energy issues.

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[a] Actual cooling water flow rate requirements for a particular plant will vary depending on type of cooling water system and design parameters.
[b] Thermoelectric generation includes coal, oil, natural gas and nuclear power generation. Coal-based generation represents approximately 58% of total U.S. thermoelectric generation based on EIA AEO 2005 estimates.
[c] This includes both surface and ground water withdrawals.

BACKGROUND

Water Use for Thermoelectric Power Generation

Thermoelectric generation represents the largest segment of U.S. electricity production and coal-based power plants alone generate more than half of the nation's electricity supply. According to USGS water use survey data, 346 billion gallons of freshwater per day (BGD) was used in the United States in 2000. Figure 1 presents the percentage of total U.S. freshwater withdrawal by source category. Thermoelectric generation accounted for 39% (136 BGD) of all freshwater withdrawals in the nation in 2000, second only to irrigation. Each kWh of thermoelectric generation requires approximately 25 gallons of water[d], primarily used for cooling purposes – a 500 MW power plant would use approximately 300 million gallons of water per day. However, power plants also use water for operation of pollution control devices such as flue gas desulfurization (FGD) technology as well as for ash handling, wastewater treatment, and wash water. When discussing water and thermoelectric generation, it is important to distinguish between water use and water consumption. Water use represents the total water withdrawal from a source and water consumption represents the amount of that withdrawal that is not returned to the source. Although thermoelectric generation is the second largest user of water on a withdrawal basis, it was only responsible for about 3% of the total of 100 BGD freshwater consumed in 1995 compared to 81% for irrigation as shown in Figure 2.[3]

Figure 1 – U.S. Freshwater Withdrawal (2000)

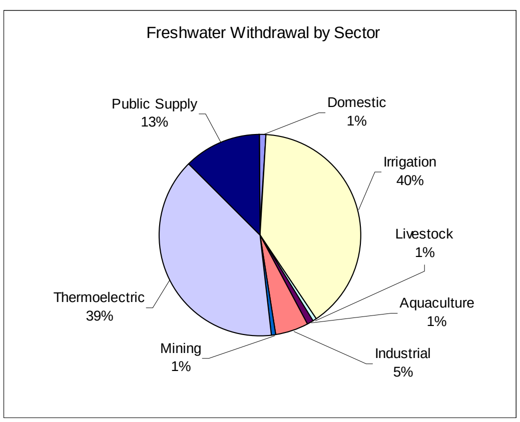
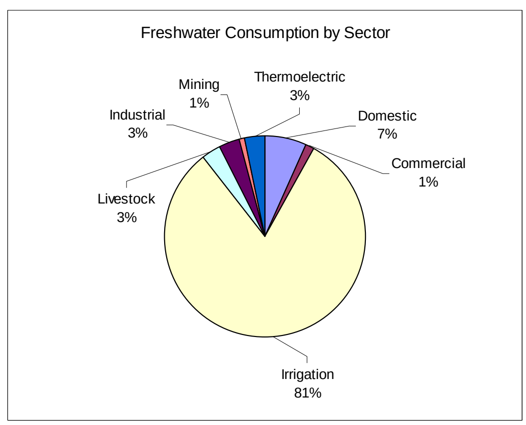


Figure 2 – U.S. Freshwater Consumption (1995)



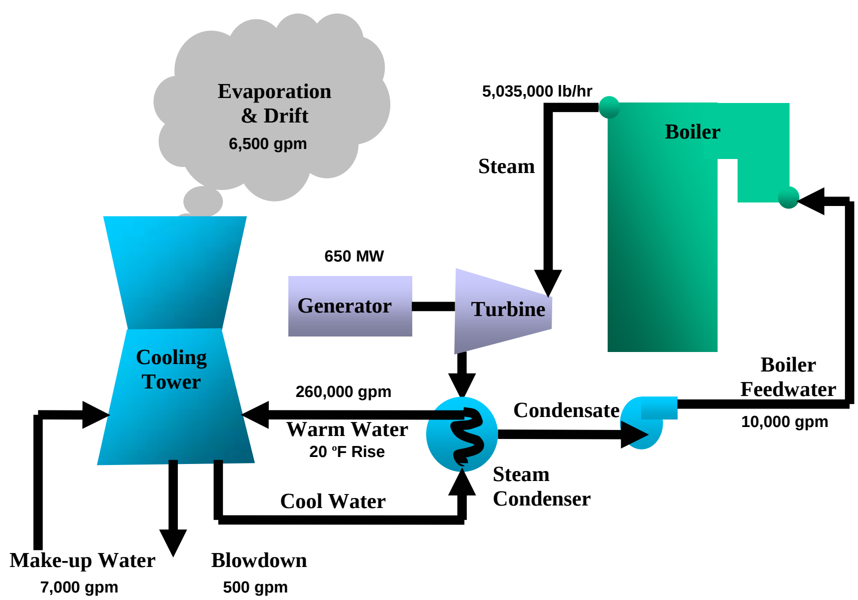
As discussed above, large quantities of cooling water are required for thermoelectric power plants to support the generation of electricity. Thermoelectric generation relies on a fuel source (fossil or nuclear) to heat water to steam that is used to drive a turbine-generator. Steam exhausted from the turbine is condensed and recycled to the steam

[d] This number is a weighted average that captures total thermoelectric water withdrawals and generation for both once-through and recirculating cooling systems.

generator or boiler. The steam condensation typically occurs in a shell-and-tube heat exchanger known as a condenser. The steam is condensed on the shell side by the flow of cooling water through tube bundles located within the condenser. Cooling water mass flow rates of greater than 25 times the steam mass flow rate are necessary depending on the allowable temperature rise of the cooling water – typically 15-25ºF. There are basically two types of cooling water system designs – once-through (open loop) or recirculating (closed loop). In once-through systems the cooling water is withdrawn from a local water body such as a lake, river, or ocean and the warm cooling water is subsequently discharged back to the same water body after passing through the condenser. As a result, plants equipped with once-through cooling water systems have relatively high water use, but low water consumption. The most common type of recirculating system uses wet cooling towers to dissipate the heat from the cooling water to the atmosphere. In wet recirculating systems the warm cooling water is typically pumped from the condenser to a cooling tower where the heat is dissipated directly to ambient air by evaporation of the water and heating the air. The cooling water is then recycled back to the condenser. In addition to cooling towers, cooling ponds or lakes can also be used to accomplish evaporation in recirculating systems.

Because of evaporative losses, a portion of the cooling water needs to be discharged from the system – known as blowdown − to prevent the buildup of minerals and sediment in the water that could adversely affect performance. For a wet recirculating system, only makeup water needs to be withdrawn from the local water body to replace water lost through evaporation and blowdown. As a result, plants equipped with wet recirculating systems have relatively low water use, but high water consumption, compared to once-through systems. Typical wet recirculating cooling water system flow rates for a 650 MW coal-fired plant are shown in Figure 3.

Figure 3 - Process Flow Schematic for Wet Recirculating Cooling Water System



Wet cooling towers are available in two basic designs – mechanical draft and natural draft. Mechanical draft towers utilize a fan to move ambient air through the tower, while natural draft towers rely on the difference in air density between the warm air in the tower and the cooler ambient air outside the tower to draw the air up through the tower. In both designs the warm cooling water is discharged into the tower for direct contact with the ambient air.

A second type of recirculating cooling system is known as dry cooling. Dry recirculating cooling systems use either direct or indirect air-cooled steam condensers. In a direct air-cooled steam condenser the turbine exhaust steam flows through air condenser tubes that are cooled directly by conductive heat transfer using a high flow rate of ambient air that is blown by fans across the outside surface of the tubes. Therefore, cooling water is not used in the direct air-cooled system. In an indirect air-cooled steam condenser system a conventional water-cooled surface condenser is used to condense the steam, but an air-cooled closed heat exchanger is used to conductively transfer the heat from the water to the ambient air. As a result, there is no evaporative loss of cooling water with an indirect-air dry recirculating cooling system and both water use and consumption are minimal. Due to relatively higher capital and operating costs and lower performance, dry recirculating cooling systems are not as prevalent as the wet recirculating cooling systems.

Of the 136 BGD of freshwater use by thermoelectric generators in 2000, USGS estimated approximately 88% was used at plants with once-through cooling systems. Table 1 presents an estimate of average water use and consumption for once-through and recirculating systems based on year 2000 data from EIA's Form 767 report.[4] Once-through systems have very high water use requirements, but since nearly all of the water is returned to the source body, consumptive losses are low on a percentage basis. Recirculating wet systems have lower water use requirements, but consumptive losses through direct evaporation can be relatively high on a percentage basis. In 2001, approximately 31% of thermoelectric generating units were equipped with wet cooling towers, representing approximately 38% of installed generating capacity.

Table 1 – Average Cooling System Water Use and Consumption

Type of Cooling Water System	Average gal/kWh	
	Water Use	Water Consumption
Once-through	37.7	0.1
Recirculating wet	1.2	1.1

It is difficult to estimate future freshwater use and consumption by thermoelectric generation due to changes in the type of generation, method of cooling, and source of water. Based on EIA projections of thermoelectric generation in 2025, DOE/NETL estimates that daily freshwater withdrawals could decrease to 113 BGD or increase to 138 BGD, and that daily freshwater consumption could remain at 3.3 BGD or increase to 8.7 BGD.[5]

Impact of Water Availability on Thermoelectric Power Generation

Freshwater availability is a critical limiting factor in economic development and sustainability and directly impacts electric-power supply. A 2003 study conducted by the Congressional General Accounting Office indicates that 36 states anticipate water shortages in the next ten years under normal water conditions, and 46 states expect water shortages under drought conditions.[6] Water supply and demand estimates by EPRI for the years 1995 and 2025 also indicate a high likelihood of local and regional water shortages in the United States.[7] The area that is expected to face the most serious water constraints is the arid southwestern United States.

In any event, the demand for water for thermoelectric generation will increasingly compete with demands from other sectors of the economy such as agriculture, domestic, commercial, industrial, mining, and in-stream use. EPRI projects the potential for future constraints on thermoelectric power in 2025 for Arizona, Utah, Texas, Louisiana, Georgia, Alabama, Florida, and all of the Pacific Coast states. Competition over water in the western United States, including water needed for power plants, led to a 2003 Department of Interior initiative to predict, prevent, and alleviate water-supply conflicts.[8] Other areas of the United States are also susceptible to freshwater shortages as a result of drought conditions, growing populations, and increasing demand.

Concern about water supply expressed by state regulators, local decision-makers, and the general public is already impacting power projects across the United States. For example, Arizona recently rejected permitting for a proposed power plant because of concerns about how much water it would withdraw from a local aquifer.[9] An existing Entergy plant located in New York is being required to install a closed-cycle cooling water system to prevent fish deaths resulting from operation of its once-through cooling water system.[10] Water availability has also been identified by several Southern States Energy Board member states as a key factor in the permitting process for new merchant power plants.[11] In early 2005, Governor Mike Rounds of South Dakota called for a summit to discuss drought-induced low flows on the Missouri River and the impacts on irrigation, drinking-water systems, and power plants.[12] Also, residents of Washoe County, Nevada expressed opposition to a proposed coal-fired power plant in light of concerns about how much water the plant would use.[13] Another coal-fired power plant to be built in Wisconsin on Lake Michigan has been under attack from environmental groups because of potential effects of the facility's cooling-water-intake structures on the Lake's aquatic life.[14]

Such events point towards a likely future of increased conflicts and competition for the water the power industry will need to operate their thermoelectric generation capacity. These conflicts will be national in scope, but regionally driven. It is likely that power plants in the west will be confronted with issues related to water rights, that is, who owns the water and the impacts of chronic and sporadic drought. In the east, current and future environmental requirements, such as the Clean Water Act's intake structure regulation, could be the most significant impediment to securing sufficient water, although local drought conditions can also impact water availability. Key environmental regulations that can potentially impact power plants are summarized below.

Environmental Regulations Affecting Thermoelectric Power Generation Water Use

The U.S. Environmental Protection Agency (EPA) has been charged with maintaining and improving the Nation's water resources for uses including but not limited to agricultural, industrial, nutritional, ecological, and recreational. To accomplish this goal, EPA has issued several regulations under the Clean Water Act and the Safe Drinking Water Act that directly impact the discharge of pollutants from power plants to receiving waters as well as the intake of water for cooling and other power plant needs. The following is a summary of regulations that affect power plant water use.

The Clean Water Act

The Clean Water Act (CWA) provides for the regulation of discharges to the Nation's surface waters. The CWA calls for a federal-state partnership in which the federal government sets the standards for pollution discharge and states are responsible for the implementation and enforcement. Initial emphasis was placed on "point source" pollutant discharge, but 1987 amendments authorized measures to address "non-point source" discharges, including stormwater runoff from industrial facilities. Permits are issued under the National Pollutant Discharge Elimination System (NPDES), which designates the highest level of water pollution or lowest acceptable standards for water discharges. With EPA approval, the states may implement standards more stringent than federal water quality standards but they may not be less stringent. Certain sections of the CWA are particularly applicable to water issues related to power generation and are described below in more detail.

- *CWA §303 Water Quality Standards and Implementation Plans* - Section 303 of the CWA, the Total Maximum Daily Load (TMDL) program, requires states to develop lists of impaired waters—water bodies that do not meet water quality standards (WQS) that the states have set, even after the installation of the minimum required levels of pollution control technology. States must then establish priority rankings for waters that do not meet the WQS and develop TMDLs for these water bodies. A TMDL specifies the maximum amount of a pollutant that an impaired water body can receive and still meet WQS. While states are responsible for establishing the TMDL, the CWA requires EPA to approve or disapprove the impaired water lists and TMDLs established by the states. After establishing a TMDL, states have 10 years to develop implementation plans for improving the quality of the affected waters.
- *CWA §316(a) Water Thermal Discharge* – Section 316(a) requires the regulation of water thermal discharge from cooling water systems in order to protect shellfish, fish, and other aquatic wildlife.
- *CWA §316(b) Cooling Water Intake Structures* – Section 316(b) is arguably the most urgent water-related issue facing thermoelectric power generation in the near term. This section requires that the location, design, construction and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impact, such as impingement or entrainment of aquatic organisms due to the operation of cooling water intake structures.

Regulations to implement Section 316(b) are being issued in three phases that cover different facility categories. The Phase I rule was issued in December 2001 and effectively requires all new thermoelectric power generation plants to install closed-cycle cooling systems due to standards for water intake capacity and velocity. The Phase II rule, issued in July 2004, applies to existing thermoelectric power generation plants that withdraw more than 50 MGD of water and use at least 25 percent of the water withdrawn for cooling purposes only. Although the Phase II rule requires significant percentage reductions in both impingement and entrainment losses from uncontrolled levels, it also provides flexible compliance alternatives so that conversions of open-cycle to closed-cycle cooling water systems are not mandated. Regulations for Phase III were proposed in November 2004 and will apply to other industrial sources and new offshore and coastal oil and gas extraction facilities.

The Safe Drinking Water Act – The Safe Drinking Water Act (SDWA) serves to protect humans from contaminants in the Nation's public drinking water supply. Amended in 1986 and 1997, the law requires many actions to protect drinking water and its sources. The SDWA requires EPA to set national drinking water standards and create a joint federal-state system to ensure compliance. While the provisions of the SDWA apply directly to public water systems in each state, the Act is relevant to thermoelectric power generation because waste streams may contain detectable levels of elements or compounds that have established drinking water standards. Under the SDWA, regulations that would require additional limits on mercury, arsenic, and other trace metals could also affect how power plants dispose of coal by-products.

INNOVATIONS FOR EXISTING PLANTS PROGRAM

DOE/NETL's IEP Program is a comprehensive R&D effort directed at the development of advanced technologies and knowledge products that can enhance the environmental performance of the existing fleet of coal-fired power plants. In response to the growing recognition of the inter-dependence between freshwater availability and quality and electricity production, the IEP program was broadened in 2003 to include research directed at coal-fired power plant related water management issues.[15] The overall goal of this effort is to reduce the amount of freshwater needed for power plant operations and to minimize potential impacts on water quality. The research encompasses laboratory and bench-scale activities through pilot- and full-scale demonstrations and is performed in partnership and collaboration with industry, academia, technology developers, and other government organizations. The program is built around four specific areas of research:

- Non-Traditional Sources of Process and Cooling Water
- Innovative Water Reuse and Recovery
- Advanced Cooling Technology
- Advanced Water Treatment and Detection Technology

The following is a brief summary of several recently completed and on-going R&D projects in these four research areas. Several water-related projects funded under the

University Coal Research and the Clean Coal Power Initiative programs are also discussed.

Non-Traditional Sources of Process and Cooling Water

Research and analysis are being conducted to evaluate and develop cost-effective approaches to using non-traditional sources of water to supplement or replace freshwater for cooling and other power plant needs. Water quality requirements for cooling systems can be less restrictive than many other applications such as drinking water supplies or agricultural applications, so opportunities exist for the utilization of lower-quality, non-traditional water sources. Examples include surface and underground mine pool water[16], geological carbon sequestration and coal-bed methane produced waters, and industrial and/or municipal wastewater.

Strategies for Cooling Electric Generating Facilities Utilizing Mine Water: Technical and Economic Feasibility

West Virginia University's Water Research Institute conducted a study to evaluate the technical and economic feasibility of using water from abandoned underground coal mines in the northern West Virginia and southwestern Pennsylvania region to supply cooling water to power plants.[17] The amount of mine water available, the quality of the water, and the types of water treatment needed are all factors that were analyzed during this study. Non-traditional water sources such as coal mine discharges not only have the potential to reduce freshwater power plant cooling requirements, they also can improve the efficiency of the cooling process due to the lower water temperatures associated with deep mine pools.

The study included identification of available mine water reserves in the region with sufficient capacity to support power plant cooling water requirements under two scenarios. The first scenario was to provide the makeup water requirements for a 600 MW plant equipped with a closed-loop recirculating cooling water system. The second scenario was to provide the entire cooling water requirement for a 600 MW plant equipped with a closed-loop recirculating cooling water system utilizing a flooded underground mine as a heat sink. If feasible, the second scenario would eliminate the need for a wet cooling tower to dissipate the heat to the atmosphere.

The study identified eight potential sites under the first scenario where underground mine water is available in sufficient quantity to support the 4,400 gallons per minute (gpm) makeup water requirements for a closed-loop 600 MW plant. Three of these sites were further evaluated for preliminary design and cost analysis of mine pool water collection, treatment, and delivery to a power plant. One site was selected for each of three mine pool water chemistry categories based on "net alkalinity" as measured in mg/L equivalent concentration of $CaCO_3$ − net acidic (<-50 mg/L), neutral (-50 to +50 mg/L), and net alkaline (>+50 mg/L). The net alkalinity of the mine pool water determines the water treatment requirements. The mine pool water treatment process includes pre- and post-aeration, neutralization with hydrated-lime, and clarification. A water treatment option using hydrogen peroxide for neutralization was also evaluated. The cost analysis concluded that depending on site conditions and water treatment requirements that utilization of mine pool water as a source of cooling water makeup can be cost competitive with freshwater makeup systems. Table 2 provides a summary of the capital and operating cost estimates for mine pool water collection and treatment systems at the three sites.

Table 2 – Cost Estimate for Mine Pool Water Collection and Treatment System

Cost	Flaggy Meadows (net-acidic)	Irwin (near-neutral)	Uniontown (net-alkaline)
Total Capital Cost, $	5,740,000	3,770,000	3,464,000
Operating Cost, $/yr	1,367,000	363,000	433,000
Annualized Cost, $/1000 gallons	0.79	0.26	0.29

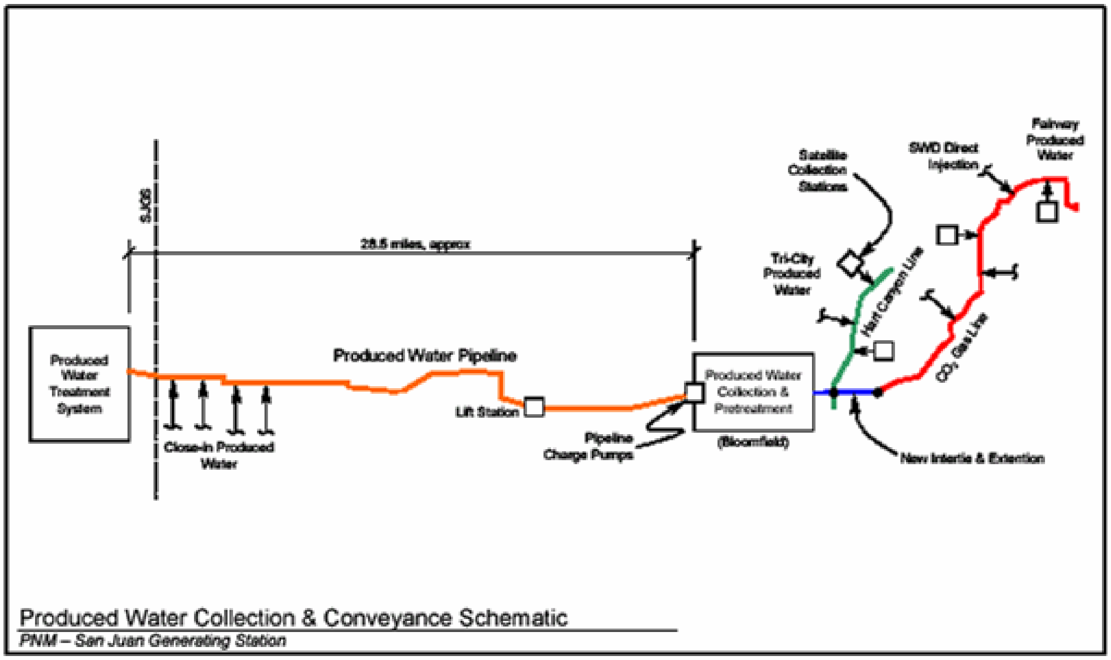
Based on fluid and heat flow modeling of the second scenario, it was determined that interconnection of two adjoining mines would be necessary to provide sufficient heat transfer residence time to adequately cool the recirculating water flow. As a result, the study identified only one potential site for a closed-loop recirculating cooling water system utilizing a flooded underground mine as a heat sink. Furthermore, that site would be limited to the cooling water requirements of a 217 MW unit. This project was completed in January 2005.

Use of Produced Water in Recirculated Cooling Systems at Power Generation Facilities

The Electric Power Research Institute (EPRI) evaluated the feasibility of using produced waters, a by-product of natural gas and oil extraction, to meet up to 10 percent of the approximately 20 MGD of make-up cooling water demand for the mechanical draft cooling towers at Public Service of New Mexico's 1,800 MW San Juan Generating Station (SJGS) located near Farmington, New Mexico.[18] Two major issues are associated with this use of produced water: 1) collection and transportation of the produced water to the plant and 2) treatment of the produced water to lower the total dissolved solids (TDS) concentration.

Providing cost-effective collection and transportation of produced water from the wellhead or disposal facility to the power plant is a significant issue. There are over 18,000 oil and gas wells in the San Juan Basin in New Mexico, where SJGS is located, that generate more than 2 MGD of produced water. Most of the produced water in the region is collected in tanks at the wellhead and transported by truck to local saltwater disposal facilities. The SJGS evaluated a two-phased approach for transportation of produced water to the plant site (Figure 3). In the first phase, an 11-mile pipeline would be built to gather and convey close-in production. Existing unused gas and oil pipelines would be converted to transport produced water in the second phase.

Figure 3 – Pipeline System for Transportation of Produced Water to San Juan Generating Station



Water quality is an issue when using produced water to supplement plant cooling water requirements due to high TDS concentrations. Cooling water currently used at the SJGS is withdrawn from the San Juan River and contains only 360 mg/L of TDS compared to produced water with a TDS concentration ranging from 5,440 to 60,000 mg/L. For comparison, sea water contains 26,000 mg/L. Therefore, the produced water would have to be treated prior to use at the plant in order to reduce TDS to an acceptable level.

In addition to cooling tower make-up, produced water was also evaluated for use as bottom ash sluice water, fly ash wetting water, and FGD absorber make-up. It was determined that FGD absorber make-up would be the least costly use for treated produced water. The most economical treatment method identified was high efficiency reverse osmosis with a brine concentrator distillation unit that would process approximately 1,100 gpm of produced water. Based on this equipment arrangement, the cost for produced water treatment would include an initial capital cost of $14.1 million and operating costs of $2.98 million per year that includes approximately 2 MW for auxiliary power. The total project capital cost including collection, transportation, and treatment facilities is $43.1 million. This study was completed in April 2005.

Innovative Water Reuse and Recovery

Research is currently underway to develop advanced technologies to reuse power plant cooling water and associated waste heat and investigate methods to recover water from coal and power plant flue gas. Such advances have the potential to reduce fossil fuel power plant water withdrawal and consumption.

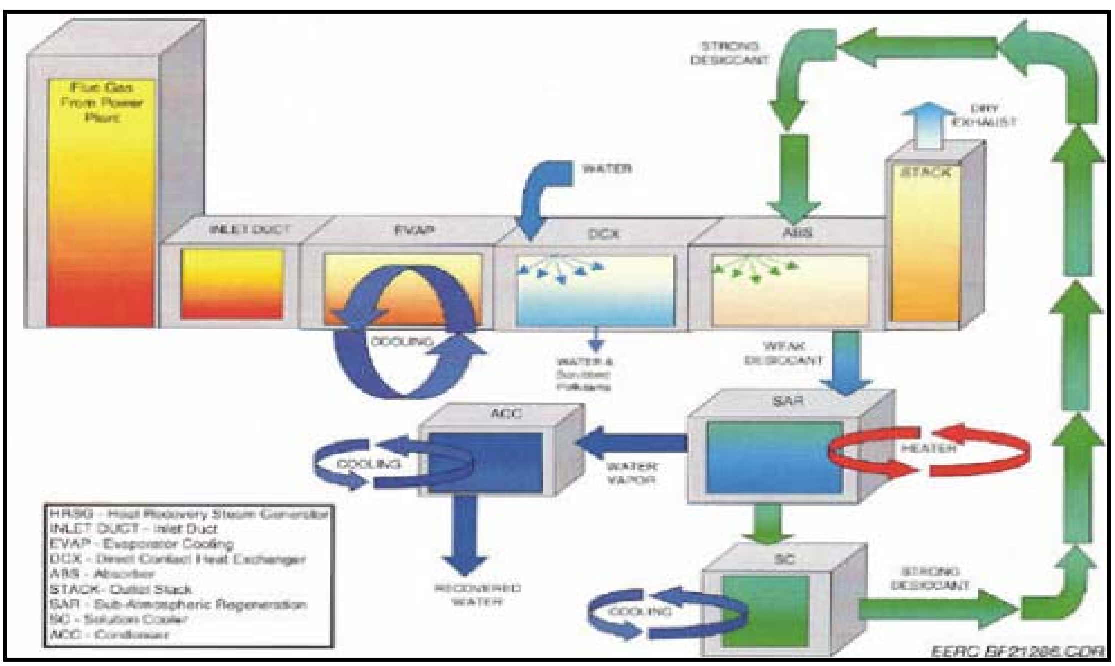
Water Extraction from Coal-Fired Power Plant Flue Gas

The University of North Dakota's Energy & Environmental Research Center (UNDEERC) is developing a technology to extract water vapor from coal-fired power plant flue gases in order to reduce makeup water requirements for the plant's cooling water system.[19] The flue gas contains large amounts of water vapor produced from the coal combustion process. Coal contains in-situ water and the combustion of the hydrogen within the coal matrix also releases additional water. The amount of water potentially available for recovery from the flue gas is sufficient to substantially reduce the need for plant makeup water withdrawals.

This project has two objectives. The first objective is to develop a cost-effective liquid desiccant-based dehumidification technology to recover a large fraction of the water present in the plant flue gas. The second objective is to perform an engineering evaluation to determine how such a technology can be integrated to recover water, improve efficiency, and reduce stack emissions of acid gases and carbon dioxide.

The liquid desiccant-based dehumidification system utilizes low-grade heating and cooling sources available at the power plant. A conceptual schematic of the proposed prototype system is shown in Figure 4. The flue gas is cooled and then subjected to a liquid desiccant absorption process that removes water from the flue gas. By stripping off the absorbed water, the weak desiccant solution is regenerated back to the strong desiccant solution. The water vapor that is produced during the regeneration process is condensed and made available for plant makeup water.

Figure 4 - Conceptual Design of Liquid Desiccant Process



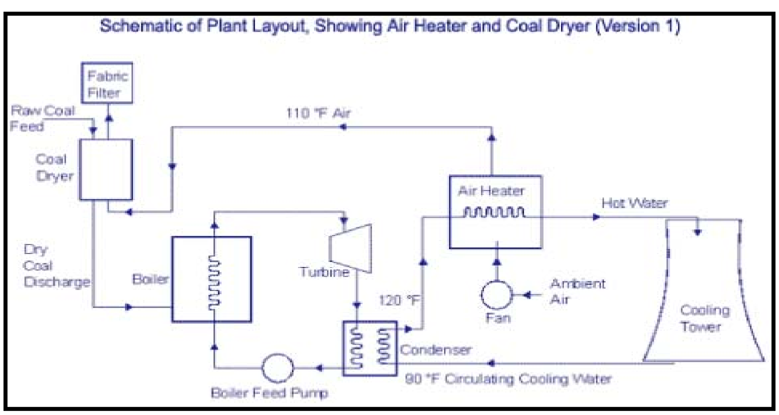
To date, a desiccant selection and characterization evaluation has been conducted by ranking the merits of potential desiccants based on physical and chemical data along with laboratory testing. One of the desiccants was selected for initial pilot-scale testing. Data from the pilot-scale testing show that the performance of the system was better than predicted by chemical process models. Based on pH and chemistry, extracted water quality is good and off-gas of undesirable species, such as SO_2 and NOx, from the solution was minimal. Prospects for commercial development of the process are encouraging. This project will be complete in September 2005.

Use of Coal Drying to Reduce Water Consumed in Pulverized Coal Power Plants

Lehigh University is conducting laboratory-scale testing to evaluate the performance and economic feasibility of using low-grade power plant waste heat to partially dry low-rank coals prior to combustion in the boiler.[20] The project will be completed in December 2005. While bituminous coals have minimal moisture content (less than 10%), low-rank coals have significant moisture content – subbituminous and lignite coals range from 15-30% and 25-40% moisture, respectively. In this process heat from condenser return cooling water is extracted upstream of the cooling tower to warm ambient air that is then used to dry the coal. Lowering the temperature of the return cooling water reduces evaporative loss in the tower, thus reducing overall water consumption.

In addition, drying the coal prior to combustion can improve the plant heat rate, and in return reduce overall air emissions. Figure 5 shows a schematic of the plant layout with the air heater and coal dryer. Variations of this approach are also being evaluated that include using heat from combustion flue gas to supplement the condenser return cooling water to dry the coal. Information from this project is being used to design a full-scale coal drying system at Great River Energy's 546 MW lignite-fired Coal Creek Power Station located near Underwood, North Dakota. The Coal Creek project is being funded under DOE/NETL's Clean Coal Power Initiative.

Figure 5 - Schematic of Lehigh Coal Drying Process



An Innovative Fresh Water Production Process for Fossil Fired Power Plants Using Energy Stored in Main Condenser Cooling Water

The University of Florida is investigating an innovative diffusion-driven desalination process that would allow a power plant that uses saline water for cooling to become a net producer of freshwater.[21] Hot water from the condenser provides the thermal energy to drive the desalination process. Saline water cools and condenses the low pressure steam and the warmed water then passes through a diffusion tower to produce humidified air. The humidified air then goes to a direct contact condenser where fresh water is condensed out. This process is more advantageous than conventional desalination technology in that it may be driven by low-temperature waste heat. Cool air, a by-product of this process, can also be used to cool nearby buildings.

To date, a diffusion driven desalination facility has been designed that can produce 1.03 MGD of fresh water from the waste heat of a 100 MW plant. The only energy cost to use this process is the energy used to power the pumps and fans. An economic simulation of the system has been performed and shows that production cost is competitive with the costs associated with reverse osmosis or flash-evaporation technologies. This project will be completed in 2005.

Advanced Cooling Technology

This component of the program is focused on research to develop technologies that improve performance and reduce costs associated with wet cooling, dry cooling, and hybrid cooling technologies. In addition, the research area covers innovative methods to control bio-fouling of cooling water intake structures as well as advances in intake structure systems.

Development of Hybrid Cooling Water System

In conjunction with the produced water feasibility study being conducted at the San Juan Generating Station, EPRI will also conduct pilot-scale testing of a hybrid cooling technology. The Wet Surface Air Cooler (WSAC) is a closed-loop cooling system coupled with open-loop evaporative cooling. Warm water from the steam condenser flows through tubes that are externally drenched with spray water. Heat is removed through the evaporative effect of the spray water. The tubes are always covered in water, hence the name "wet surface". The WSAC is capable of operating in a saturated mineral regime because of its spray cooling configuration. A high spray rate is used to ensure that the tubes are constantly flooded and helps the spray nozzles from becoming plugged. Co-current flow of air and spray water eliminates dry spots on the underside of the tubes where fouling often occurs. The tubes have no fins and are spaced far enough apart that solids or precipitates from the poor quality water are washed into the basin.

At SJGS this system will be used as auxiliary cooling for condenser cooling water. The spray water will be blowdown water from the existing cooling towers. The testing will determine to what extent the WSAC can concentrate untreated cooling tower blowdown before thermal performance is compromised. It will be used as a pre-concentrating device for the cooling tower blowdown that is typically evaporated in a brine concentrator or evaporation pond at this zero discharge facility. The pilot test unit will be skid mounted and will consist of three separate tube bundles. Each bundle will be constructed of a different metal to evaluate the corrosion potential of the degraded water. The pilot unit will be instrumented to monitor thermal performance, conductivity of the spray water, and corrosion.

Environmentally-Safe Control of Zebra Mussel Fouling

Zebra mussels are small, fingernail-sized bivalves that can live in rivers and lakes in enormous densities. Native to Europe, these mussels were first discovered in Lake St. Clair, near Detroit, in 1988 and have since spread as far south as Louisiana and as far west as Oklahoma. Figure 6 shows the distribution of zebra mussels in North America. Zebra mussels can attach to almost any hard surface and their colonization on cooling water intake structures can restrict water intake and lead to significant plant outages. There is a need for economical and environmentally safe methods for zebra mussel control where this invasive species has become problematic. Researchers with the New York State Education Department are conducting a three-year study to evaluate a particular strain of naturally occurring bacteria, *Pseudomonas fluorescens,* that has shown to be selectively lethal to zebra mussels but benign to non-target organisms.[22] Testing is being conducted on the service water treatment system for Rochester Gas and Electric Corporation's Russell Station that withdraws 4 to 5 MGD from Lake Ontario.

Figure 6 - North America Distribution of Zebra Mussels

To date, research suggests that that this method for zebra mussel control will pose less of an environmental risk than the current use of biocides like chlorine. However, if this method is to be widely adopted, it must also be cost competitive. Laboratory experiments to define key nutrients required to produce more toxin per bacterial cell are underway. This is a long-term experiment and an accurate measurement of this increase in cell toxicity will not be available until design of the entire chemically-defined culture medium and culturing protocol is finalized in 2005.

Enhanced Performance Carbon Foam Heat Exchanger for Power Plant Cooling

Ceramic Composites, Inc. has partnered with SPX Corporation to develop high thermal conductivity foam to be used in an air-cooled steam condenser for power plants that could significantly decrease energy consumption associated with conventional dry cooling systems.[23] In addition, the availability of a more efficient dry cooling technology would offer an alternative to power plants for minimizing adverse impacts such as organism intake, warm water discharge, and evaporative water loss associated with wet or wet-dry hybrid cooling technology. This project will be complete in July 2006.

Advanced Water Treatment and Detection Technology

Future controls on the emission of mercury and possibly other trace elements have raised concerns about the ultimate fate of these contaminants once they are removed from the flue gas. Preventing these "air pollutants" from being transferred to surface or ground waters will be critical. In addition, ammonia from selective catalytic reduction systems used to control nitrogen oxide emissions can appear in a power plant's wastewater streams such as ash sluice water. Research is needed for advanced technologies to detect and remove mercury, arsenic, selenium and other components from the aqueous streams of coal-based power plants should effluent standards be tightened in the future.

Fate of As, Se, and Hg in a Passive Integrated System for Treatment of Fossil Plant Waste Water

Tennessee Valley Authority (TVA) and EPRI are conducting a three-year study of a passive treatment technology to remove trace levels of arsenic, mercury, and selenium, as well as ammonia and nitrate from fossil power plant wastewater. An extraction trench containing zero-valent iron for removal of trace contaminants is included in the study in order to evaluate an integrated passive treatment system for removal of these trace compounds. This project will be complete in 2006.

Demonstrating a Market-Based Approach to the Reclamation of Mined Lands in West Virginia

EPRI is demonstrating a market-based approach to abandoned mine land (AML) reclamation by creating marketable water quality and carbon emission credits. The project involves the reclamation of thirty acres of AML in West Virginia through (1) the installation of a passive system to treat acid mine drainage, (2) application of fly ash as a mine soil amendment, and (3) reforestation for the capture and sequestration of atmospheric carbon dioxide (CO_2). Water quality and CO_2 uptake will be measured and the costs and environmental benefits of the remedial treatments will be developed. Potential eco-credits include water quality credits due to decreased acid mine drainage and other benefits resulting from the soil amendment, as well as potential credits for CO_2 sequestration due to more than 36,000 seedlings to be planted at the site. This project will be completed in 2005.

Novel Anionic Clay Adsorbents for Boiler-Blow Down Waters Reclaim and Reuse

The University of Southern California is conducting a feasibility study of using novel anionic clay sorbents for treating and reusing power plant boiler blowdown water that can contain metals such as arsenic and selenium.[24] Currently, it is difficult to economically and effectively clean this waste stream as flow rates are high and the metals concentrations are at trace levels. The goal of this project is to develop an inexpensive clay-based adsorbent that can be used to treat the high-volume, low-concentration wastewater stream. This project will be complete in August 2005.

Specifically Designed Constructed Wetlands: A Novel Treatment Approach for Scrubber Wastewater

Clemson University will evaluate pilot-scale constructed wetland treatment systems for treatment of trace elements in coal-fired power plant FGD wastewater. The overall goal of this project is to decrease arsenic, mercury, and selenium concentrations in FGD wastewater to achieve applicable discharge limitations. Specific objectives are to: 1) measure trace element removal performance; 2) determine wetland treatment system biogeochemical reactions and rates; and 3) measure changes in the bioavailability of the trace elements (e.g. toxicity of sediments in constructed wetlands and toxicity of outflow waters from the treatment system). The pilot-scale constructed wetland treatment system consists of a 6,800 liter (L) upstream equalization basin followed by three parallel treatment trains. Each of the treatment trains includes four 378-L cells – two wetland cells planted with bulrush, a gravel manganese oxidation cell, and a wetland cell planted with cattails. Both simulated and actual FGD wastewater samples will be included in the evaluation. This project will be complete in August 2005.

SUMMARY

Freshwater resources and reliable and secure electrical energy are inextricably linked. Thermoelectric generation requires a sustainable, abundant, and predictable source of water and is second only to irrigation as the largest user of freshwater in the United States. As the demand for electricity increases, so will the need for water for power generation. However, thermoelectric power plants will increasingly compete with demands for freshwater by the domestic, commercial, agricultural, industrial, and in-stream use sectors. In addition, current and future water-related environmental regulations and requirements will continue to challenge power plant operations. As such, there will be increasing pressure to retire existing plants and deny permits for new power plants due to water availability and quality issues.

In response to this challenge to national energy sustainability and security, DOE's Office of Fossil Energy/NETL is carrying out an R&D program focused on the development and application of advanced technologies and concept to better manage how power plant use and impact freshwater. Research is currently underway to assess and develop non-traditional sources of cooling and process water, advanced cooling water technologies, innovative water reuse and recovery technologies, and advanced wastewater treatment and detection technologies. It is anticipated that this research will help to alleviate potential conflicts between growing demands for electricity and increasing pressures on the Nation's freshwater resources. For more information on NETL's power plant water R&D activities, please visit: http://www.netl.doe.gov/coal/E&WR/water/index.html.

DISCLAIMER

Reference in this article to any specific commercial product or service is to facilitate understanding and does not imply endorsement by the U.S. Department of Energy.

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