

## **Department of Energy/National Energy Technology Laboratory's Power Plant-Water R&D Program**

Thomas J. Feeley, III<sup>1</sup>, Sara Pletcher<sup>1</sup>, Barbara Carney<sup>1</sup>, and Andrea T. McNemar<sup>2</sup>

<sup>1</sup> U.S. Department of Energy, National Energy Technology Laboratory, 626 Cochrans Mill Road, P.O. Box 10940 Pittsburgh, PA 15236-0940

<sup>2</sup> Science Applications International Corporation, 626 Cochrans Mill Road, P.O. Box 10940 Pittsburgh, PA 15236-0940

### **ABSTRACT**

Thermoelectric power plants utilize significant quantities of water for generating electrical energy. For example, a 500 MW power plant that employs once-through cooling uses over 12 million gallons per hour of water for cooling and other process requirements. The United States Geological Survey (USGS) estimates that thermoelectric generation accounts for approximately 136,000 million gallons per day (MGD) of freshwater withdrawals, ranking only slightly behind agricultural irrigation as the largest source of freshwater withdrawals in the United States. 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 2004 to 453 GW in 2030.<sup>1</sup> 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 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 Innovations for Existing Plants (IEP) Program in the following four areas: non-traditional sources of process and cooling water; innovative water reuse and recovery; advanced cooling technology; and advanced water treatment and detection technology

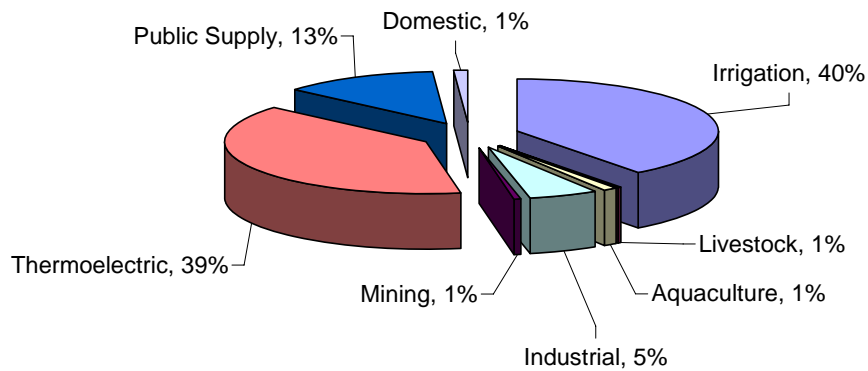
### **INTRODUCTION**

With U.S. population and electricity needs projected to grow steadily in the first quarter of the 21st century, the relationship between energy and water resources – and developing a sustainable approach to the challenges that lie ahead – is of paramount importance. Since a growing population consumes more food, the two largest water users – energy and agriculture – will be competing for limited resources with other sectors such as domestic, industrial, ecological and recreational. Other issues – including general accessibility of freshwater supplies, protecting aquatic ecosystems adjacent to energy production or power generation facilities, the impact of

plentiful, affordable energy supplies on water price and availability, and the inter-dependency between the water and carbon cycles – further complicate the energy-water nexus.

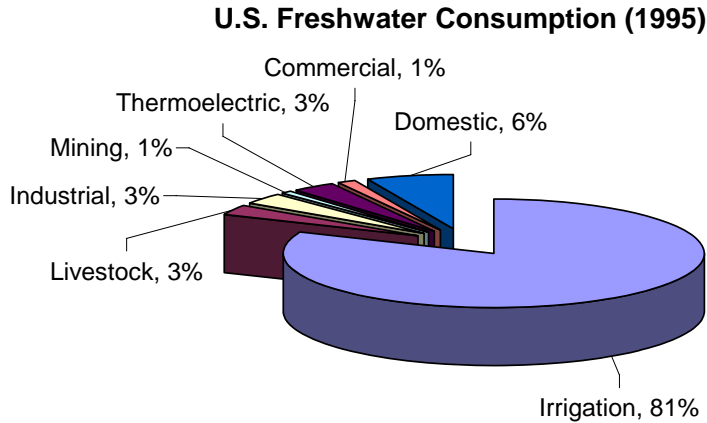
Concerns over limited water quantities are not restricted to thermoelectric generation. According to a United States Geological Survey (USGS) report<sup>2</sup> on water use, 346 billion gallons of freshwater were withdrawn *per day* in the United States in the year 2000. The largest use, agricultural irrigation, accounted for 40% of freshwater withdrawn (see Figure 1). The second largest use, thermoelectric generation, withdrew 136 billion gallons per day (BGD), followed by public supply, industrial uses, aquaculture, domestic use, mining, and livestock. Interestingly, thermoelectric generation withdrew the largest amount of saline water, 60 BGD (96% of all saline withdrawn). Withdrawal of saline water (and other non-traditional waters) reduces the strain on freshwater supplies and is one research area facilitated by the IEP program.

### U.S. Freshwater Withdrawal (2000)



**Figure 1. Percent of freshwater withdrawal by use category<sup>3</sup>**

Freshwater consumption for the year 1995 (the most recent year for which this data is available) is presented in Figure 2. Water consumption differs from water withdrawal in that withdrawal denotes all water that is taken from the water source. Consumed water refers to the amount of water that is lost (typically by evaporation) and not returned to the source. Freshwater consumption for thermoelectric purposes appears low (only 3%) when compared to other use categories. However, even at 3% consumption, over 3 BGD is consumed, which is equivalent to consuming the volume of more than 4,500 Olympic sized swimming pools each day. As a result of growing public pressures to withdraw less water, coupled with requirements under Section 316(b) of the Clean Water Act, consumption will likely increase significantly due to greater use of closed-loop cooling systems. Due to the evaporation losses, close-loop cooling technology consumes far more water than once-through cooling systems.



**Figure 2. Percent of freshwater consumption by use category<sup>4</sup>**

Because freshwater supply is limited, choices will have to be made regarding withdrawal and consumption of this natural resource. As with all resources, tradeoffs will occur, and concerns will increasingly be raised over which use is more important: water for drinking and personal use, growing food, or energy production. In addition to these water uses, increased value is being placed on in-stream freshwater uses, consisting mainly of habitat/species protection and recreational uses. In-stream uses will require a minimum flow rate or depth to be maintained in water bodies.

As part of a broader energy-water activity, DOE/NETL has embarked on a research program to develop advanced concepts and technologies that will reduce both the withdrawal and consumption of freshwater by thermoelectric power systems. This R&D effort responds to critical issues, barriers, challenges, and research needs that have been identified by key stakeholders including the electric utility industry, coal, oil, and natural gas developers, Federal and state regulatory agencies, equipment suppliers, universities, and research laboratories.

### **STATE OF THE INDUSTRY**

Traditionally, power plant owners have had ready access to the necessary quantities of water required for cooling purposes, and have been able to choose from technologies (open-loop and closed-loop) that offered flexibility in terms of cost, performance, water supply sources, siting, etc. As concern over water availability and the ecological impacts of water intake structures grew, this flexibility has diminished. Water supply issues are increasing in importance for existing power plant owners and for developers of new power plants. Many existing power plant owners are investigating the viability of non-traditional or “impaired” water for plant process purposes. At the Martin Drake Power Plant in Colorado Springs, for example, Colorado Springs Utilities modified its plant to accommodate water from the local wastewater treatment facility. The main motivation behind this project was the extended drought that impacted Colorado and other western states for the past five-plus years, which raised public concern and placed considerable strain on available water supplies. Other examples include the Limerick Nuclear Plant and several small fluidized bed combustion boilers in Pennsylvania, which are all using mine pool water for cooling. Multiple power plants around the country, mostly in the west, have shifted to non-traditional waters, and this trend is expected to continue where non-traditional water sources are available in sufficient quantities to support power plant operation.

For companies considering the development of new thermoelectric power plants, water is a first-order concern. Federal, state, regional and local entities are all actively pursuing opportunities to conserve water. Environmental and other special purpose groups are also getting involved in water availability issues. For example, concerns about water supply and availability played a large role in Xcel Energy's decision to equip its new Comanche 3 Power Plant near Pueblo, Colorado with a hybrid cooling system. Xcel's original design was based on a 100% wet cooling system, but due in part to pressure from local and regional interest groups, Xcel adopted the hybrid system. Hybrid cooling uses both air and water for cooling and results in about 50% less water consumption than a conventional closed-loop wet cooling system.

Dry cooling is also gaining some traction in the power industry. Air-cooled condensers have been installed at several power plants in recent years, predominantly for new natural gas-fired combined-cycle power plants. Only one operating U.S. coal-fired power plant uses dry cooling: the 360 MW Wyodak plant in Wyoming. No nuclear power plants use dry cooling. This reflects the lack of experience with dry cooling at large scale. The use of hybrid cooling technology, therefore, might emerge as a middle-ground option in the siting, permitting and public acceptance activities undertaken by plant developers in certain locations.

Although industry has begun to implement some alternative technologies to reduce freshwater withdrawal and consumption, such as the use of nontraditional water for cooling or the use of dry cooling towers, application of these technologies remains limited. In most cases, these options are not economically feasible and plant owners are concerned about potential process impacts as well as the long-term availability of an impaired water source. Additionally, innovative water recovery approaches, such as flue gas dehumidification or reductions in cooling tower evaporative loss, are not being pursued by industry at this time. Additional research and development is necessary to bridge the gap between current industry practices and the critical need for technologies that enable thermoelectric plants to withdraw and consume less freshwater in an economically feasible manner.

## **REGULATORY IMPACTS**

The power industry must comply with a variety of local, state and federal regulations pertaining to water acquisition, use, and quality. The cooling water intake structure regulations established under the Clean Water Act, Section 316(b) will likely have the greatest impact on long-term water withdrawal and consumption patterns in the power sector. Designed to protect aquatic life from inadvertently being killed by intake structures at power stations and certain manufacturing facilities, Section 316(b) requires EPA to ensure that the "location, design, construction and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impact."

The largest design impact of 316(b) compliance is that most new power plants will be required to implement closed-loop, recirculating cooling systems or dry (air-cooled) systems. Open-loop systems are strongly discouraged unless the permit applicant can demonstrate that alternative impingement mortality and entrainment (IM&E) measures can provide a reduction level comparable to that achieved through closed-loop cooling or that the compliance costs, air quality

impacts, and/or energy generation impacts would outweigh the IM&E benefits and justify an open-loop system.

Because 316(b) portends a greater reliance on closed-loop cooling systems, water withdrawal and consumption patterns for the thermoelectric power sector are destined to change over time. Even accounting for significant thermoelectric capacity additions, water withdrawal levels will likely remain relatively constant. Water consumption, on the other hand, is expected to increase substantially since closed-loop cooling systems consume more water, due to evaporation, than open-loop systems.

Existing and future air quality regulations will also affect water withdrawal and consumption patterns, although to a lesser extent than cooling water regulations. Tighter emission levels for sulfur dioxide, for example, have sparked a mini-boom in the flue gas desulfurization (FGD) market. The size of the U.S. FGD market is expected to increase by more than 100,000 megawatts (MW) over the next 10 years. Although FGD water requirements are a fraction of those required for cooling purposes, FGD units require a significant amount of water to produce and handle the various process streams. Makeup water requirements for the FGD system at a 550 MW subcritical coal-fired power plant are about 570 gallons per minute (gpm), versus about 9,500 gpm for cooling water makeup.<sup>5</sup>

Several other regulatory actions warrant attention due to their potential impact on water withdrawal and consumption. Under section 303(d) of the 1972 Clean Water Act, states, territories, and authorized tribes are required to develop a list of impaired waters not meeting water quality standards and then establish total maximum daily loads (TMDL) for these waters. TMDL requirements could potentially constrain a power plant's ability to discharge cooling water and waste water streams that contain trace metals and other pollutants. The power plant may then be required to seek an alternate water source or install additional water treatment equipment.

## **POWER PLANT WATER PROJECTIONS**

Thermoelectric generating capacity is expected to increase by nearly 22% between 2005 and 2030, based on the Energy Information Administration's (EIA) *Annual Energy Outlook 2006* (AEO 2006) projections.<sup>6</sup> A water needs analysis conducted by DOE/NETL in 2004 suggested that national freshwater withdrawals may increase slightly or decline depending on assumptions, while freshwater consumption will likely increase dramatically.<sup>7</sup> However, regional water impacts can be significantly different than national data averages might suggest. To characterize the significance of the regional impacts on water use, further analysis was conducted in 2006 comparing regional electricity demand and capacity forecasts with representative water withdrawal and consumption estimates to identify regions where water issues might become acute.

Future freshwater withdrawal and consumption requirements for the U.S. thermoelectric generation sector were estimated for five cases, using AEO 2006 regional projections for capacity additions and retirements:

Case 1 – Additions and retirements are proportional to current water source and type of cooling system.

Case 2 – All additions use freshwater and wet recirculating cooling, while retirements are proportional to current water source and cooling system.

Case 3 – 90% of additions use freshwater and wet recirculating cooling, and 10% of additions use saline water and once-through cooling, while retirements are proportional to current water source and cooling system.

Case 4 – 25% of additions use dry cooling and 75% of additions use freshwater and wet recirculating cooling. Retirements are proportional to current water source and cooling system.

Case 5 – Additions use freshwater and wet recirculating cooling, while retirements are proportional to current water source and cooling system. Five percent of existing freshwater once-through cooling capacity is retrofitted with wet recirculating cooling every five years starting in 2010.

Summary results for the five cases, on a national basis, are presented in Table 1. For all cases, withdrawal is expected to decline, and consumption is expected to increase. These results are consistent with current and anticipated regulations and industry practice, which favor the use of freshwater recirculating cooling systems that have lower withdrawal requirements, but higher consumption requirements, than once-through cooling systems. Case 5 provides the most extreme water consumption impacts. Converting a significant share of existing once-through freshwater power plants to recirculating freshwater plants significantly reduces water withdrawal, but significantly increases water consumption. Case 4 indicates that dry cooling could have a significant impact on water consumption; compared to Cases 1-3, which have an average consumption of 8.1 BGD, Case 4 results in a 7% decline, equivalent to more than 200 billion gallons per year.

**Table 1 - Thermoelectric Water Impacts, National Results**

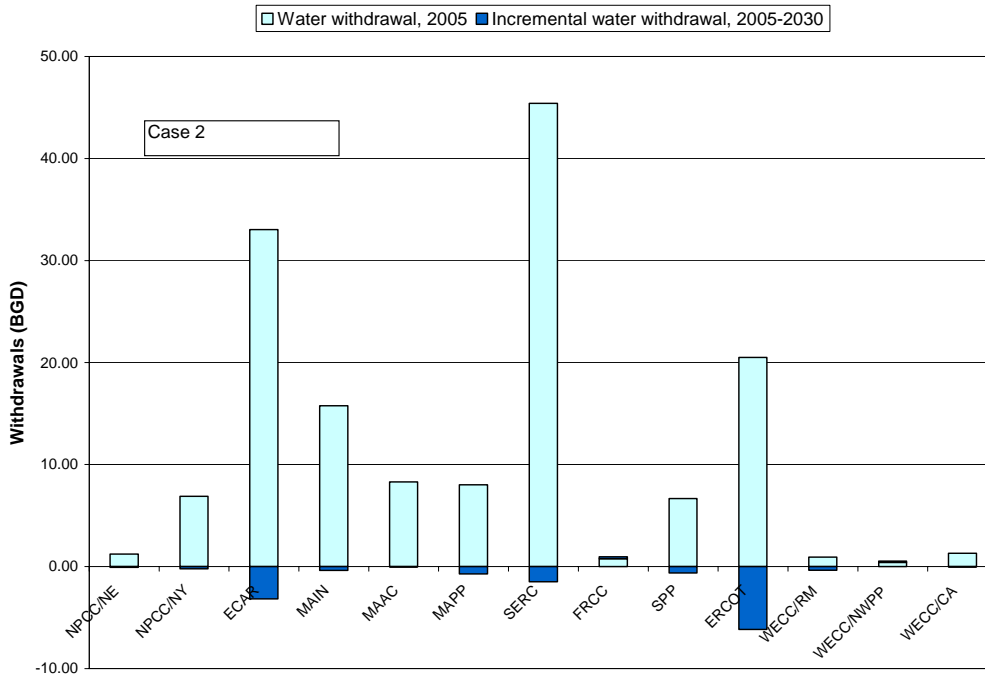
		Freshwater withdrawal or consumption (BGD)					
		2005	2010	2015	2020	2025	2030
Case 1	Withdrawal	149.2	152.7	145.6	147.6	148.8	148.4
	Consumption	6.2	6.6	6.8	7.3	7.6	7.9
Case 2	Withdrawal	149.2	149.4	141.0	138.6	138.0	136.3
	Consumption	6.2	6.7	6.9	7.5	7.9	8.2
Case 3	Withdrawal	149.2	149.4	140.9	138.5	137.9	136.1
	Consumption	6.2	6.6	6.9	7.4	7.8	8.1
Case 4	Withdrawal	149.2	149.3	140.8	138.3	134.6	135.4
	Consumption	6.2	6.6	6.8	7.3	7.4	7.5
Case 5	Withdrawal	149.2	137.7	122.7	114.2	109.4	103.7
	Consumption	6.2	6.9	7.4	8.2	8.7	9.2

The year 2005 was used as a baseline against which to measure projected future withdrawal and consumption. Using this baseline, Table 2 was generated to show the percent change from the 2005 baseline for each of the future years. The negative values in Table 2 for withdrawal indicate decreased withdrawal while the positive consumption values indicate increasing consumption over time.

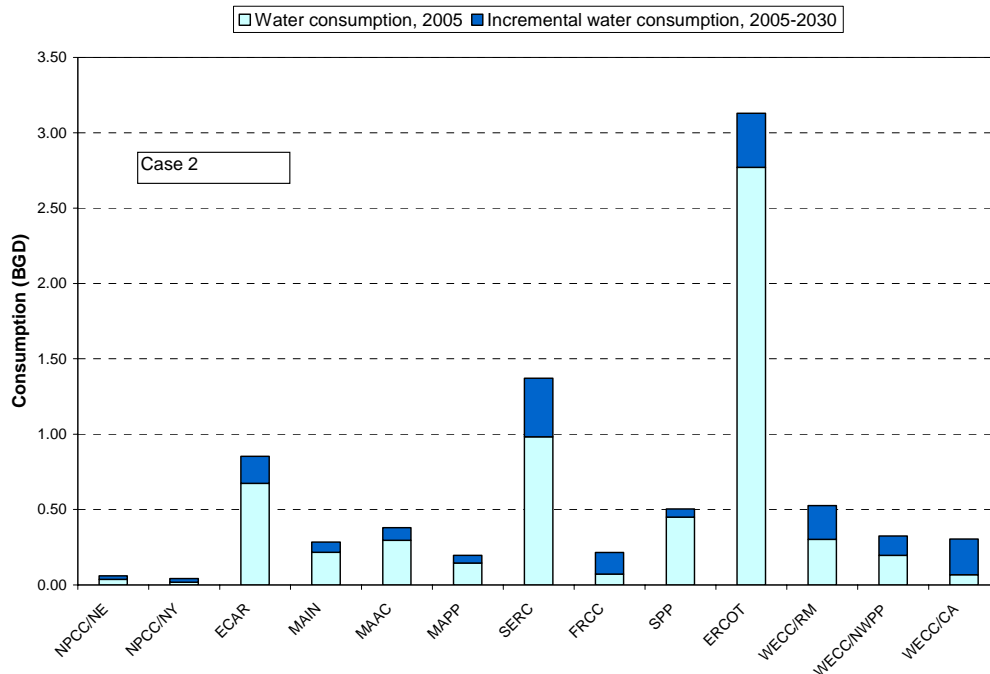
**Table 2 – Percent Change from 2005 Baseline, National Results**

		Percent change from 2005 baseline				
		2010	2015	2020	2025	2030
Case 1	Withdrawal	2.3	-2.4	-1.1	-0.3	-0.5
	Consumption	6.5	9.7	17.7	22.6	27.4
Case 2	Withdrawal	0.1	-5.5	-7.1	-7.5	-8.6
	Consumption	8.1	11.3	21.0	27.4	32.3
Case 3	Withdrawal	0.1	-5.6	-7.2	-7.6	-8.8
	Consumption	6.5	11.3	19.4	25.8	30.6
Case 4	Withdrawal	0.1	-5.6	-7.3	-9.8	-9.2
	Consumption	6.5	9.7	17.7	19.4	21.0
Case 5	Withdrawal	-7.7	-17.8	-23.5	-26.7	-30.5
	Consumption	11.3	19.4	32.3	40.3	48.4

The regional component of the 2006 water needs analysis revealed some significant differences from the national averages. For example, consider Case 2, which represents a plausible future cooling system scenario. The national percent changes in Table 2 indicate that water withdrawal will fall by 8.6% and that water consumption will rise by 32.3% between 2005 and 2030. As shown in Figure 3 and Figure 4, on a regional basis, however, water withdrawal ranges from a 25% increase in Florida to a 30% decline in Texas; and while freshwater consumption increases in all regions, the biggest gains come in California (352%), Florida (199%), New York (132%) and the Rocky Mountain/desert southwest region (74%).



**Figure 3 – Average Daily Regional Freshwater Withdrawal for Thermolectric Power Generation – Case 2**



**Figure 4 - Average Daily Regional Freshwater Consumption for Thermolectric Power Generation – Case 2**

The regional results reflect recent U.S. population shifts. Regions with strong population growth, such as the southeast and southwest, exhibit high growth in water consumption requirements, while regions with minimal to modest population growth, such as the Midwest and mid-Atlantic, exhibit modest growth in water consumption requirements.

#### **DOE/NETL ENERGY-WATER RESEARCH**

Under the Strategic Center for Coal, the IEP Program is a comprehensive R&D effort focused on the development of advanced technologies to enhance the environmental performance of the existing fleet of coal-fired power plants, with application to new plants as well. The need to address pressing and impending water related issues (ranging from a need to control bio-fouling of plant's water intake structures to a need to design less water intensive cooling systems) was identified through stakeholder input from workshops, meetings, and other research activities. In response, the IEP program was broadened in 2002 to include research directed at energy-water issues, focusing specifically in the following areas: non-traditional sources of process and cooling water; innovative water reuse and recovery; advanced cooling technology; and advanced water treatment and detection technology. The program area's goal is to ensure that technologies are available by 2015 that if widely deployed could reduce power plant freshwater withdrawal and consumption by 5% to 20% while minimizing the impacts of power plant operation on water quality. Two competitive solicitations have been performed, with five projects awarded in August 2003 and seven in November 2005. The following sections provide brief summaries of the IEP R&D projects being conducted in each of the four areas.



## **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 stringent than many other applications such as drinking water supplies or agricultural applications, so opportunities exist for the utilization of lower-quality, impaired water sources. Sponsored research includes analysis of the use of water from abandoned underground coal mines to supply cooling water to power plants; analysis of the use of natural gas and oil produced waters to partially meet power plant cooling water needs; development and demonstration of mine water usage to cool thermoelectric power plants; development of membrane separation and scale-inhibitor technologies to enable power plant use of impaired waters; and pilot-scale demonstration of a variety of impaired waters for cooling.

### Strategies for Cooling Electric Generating Facilities Utilizing Mine Water

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.<sup>8</sup> Coal mine discharge not only has the potential to reduce freshwater power plant cooling requirements, but also can improve the efficiency of the cooling process due to lower water temperatures associated with deep-mine discharges. 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 would provide makeup water requirements for a 600 MW plant equipped with a closed-loop recirculating cooling system. The second scenario would provide all cooling water required for a 600 MW plant equipped with a closed-loop recirculating cooling system utilizing a flooded underground mine as a heat sink.

The study identified eight potential sites under the first scenario. Three of the sites were further evaluated for preliminary design and cost analysis of mine pool water collection, treatment, and delivery. The cost analysis concluded that depending on site conditions and water treatment requirements, utilization of mine pool water as a source of cooling water makeup can be cost competitive with freshwater makeup systems. 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. 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 2005.

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

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 make-up cooling water demand for the mechanical draft cooling towers at the 1,800 MW San Juan Generating Station (SJGS) located near Farmington, New Mexico.<sup>9</sup> Two major issues are associated with this use of produced water: (1) collecting and transporting the produced water to the plant and (2) treatment of the produced water to lower the total dissolved solids (TDS) concentration.

There are over 18,000 oil and gas wells in the San Juan Basin in New Mexico, where SJGS is located, that generate over 2 MGD of produced water. Most of the produced water is collected in tanks at the wellhead and transported by truck to local saltwater disposal facilities. SJGS evaluated an approach for transportation of produced water to the plant site. 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. Produced water must be treated prior to use at the plant in order to reduce TDS to an acceptable level. The most economical treatment method found was use high efficiency reverse osmosis with a brine concentrator distillation unit. This project was finalized in 2006.

#### Development and Demonstration of a Modeling Framework for Assessing the Efficacy of Using Mine Water for Thermoelectric Power Generation

A 300 megawatt power plant (Beech Hollow Power Plant) has been proposed to burn coal refuse from the Champion coal refuse pile. Figure 5 depicts the site. Plans called for use of public water at 2,000 to 3,000 gpm. Numerous surface and underground mines exist within six miles of the proposed power plant. Under this project, West Virginia University's National Mine Land Reclamation Center will locate, sample, and determine the flow under wet and dry weather conditions of mine discharges in the vicinity of the proposed plant. This data will be integrated with power plant water requirements and environmental considerations to design a mine water collection, treatment, and delivery system to meet the power plant's water needs.



**Figure 5. Beech Hollow Power Plant Site**

Using the data and decision-making process derived in this project, a computer-based design tool will be developed for estimating the cost of water acquisition and delivery to the power plant. The cost of mine water use by power plants will be compared to the cost of using traditional

water supplies, including surface water and public water supplies. In addition, the potential environmental improvements resulting from the utilization of mine water currently contaminating area streams will be documented. This project will be completed in 2007.

#### Advanced Separation and Chemical Scale Inhibitor Technologies for Use of Impaired Water in Power Plants

The overall objective of this project, conducted by Nalco Company in partnership with Argonne National Laboratory, is to develop advanced-scale control technologies to enable coal-based power plants to use impaired water in recirculating cooling systems. The use of impaired water is currently challenged technically and economically due to additional physical and chemical treatment requirements to address scaling, corrosion, and biofouling. Figure 6 displays an example of pipe scaling.



**Figure 6. Example of Pipe Scaling**

Researchers will work to establish quantitative technical targets, develop scale inhibitor chemistries for high stress conditions, and determine the feasibility of membrane separation technologies to minimize scaling. Subsequently, researchers will develop selected separation processes and optimize the compatibility of technology components at the laboratory scale. Finally, integrated technologies will be tested using selected pilot scale model sites to validate the performance. If successful, the technology developed will make the use of impaired waters by coal-fired power plants more feasible. The new technologies developed have the potential to: reduce the volume of make-up water required for recirculating cooling systems; reduce the volume of water generated from cooling tower blowdown; and lower the cost of using impaired water to a point that is as cost efficient as using freshwater. This project will be completed in 2009.

#### Reuse of Treated Wastewaters in the Cooling Systems of Coal-Based Power Plants

The objective of this study, conducted by the University of Pittsburgh and Carnegie Mellon University, is to assess the potential of three types of impaired waters for cooling water makeup in coal-based plants. The impaired waters to be studied include the following: secondary treated municipal wastewater; passively treated coal mine drainage; and ash pond effluent. To determine the feasibility of impaired water use, the following activities will be conducted: assessment of the availability and proximity of impaired waters at twelve power plant locations; assessment of regulations and permitting issues relevant to use of impaired waters; determination

of general water quality of the three types of impaired waters being studied and specific water quality of impaired waters at the selected sites; construction and testing of model cooling towers; field testing of key operational parameters for the cooling system operated with the three different impaired waters; development of a mathematical model for water quality characteristics in cooling systems operated with different impaired waters; and assessment of the treatment needs for the cooling tower discharge streams.

The technology developed will make use of impaired waters by coal-fired power plants more feasible by providing necessary information on geographic proximity, pretreatment requirements, available quantities, and regulatory and permitting issues. Additionally, key design and operating parameters will be determined to aid in successful use of the impaired waters without detrimental impact on cooling system performance. This project will be completed in 2009.

### **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. Sponsored research includes development of cost effective liquid desiccant-based dehumidification technology to recover water from plant flue gas; analysis of power plant waste heat to dry low-rank coals; diffusion-driven desalination to allow a power plant that uses saline water for cooling to become a net producer of freshwater; investigation of the use of condensing heat exchangers to recover water from boiler flue gas; and demonstration of regenerative heat exchange to reduce freshwater use in plants with wet flue gas desulfurization systems.

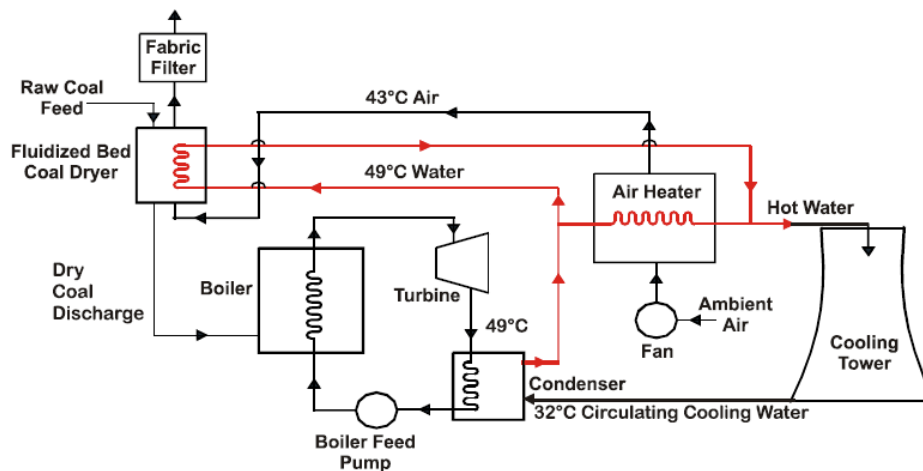
#### Water Extraction from Coal-Fired Power Plant Flue Gas

The University of North Dakota's Energy & Environmental Research Center (UNDEERC) developed a technology to extract water vapor from coal-fired power plant flue gases.<sup>10</sup> The project's objectives were to: 1) develop a cost-effective liquid desiccant-based dehumidification technology to recover water in plant flue gas; and 2) perform an engineering evaluation to determine how this technology could 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. 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. A desiccant selection and characterization evaluation was conducted, and one of the desiccants was selected for initial pilot-scale testing, the results of which indicated that performance of the system was better than predicted by chemical process models. Extracted water quality was good and off-gas of undesirable species from the solution was minimal. This project was finalized in 2006.

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

Lehigh University conducted 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.<sup>11</sup> While bituminous coals have minimal moisture content (less than 10%), low-rank coals contain significant amounts of water – subbituminous and lignite coals contain 15-30% and 25-40% respectively. In Lehigh's project, the process heat from condenser return cooling water was extracted upstream of the cooling tower in order to warm ambient air that was then used to dry the coal. A schematic of the plant layout is shown in Figure 7. Lowering the temperature of the return cooling water reduced evaporative loss in the tower, thus reducing overall water consumption.



**Figure 7. Plant Layout Schematic for Coal Drying**

In addition, drying the coal prior to combustion can improve the plant heat rate, and in return reduce overall air emissions. Variations of this approach were also being evaluated such as 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. Lehigh's project was finalized in 2006.

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

The University of Florida investigated an innovative diffusion-driven desalination process to allow power plants that use saline water for cooling to become net producers of freshwater.<sup>12</sup> 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 freshwater 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.

A diffusion driven desalination facility was designed that could produce 1.03 MGD of freshwater 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 was performed and showed that production cost was competitive with the costs associated with reverse osmosis or flash-evaporation technologies. This project was finalized in 2006.

#### Recovery of Water from Boiler Flue Gas

Conducted by Lehigh University, this project will be a combination of laboratory and pilot scale experiments and computer simulations to investigate use of condensing heat exchangers to recover water from boiler flue gas at coal-fired power plants.<sup>13</sup> Researchers will conduct computational fluid mechanics analyses to aid in the design of the compact fin tube heat exchanger that will condense water vapor from flue gas. The extent to which removal of acid vapors from flue gas and condensation of water vapor can be achieved in separate stages of the heat exchanger system will be determined via laboratory and pilot plant experiments. The technology developed will provide coal-fired utilities with a method of producing water from flue gas that would otherwise be evaporated from the stack. This water would then be available for power plant operations such as cooling tower or FGD make-up water. An added benefit of cooling the flue gas to remove water is the potential to remove vapor phase sulfur trioxide/sulfuric acid, and to utilize the rejected sensible and latent heat in the boiler or turbine cycle resulting in increased boiler efficiency. This project will be completed in 2008.

#### Reduction of Water Use in Wet FGD Systems

The project team, consisting of URS Group, Inc. as the prime contractor, EPRI, Southern Company, Tennessee Valley Authority (TVA), and Mitsubishi Heavy Industries, will demonstrate the use of regenerative heat exchange to reduce flue gas temperature and minimize evaporative water consumption in wet FGD systems on coal-fired boilers. Researchers will conduct pilot-scale tests of regenerative heat exchange to determine the reduction in FGD water consumption and assess the resulting impact on air pollution control systems. The tests are intended to determine the impact of operation at cooling flue gas temperatures on FGD water consumption, electrostatic precipitator (ESP) particulate removal, SO<sub>3</sub> removal, and Hg removal.

This project will demonstrate use of regenerative heat exchange to reduce evaporative consumption. Additionally, it will demonstrate possible benefits due to flue gas being cooled upstream of the ESP, such as: control of SO<sub>3</sub> emissions by condensation on fly ash; improved particulate control by the ESP due to reduced gas volume and lower ash resistivity; avoided costs associated with flue gas reheat or wet stacks; and potential additional reduction in native Hg removal in the ESP due to operation at a cooler flue gas temperature. This project will be completed in 2008.

### **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. Sponsored research includes pilot scale testing of a hybrid cooling technology; testing of an environmentally safe control method to prevent zebra mussel fouling; development of high thermal conductivity foam to be used in air cooled steam condensers for power plants;

evaluation of condensing technology applied to wet evaporative cooling towers; and development of scale-prevention technologies and novel filtration methods.

#### Development of Hybrid Cooling Water System

In conjunction with the produced water feasibility study conducted at the San Juan Generating Station, EPRI also conducted 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.

At SJGS this system was used as auxiliary cooling for condenser cooling water. The spray water was blowdown water from the existing cooling towers. Testing was performed to determine to what extent the WSAC could concentrate untreated cooling tower blowdown before thermal performance was compromised. It was also 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 was skid mounted and consisted of three separate tube bundles. Each bundle was constructed of a different metal to evaluate the corrosion potential of the degraded water. The pilot unit was instrumented to monitor thermal performance, conductivity of the spray water, and corrosion. This project was finalized in 2006.

#### Environmentally-Safe Control of Zebra Mussel Fouling

Zebra mussels are small, fingernail-sized bivalves that can live in rivers and lakes in enormous densities. They can attach to almost any hard surface with their adhesive basal threads. The colonization of zebra mussels on cooling water intake structures can lead to significant plant outages.<sup>14</sup> 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 evaluating 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. Testing is being conducted on the house service water treatment system for Rochester Gas and Electric Corporation’s Russell Station that withdraws 4 to 5 MGD from Lake Ontario.

The research suggests 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 be cost competitive. Laboratory experiments to define key nutrients required to produce more toxin per bacterial cell are underway. This project was finalized in 2006.

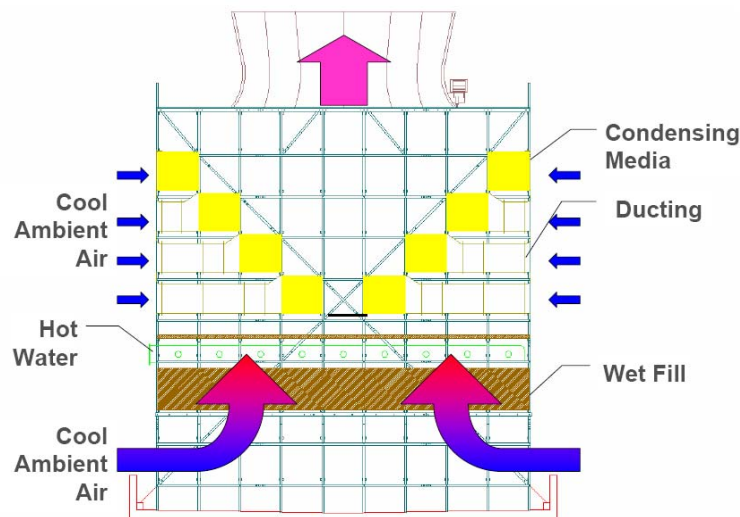
#### Enhanced Performance Carbon Foam Heat Exchanger for Power Plant Cooling

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 while enhancing water conservation within the power industry. The development of this technology will help power plants meet §316(b) requirements through the prevention of adverse environmental impacts such as organism intake, warm water discharge, and wet or hybrid tower evaporation. This project was completed in 2006.



### Use of Air2Air™ Technology to Recover Fresh-Water at Thermoelectric Power Plants

SPX Cooling Systems will evaluate the performance of its patented Air2Air™ condensing technology (displayed in Figure 8) in cooling tower applications at coal-fired electric power plants. Researchers will quantify Air2Air™ water conservation capabilities with results segmented by season and time of day. They will determine the pressure drop and energy use during operation. Additionally, SPX Cooling Systems will analyze water quality and identify potential on-site processes capable of utilizing the recovered water. Research conducted will also examine freezing condition operation. A wet/dry air mixing system will be developed for plume abatement, and the dissipation of the plume discharged from the cooling tower fan will be studied. The project could demonstrate significant water savings due to recovery using the condensing technology. This project will be completed in 2008.



**Figure 8. Air2Air™ Technology**

### Application of Pulsed Electrical Fields for Advanced Cooling in Coal-Fired Power Plants

Drexel University will be conducting research to develop a scale prevention technology based on novel filtration and an integrated system of physical water treatment in an effort to reduce cooling tower blowdown. The filter will be a self-cleaning metal membrane, utilizing electrical pulses to rapidly polarize water molecules on the filter membrane such that water molecules are pulled to the membrane, pushing out the attached particles, which will then be removed by reject flow. Development of the system will be followed with validation testing. Potential benefits from this research include the ability to operate at a higher cycle of concentration, which will reduce cooling tower blowdown water requirements (which also reduces the amount of freshwater make-up needed). Additional environmental benefits are expected due to the reduction in the use of chemicals for scaling and bio-fouling prevention. This project will be completed in 2009.



## **Advanced Water Treatment and Detection Technology**

Future controls on the emission of mercury (Hg) 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. Sponsored research includes study of the fate of arsenic (As), selenium (Se), and Hg in a passive integrated treatment system for fossil plant waste water; demonstration of a market-based approach to abandoned mine land reclamation by creating marketable water quality and carbon emission credits; utilization of anionic clay sorbents for treating and reusing power plant effluent; and evaluation of wetland use to treat plant scrubber wastewater.

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

Hg, As, and Se are pollutants often present at trace-levels in power plant flue gas and wastewater. In addition, ammonia “slip” from selective catalytic reduction systems (SCRs) for reduction of NO<sub>x</sub> emissions can appear in wastewater streams such as FGD effluents and ash sluice water. TVA and EPRI are conducting a three-year study of a passive treatment technology to remove trace levels of As, Se, and Hg as well as ammonia and nitrate from fossil power plant wastewater at the Paradise Fossil Plant near Drakesboro, Kentucky. An extraction trench containing zero-valent iron is being evaluated as an integrated passive treatment system for removal of these trace compounds and wetlands are being used for denitrification.

Objectives of this project include to: (1) design and install an extraction trench; (2) monitor the movement of As, Se, and Hg through the treatment system; (3) assess the removal efficiency of As, Se, and Hg from power plant wastewater by each component of the treatment system; and (4) determine the effect of each component of the treatment system on the speciation of As, Se, and Hg. This project was completed in 2006.

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

EPRI demonstrated a market-based approach to abandoned mine land (AML) reclamation by creating marketable water quality and carbon emission credits. The project involved the reclamation of thirty acres of AML in West Virginia through installation of a passive system to treat acid mine drainage. Site layout is presented in Figure 9. Water quality was measured and conventional economic principals were used to develop the costs and environmental benefits of the remedial treatments. Potential environmental credits considered included water quality credits due to decreased acid mine drainage and other benefits resulting from the soil amendment, as well as potential credits at other sites for CO<sub>2</sub> sequestration. This project will be finalized in 2006.



**Figure 9. Site Layout Including Location of Passive Treatment Channels**

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

The University of Southern California studied the utilization of novel anionic clay sorbents for treating and reusing power plant effluents.<sup>15</sup> Concerns exist about heavy metals, such as Hg, As and Se, that can be found at low levels in power plant effluents. Since the waste stream flow rates are high and the metals concentrations are at trace levels, it is difficult to effectively clean the water. As a result, highly efficient treatment techniques are required. The University of Southern California studied the feasibility of applying novel sorbents to treat, recycle, and reuse boiler blow-down streams. The goal of this project was to develop an inexpensive clay-based adsorbent that could be used to treat high-volume, low-concentration wastewater containing arsenic and selenium. This project was completed in 2005.

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

This research evaluated specifically designed pilot-scale constructed wetland treatment systems for treatment of targeted constituents in coal-fired power plant FGD wastewater. The overall objective of this project was to decrease targeted constituents, Hg, Se, and As concentrations, in FGD wastewater to achieve discharge limitations established by NPDES and CWA. Specific objectives of this research were: (1) to measure performance of this treatment system in terms of decreases in targeted constituents (Hg, Se and As) in the FGD wastewater; (2) to determine how the observed performance is achieved (both reactions and rates); and (3) to also measure performance in terms of decreased bioavailability of these elements (i.e. toxicity of sediments in constructed wetlands and toxicity of outflow waters from the treatment system).

## **Program Successes**

The IEP Program's energy-water research began only a few years ago. However, program successes are already evident:

- Based in part on a study of underground mine pools and their water chemistry and levels, Longview Power LLC has decided to utilize mine pool water for all of the make-up water needs for its coal-fired power plant planned for construction in northern West Virginia. In addition to withdrawing no freshwater for the plant, the water use plan is expected to improve watershed conditions by removing, treating, and using the mine pool acid mine drainage (AMD) instead of the AMD discharging to local waterways.
- Research at the San Juan Generating Station in New Mexico showed that oil and natural gas produced waters could be used for 2 MGD of the plant's make-up waters, lowering the plant's freshwater withdrawals while reducing the volume of produced water that must be disposed.
- Successfully demonstrated at a 550 MW plant that coal drying can be used to reduce evaporative loss by up to 380 gpm.
- Completed a nationwide and regional assessment of freshwater needs based on the EIA's 2006 Annual Energy Outlook energy demand projections.
- Developed and demonstrated at pilot scale the use of power plant waste heat to produce freshwater by powering a diffusion driven desalination process.
- Developed and demonstrated at pilot scale the use of a liquid desiccant-based absorption water recovery technology to recover up to 50 percent of flue gas moisture.
- Facilitated the development of bacteria that specifically attack zebra mussels, resulting in improved cooling water flow and efficiency improvements.

## **CONCLUSIONS**

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/NETL is carrying out an R&D program focused on the development and application of advanced technologies and concepts to better manage how power plants 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 DOE/NETL's power plant water R&D activities, please visit:  
<http://www.netl.doe.gov/technologies/coalpower/ewr/water/index.html>.

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