ADDRESSING THE CRITICAL LINK BETWEEN FOSSIL ENERGY AND WATER

The Department of Energy/Office of Fossil Energy's Water-Related Research, Development, and Demonstration Programs

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October 2005

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INTRODUCTION

The production of energy from fossil fuels (coal, oil, and natural gas) is inextricably linked to the availability of adequate and sustainable supplies of water. While providing the United States with almost 60% of its annual energy needs[a], fossil fuels also place a high demand on the Nation's water resources in terms of both use and quality impacts.[1] Thermoelectric generation is water intensive – on average each kilowatt-hour (kWh) of electricity generated via the steam cycle requires approximately 25 gallons of water[b] to produce. According to the United States Geological Survey (USGS), power plants rank only slightly behind irrigation in terms of freshwater withdrawals in the United States.[2] Water is also required in the mining, processing, and transportation of coal to generate electricity all of which can have direct impacts on water quality. Surface and underground coal mining can result in acidic, metal-laden water that must be treated before it can be discharged to nearby rivers and streams. In addition, the USGS estimates that in 2000 the mining industry withdrew approximately 2 billion gallons per day of freshwater. Although not directly related to water quality, about 10% of total U.S. coal shipments were delivered by barge in 2003.[3] Consequently, low river flows can create shortfalls in coal inventories at power plants. Natural gas and oil production can displace significant quantities of ground water. Approximately 10 barrels (420 gallons) of "produced water" are pumped to the surface for each barrel of oil in the U.S.[4] The development of coalbed natural gas resources, commonly referred to as coalbed methane (CBM), can also generate a substantial volume of produced water that may require expensive treatment and disposal. Water management issues can and do materially impact domestic natural gas and oil development projects – at a time when commodity prices are extremely high and additional supplies are sorely needed.[5]

As our population increases and economic development continues, the demand for fossil energy will grow, putting additional stress on the Nation's water resources. At the same time, fossil energy's demands for water will increasingly compete with demands from other sectors of the economy such as public supply, agriculture, domestic, livestock, industrial, and in-stream use – particularly in regions of the country with limited freshwater supplies. In response to this challenge, the Department of Energy's Office of Fossil Energy (DOE/FE) is carrying out an integrated energy-water research, development, and demonstration (RD&D) effort that cuts across its coal, oil, and natural gas programs. This paper presents background information on the link between energy and water and summarizes the current water-related RD&D activities currently being sponsored by DOE/FE and implemented by the National Energy Technology Laboratory (NETL) in the areas of (1) fossil-fuel-based thermoelectric power generation, (2) coal mining, and (3) oil and natural gas production.

[a] This number is based on a calculation of consumption in 2003 by residential, commercial, industrial, and transportation.

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

FOSSIL-FUEL-BASED THERMOELECTRIC POWER GENERATION

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 the withdrawal of approximately 25 gallons of water, primarily used for cooling purposes. 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.[6]

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

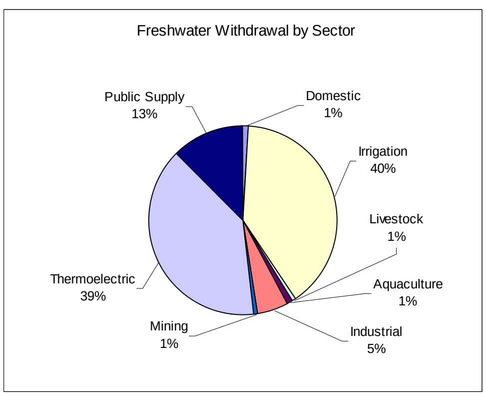
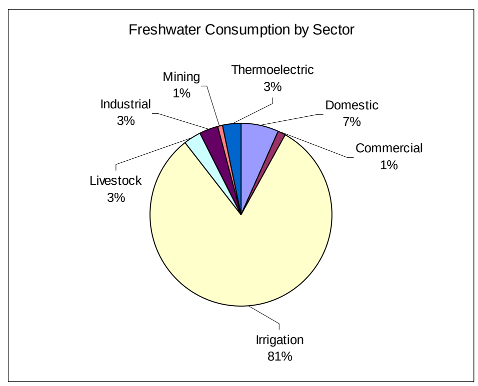


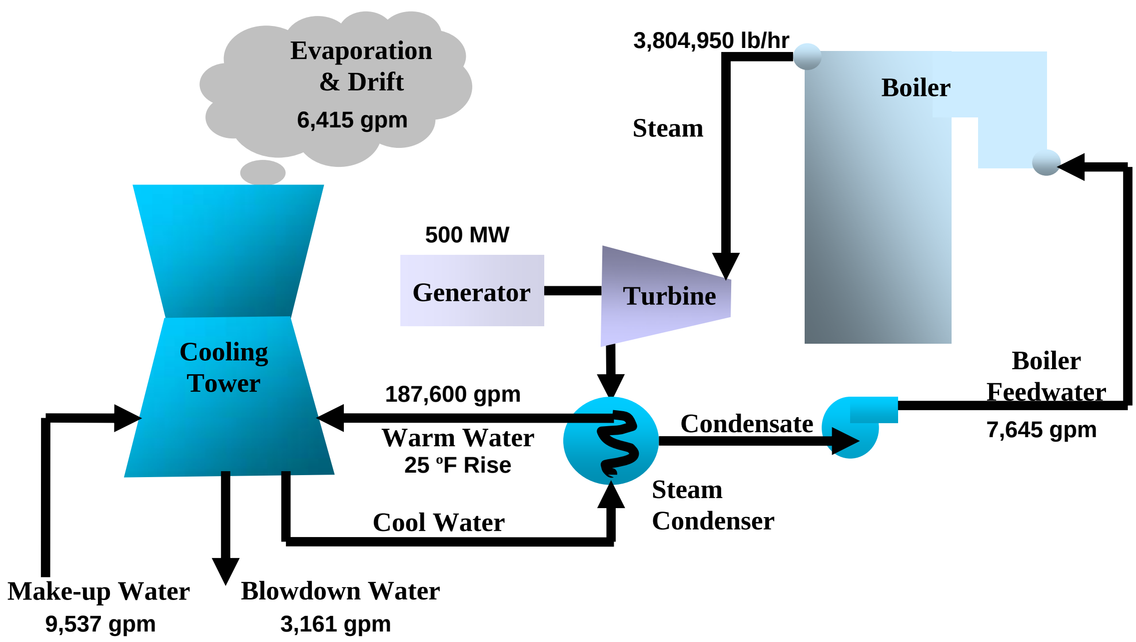
Figure 2 – U.S. Freshwater Consumption (1995)



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 generator or boiler. 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 500 MW coal-fired plant are shown in Figure 3.

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



Wet recirculating 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.[7] 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.[8]

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 Government Accountability 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.[9] 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.[10] 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.[11] 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.[12] 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.[13] 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.[14] 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.[15] 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.[16] 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.[17]

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.

Innovations for Existing Plants Program

NETL's IEP Program is a comprehensive R&D effort directed at the development of advanced technologies 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.[18] 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 assessments, analyses, and laboratory through pilot-scale testing and is performed in partnership 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[19], water displaced by geological carbon sequestration, 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 Water Research Institute
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.[20] The amount of mine water available, the quality of the water, and the types of water treatment needed are all factors 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 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 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 – Electric Power Research Institute (EPRI)
This study is evaluating 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 million gallons per day (MGD) of cooling water demand at the San Juan Generating Station (SJGS) in

New Mexico.[21] 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 is evaluating a two-phased approach for transportation of produced water to the plant site. 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 produce water transport in the second phase.

Cooling water currently used at the SJGS is withdrawn from the San Juan River and contains only 360 mg/L of TDS. Water quality is an issue when using produced water to supplement plant cooling water requirements due to high TDS concentrations. Produced water from CBM and natural gas extraction has a TDS concentration ranging from 5,440 to 60,000 mg/L. For comparison, seawater contains 26,000 mg/L. 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 is to use high efficiency reverse osmosis with a brine concentrator distillation unit. This project will be completed in 2005.

Innovative Water Reuse and Recovery

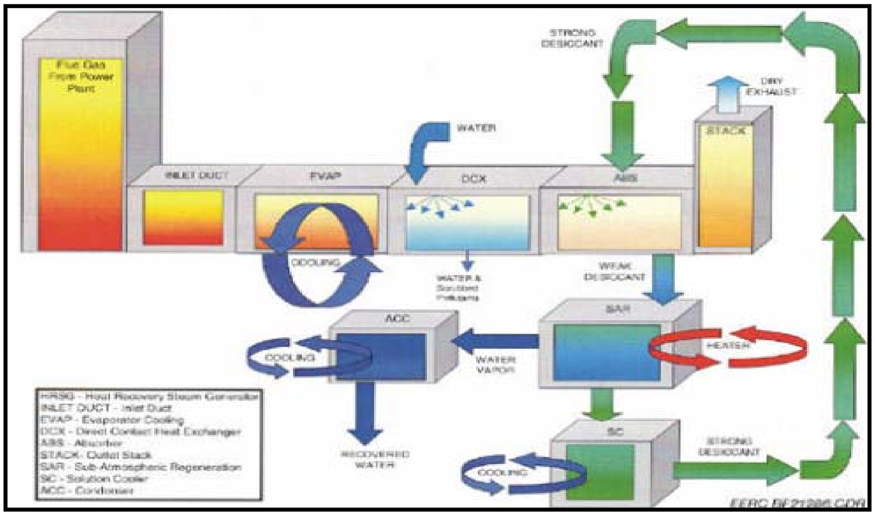
Research is currently underway to develop advanced technologies to reuse power plant cooling water and associated waste heat and investigate methods to recover water from coal and power plant flue gas. Such advances have the potential to reduce fossil fuel power plant water withdrawal and consumption.

Water Extraction from Coal-Fired Power Plant Flue Gas - University of North Dakota Energy & Environmental Research Center (UNDEERC)
The primary purpose of this project is to develop 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.[22] 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 releases additional water. The amount of water potentially available for recovery from the flue gas is sufficient to substantially reduce the need for freshwater makeup.

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, which 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



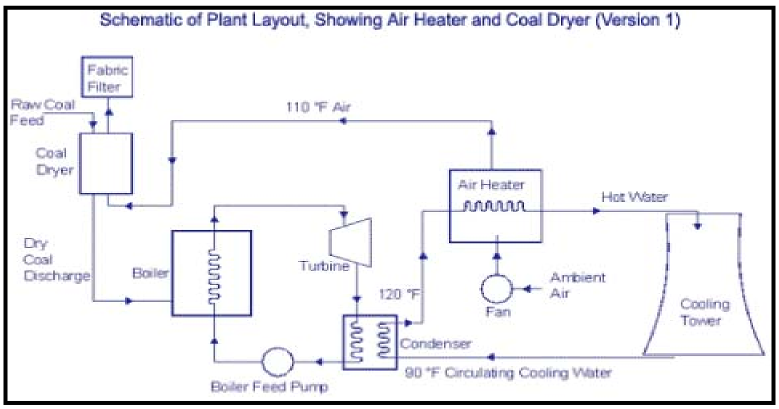
To date, a desiccant selection and characterization evaluation has been conducted by ranking the merits of potential desiccants based on physical and chemical data along with laboratory testing. One of the desiccants was selected for initial pilot-scale testing. Data from the pilot-scale testing show 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 completed in September 2005.

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

The purpose of this project is to determine the feasibility of using low-grade power plant waste heat to dry low-rank coals prior to introduction into the boiler.[23] Heat from condenser cooling water is extracted upstream of the cooling tower and 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, thus reducing overall air emissions. Figure 5 shows a schematic of the plant layout with the air heater and coal dryer.

To date, coal drying experiments were performed with lignite and PRB coals to determine the effects of inlet air moisture level on the equilibrium relationship between coal moisture and exit air relative humidity and temperature. Analyses were also performed to determine the effect of lignite product moisture on unit performance for a high temperature drying system. With this process design, energy for drying is obtained from the hot flue gas entering the air preheater and the hot circulating cooling water leaving the steam condenser. Comparisons were made to the same boiler operating with lignite which had been dried off-site. Lehigh will continue working on system drying analyses. The calculations will be extended to other drying systems, the projected impacts on emissions and cooling tower makeup water will be determined and work will begin on gathering cost data for components such as heat exchangers, fans and fluidized bed dryers. The project will be completed in December 2005.

Figure 5 - Schematic of Plant Layout



An Innovative Fresh Water Production Process for Fossil Fired Power Plants Using Energy Stored in Main Condenser Cooling Water - University of Florida
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.[24] 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 waste heat with very low thermodynamic availability. Cool air, a by-product of this process, can be used to cool nearby buildings.

To date, a diffusion driven desalination (DDD) facility as been developed and using this process waste heat from a 100 MW plant could produce 1.03 MGD of fresh water. 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 - New York State Education Department
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. They can attach to almost any hard surface with their adhesive basal threads.[25] The colonization of zebra mussels on cooling water intake structures can 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 a 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.

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 be cost competitive. Laboratory experiments to define key nutrients required to produce more toxin per bacterial cell are underway, and progress has been achieved. 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
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 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. 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) & EPRI
Mercury, arsenic, and selenium 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 NOx 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 arsenic, selenium, and mercury as well as ammonia and nitrate from fossil power plant wastewater. An extraction trench containing zero-valent iron is being evaluated as 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
EPRI will demonstrate a market-based approach to abandoned mine land (AML) reclamation by creating marketable water quality and carbon emission credits. The project will involve 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 conventional economic principals will be used to develop the costs and environmental benefits of the remedial treatments. 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 the more than 36,000 seedlings planned for the site. This project will be complete in 2005.

Novel Anionic Clay Adsorbents for Boiler-Blow Down Waters Reclaim and Reuse – University of Southern California
The University of Southern California will study the utilization of novel anionic clay sorbents for treating and reusing power plant effluents.[26] Concerns exist about heavy metals, such as mercury (Hg), arsenic (As) and selenium (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 will study the feasibility of applying novel sorbents to treat, recycle and reuse boiler blow-down streams. The goal of this project is to develop an inexpensive clay-based adsorbent that can be used to treat high-volume, low-concentration wastewater containing arsenic and selenium. This project will be complete in August 2005.

Specifically Designed Constructed Wetlands: A Novel Treatment Approach for Scrubber Wastewater – Clemson University
This research will evaluate 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 is to decrease targeted constituents, mercury, selenium, and arsenic concentrations, in FGD wastewater to achieve discharge

limitations established by the National Pollution Discharge Elimination System (NPDES) and Clean Water Act (CWA). Specific objectives of this research are: 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). This project will be complete in August 2005.

As part of the IEP program a second competitive solicitation was issued in April 2005 entitled "Advanced Technologies and Concepts to Minimize Freshwater Use in Coal-Based Thermoelectric Power Plants." NETL anticipates making multiple awards under this solicitation in the areas of non-traditional water use, advanced water recovery and reuse technology, advanced cooling technology, and reuse of water from geological sequestration. Projects are expected to be awarded in late 2005.

Advanced Power Systems

In addition to the research being conducted under the IEP program, NETL is developing an advanced power system known as Integrated Gasification Combined Cycle (IGCC) that can reduce overall thermoelectric power plant water withdrawals and consumption. IGCC is a technology that efficiently converts coal to a synthesis gas that may be used in a gas turbine for power production. Roughly two-thirds of power generated in an IGCC is in the gas turbine. The waste heat from the gas turbine is used to produce steam in a heat recovery steam generator that is used to power a steam turbine which produces the remaining one-third of power. Pulverized coal (PC) plants, on the other hand, generate all power with the steam turbine. Since the gas turbine doesn't require cooling water, IGCC plants require appreciably less cooling water on a gallons/kWh output basis compared to a similar capacity PC plant.

COAL MINING

Coal Mining Impact on Water Quality

The mining and preparation of coal for use in thermoelectric generation can impact the availability and quality of freshwater resources. The USGS estimates that the U.S. mining industry withdrew approximately 2 BGD of freshwater in 2000[c]. United States coal production in 2002 was 1,094 million short tons, of which 571 million tons was bituminous according to the EIA.[27] It is estimated that about three quarters of bituminous coal is cleaned at preparation plants to reduce the ash and sulfur content and increase the coal's heating value.[28] Coal preparation plants use an average of 13 gallons of water for each ton of coal cleaned, which would be equivalent to a total of 5.5 billion gallons of

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[c] The USGS mining water-use estimate includes all mineral extraction industries, as well as oil and natural gas recovery.

water used in 2002.[29] As a result, U.S. water consumption for coal cleaning represents about 0.5% of the freshwater consumption by thermoelectric generation.

The water discharge from mine pools in abandoned underground coal mines – known as acid mine drainage (AMD) − is mostly uncontrolled and in many regions is a major pollution source to rivers, streams and groundwater supplies. The mine pools are formed after coal is excavated from the mine and the resultant void space fills with surface and/or groundwater. No viable beneficial use of the enormous volumes of mine pool water currently exists. EPA estimates that approximately 10% of the 270,000 miles of pollution-impaired rivers and streams in the United States is a result of natural resource extraction operations.[30] It has been estimated that over 4,000 miles of rivers and streams are affected by AMD.[31]

NETL In-House Research and Development

The Geosciences Division of NETL's Office of Science, Technology and Analysis conducts research directed at water issues related to the cradle-to-grave use of fossil energy. These activities focus on developing a better understanding of hydrological and geological systems that are impacted by the extraction and use of fossil fuels, including remote sensing systems and advanced technologies that simplify and reduce the cost and complexity of AMD treatment operations and make use of the beneficial properties of mine water. The following section describes projects currently being carried out by NETL's in-house water team in the areas of (1) airborne geophysical mapping and (2) mine pool discharge treatment and beneficial use.

Airborne Geophysical Mapping

Understanding surface and groundwater systems requires the large-scale geophysical mapping of these hydrological features. Historically, such large-scale mapping, data processing, and interpretations were not technologically feasible. Consequently, the understanding of these systems had been limited. NETL is breaching these barriers by pioneering the application of airborne sensing and geophysical technologies as new tools for the assessment of watershed-scale areas. Remote sensing and geophysical technologies developed over the past fifty years (primarily as mineral exploration tools and for defense purposes) are now being applied to water-related fossil fuel issues. NETL is integrating these technologies with recent developments in global positioning satellites (GPS), geographical information systems (GIS), and improved computer technologies to create new and powerful analytical tools. NETL's expertise is such that it is frequently funded by outside agencies to conduct research to solve real-world water-related problems. Meanwhile, NETL continues to evaluate additional airborne technologies that can provide subsurface data from deeper horizons, apply airborne technologies to new fossil fuel related issues, and refine data processing approaches that will progress into expert systems and better decision making models. Current efforts are being focused on sites that have known environmental problems.

State of Maryland

NETL had previously surveyed approximately 30 square miles of the Kempton Mine Complex, which underlies portions of West Virginia and Maryland, using airborne frequency domain electromagnetic technology. The State of Maryland is currently evaluating and verifying these data. NETL has developed software that provides a view of each individual flight line (at 30 meter spacing) and the corresponding conductivity depth image that is processed from the airborne data. The outcome of this work will allow NETL customers hands-on opportunities to review and evaluate airborne data with user-friendly software and prioritize field efforts.

Large-Scale Mapping of Contaminated Mine Pools Using Airborne Geophysical Surveys

NETL will evaluate the use of a new airborne geophysical technique − time domain electromagnetic conductivity − for the large-scale mapping of contaminated pools in abandoned underground coal mines in Pennsylvania and West Virginia. Previous attempts to map mine pools using frequency domain electromagnetic technology were limited to a depth of 150 feet. If successful, the use of time domain electromagnetic conductivity technology will provide much deeper (300 – 800 ft) data needed to map underground mine pools and geology. This data will provide researchers information needed to: 1) predict the timing and location of mine pool overflows; 2) plan in situ or closed-loop treatment of contaminated mine water; 3) assess the quality, quantity, and location of potential water supplies (e.g., power plant usage); and 4) mitigate the hazards posed by unmapped flooded mines, i.e., the Quecreek Mine scenario[d]. Furthermore, the accurate mapping of mine pools will significantly increase the efficiency and economics for recovering methane from abandoned coal mines.

Coal Slurry Impoundments

During the coal preparation process, slurry consisting of water and coal fines is generated as a waste product that is disposed of in surface impoundments. These coal slurry impoundments, particularly in the mountainous regions of WV and KY, are constructed as a valley fill. Historically, several large failures of these impoundments have occurred, resulting in loss of life and significant environmental damage. Impoundment failures can result from poorly designed or clogged drainage systems in the earthen dam, or collapse of the impoundment floor due to mine subsidence beneath the impoundment. Furthermore, due to the poor mapping practices of early mining operations, the proximity or presence of an underground mine may be unknown. Airborne electromagnetic surveys of 14 coal slurry impoundments have been completed and NETL is currently evaluating the data. If successful in mapping groundwater in earthen dams and mine pools beneath the impoundments, potential failures can be targeted, corrected, and avoided. This technology should also be applicable to detecting potential problems at tailings ponds, the failure of which has caused major environmental problems at metal mines around the world. This project will be completed in December, 2005.

[d] In 2002, nine miners were trapped underground for three days in the flooded Quecreek mine in Somerset, PA.

Fate and Transport of Coal Bed Methane Produced Waters
NETL is evaluating the use of helicopters equipped with electromagnetic technologies − known as helicopter electromagnetic (HEM) − for mapping produced waters from coalbed methane (CBM) extraction in Wyoming's Powder River Basin. CBM produced waters can be disposed of in impoundments, discharged to receiving streams, or used for agricultural irrigation. HEM can be used to evaluate hydrological and geological features under produced water impoundments. Specifically, HEM results will be tested for its ability to detect salt accumulations in the vadose zone. Salt accumulations should be avoided when locating new impoundments because infiltrating water will dissolve the salt and contaminate underlying aquifers. Near-surface conductivity maps appear to accurately show the location of salt accumulations. This information has the potential to streamline permitting of new impoundments, while protecting the quality of underlying aquifers. Furthermore, HEM data appears to be able to predict groundwater flow paths beneath the Powder River floodplain. Groundwater movement in this area is predominantly within the paleochannels of the ancestral Powder River. HEM data can be used to delineate these buried channels and therby predict the flow direction for infiltrating produced water. Knowing this will enable hydrologists to predict the residence time for produced water within the shallow aquifer system and to determine how much of this water will ultimately enter the Powder River and how much will infiltrate to deeper, bedrock aquifers. This phase of the project will end in FY 2005, when the focusof the project will shift to developing methodology to minimize or reduce the adverse environmental effects.

Mine Pool Treatment and Beneficial Use

Mine drainage, which can be controlled through pump and treat operations, represents a long-term economic burden. Water treatment operations involve passive or active systems. Passive treatment systems are generally applied to low flow discharges and require significant surface area. Active treatment systems are generally complex with energy consuming equipment to pump the water, add chemicals, and aerate the water. Active treatment also requires enhanced sludge settling and disposal operations. NETL's research efforts focus on reducing land requirements and treatment costs through the use of water-powered technologies. In addition, due to the relatively large volumes of flowing (controlled and uncontrolled) water and its constant 55°F temperature, NETL is pursuing the development of mine pools as a geothermal energy source for heat pumps and as a small-scale hydroelectric power source.

Water-Powered Treatment Systems
NETL has constructed and is currently evaluating a water-powered treatment system at an abandoned anthracite mine site that discharges over 1,000 gpm of mine pool water. Three different water-powered treatment technologies have been employed at this site and are currently being used in series for treating about 600 gpm. These technologies include a diversion well that uses limestone as a pre-treatment, an overshot water-wheel feeder that uses lime as a final treatment, and an overshot water-wheel pump used to pump sludge out of the settling pond. A pond and wetland are used for settling and filtration, respectively, and the land requirements are significantly reduced because of

this configuration   In addition, due to the gradient of the surface stream, the production of hydroelectric power using a micro turbine is being pursued as a means of off-setting the $5,000 per year cost for chemical treatment. If successful, acid and metal loads on the main tributary will be significantly reduced, ensuring suitable habitat for fish and other aquatic wildlife.

Semi-Passive Water Treatment
An overshot water-wheel powered lime feeder has been installed at a standard aerobic wetland. By a minor adjustment of pH, the precipitation of iron is accelerated and land requirements are reduced significantly. If successful, semi-passive treatment technology could be applied in cases where adequate land requirements would not support standard passive treatment systems.

Geothermal Applications using Mine Pools
Significant cost savings can be realized using geothermal heat pump technology. Conventional geothermal heat pumps use underground refrigerant coils in either a horizontal or vertical configuration. The installation of these coils can be very expensive and limits the use of this technology. An alternative of using the ground as a geothermal source is using underground mine pool water. There exists an enormous quantity of mine pool water in Pennsylvania and West Virginia. The abandoned mine areas associated with just the Pittsburgh coal seam discharge over 45 billion gallons of water every year and is likely to increase as the mines continue to fill.[32] Currently, this water is being discharged without any effort to recover its geothermal energy. NETL and an industry partner recently completed a white paper addressing the potential of coupling geothermal heat pump technology with mine pools. If this technology were applied to the entire flooded Pittsburgh coal basin alone, up to 86,000 tons of heating and cooling could be provided – enough to heat and cool 34.4 million square feet, or over 17,000 homes for an entire day. This technology could save approximately 374,000 MWh per year compared to standard electrical heating and cooling systems and 204,000 MWh compared to conventional heat pumps. DOE funding of this effort is scheduled to end in FY 2005 but the state of Pennsylvania may provide funds for a field-scale evaluation in downtown Pittsburgh.

NATURAL GAS AND OIL PRODUCTION

Produced Water from Natural Gas & Oil Extraction

The production of natural gas and crude oil results in significant quantities of water being produced along with recovery of the commodities. According to the American Petroleum Institute, about 18 billion barrels (bbl) (756 billion gallons)[e] of produced water was generated by U.S. onshore operations during 1995.[33] Additional large volumes of produced water are generated at U.S. offshore wells and at thousands of wells in other

[e] 1 barrel equals 42 gallons.

countries. It is estimated that an average of 210 million bbl (8820 million gallons) of water was produced each day in 1999 worldwide.[34] Clearly, natural gas and oil production activities have an impact on both the availability and quality of U.S. surface and groundwater resources.

Exploration and production (E&P) operations can potentially impact surface and groundwater resources in a variety of ways. For example, concerns have been expressed that hydraulic fracturing – a production enhancement technique in which fluids and proppant[f] are pumped at high pressures into wells to create a high conductivity *crack* in a hydrocarbon bearing formation – can impact underground sources of drinking water (USDW). Production operations can also result in local aquifer drawdown. Once withdrawn from wells, management of produced waters (e.g., surface discharge, impoundment, and crop irrigation) can affect surface water quality in addition to having impacts on riparian zones, and flora and fauna in general.

Produced water comprises approximately 98% of the total volume of E&P waste generated by the industry. It has been estimated that 71% of produced water is being used for improved oil recovery (IOR) operations, 21% is being injected for disposal, 5% is put to beneficial use such as livestock watering, irrigation, etc., and 3% is pumped into percolation and evaporation ponds.[35] In the United States, the volume of produced water is projected to remain on the order of 18 to 20 billion bbls (756 to 840 billion gallons) per year through 2025. DOE's target is to beneficially use 24% of the produced water volume or about 500 MGD.

The CWA and the Safe Drinking Water Act (SDWA) provide the authority to regulate produced water management and injection operations. Permits for all discharges to surface waters and injection into underground formations are governed by the National Pollutant Discharge Elimination System (NPDES) and Underground Injection Control (UIC) programs, respectively. A couple of exceptions exist with respect to surface discharges. One relates to the agricultural and wildlife water use subcategory, which requires that the produced water be of good enough quality to be used for wildlife or livestock watering or other agricultural uses and that the produced water actually be put to such use during periods of discharge. EPA regulations, 40 CFR Part 435, apply to those onshore facilities located in the continental United States and west of the 98^{th} meridian[g]. The majority of produced water is sourced west of the 98^{th} meridian. This is expected to remain the case for the next 20 years thus providing much opportunity for beneficial reuse. Figures 7 and 8 show EIA forecasts through 2025 for produced water by resource type and supply region.

The second exception relates to marginal oil wells—facilities that produce 10 barrels per day or less of crude oil. EPA has not published national discharge standards for this subcategory, effectively leaving any regulatory controls to the states or EPA's regional offices. The Interstate Oil and Gas Compact Commission reports the operation of more

[f] Examples include 20-40 mesh sand, resin coated sand, and sintered bauxite

[g] The 98^{th} meridian extends from the eastern edge of the Dakotas through central Nebraska, Kansas, Oklahoma, and Texas.

than 390,000 marginal oil wells and 261,000 stripper gas wells during 2003.[36] Generally, marginal oil and natural gas wells are owned, produced, and maintained by independent operators – producers with limited resources – and not the integrated E&P firms that operate globally. These operations create jobs and support economic growth that, while small on an individual basis, are collectively significant. The cost of pumping produced water is significant and the ability to widely transform this *liability* into an *asset* would be a boon to independent operators.

Figure 7 - Produced Water by Resource Type based on AEO-2004 Reference Case

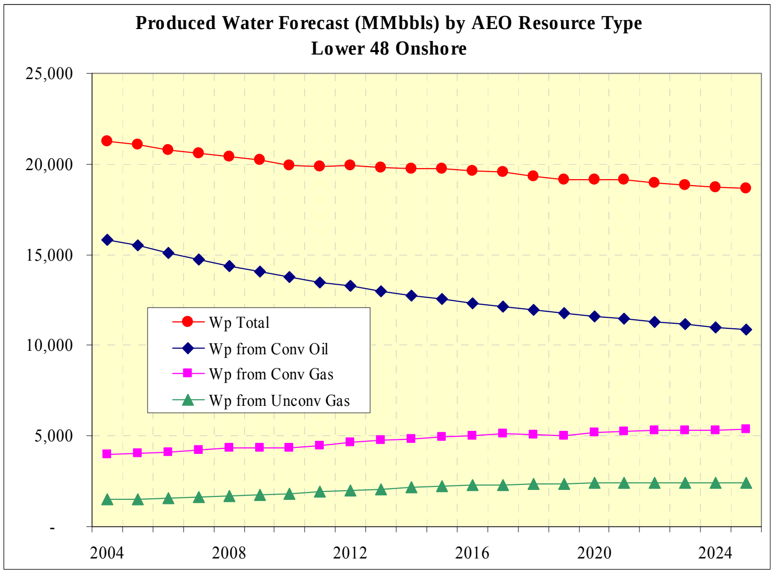
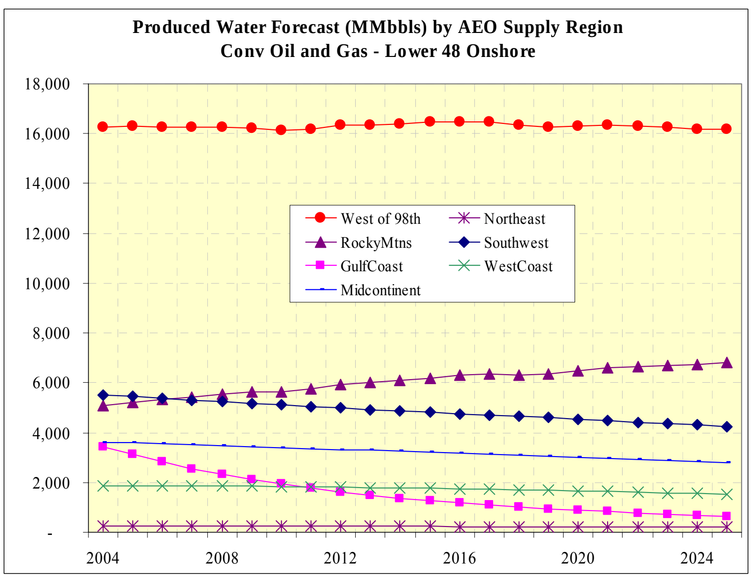


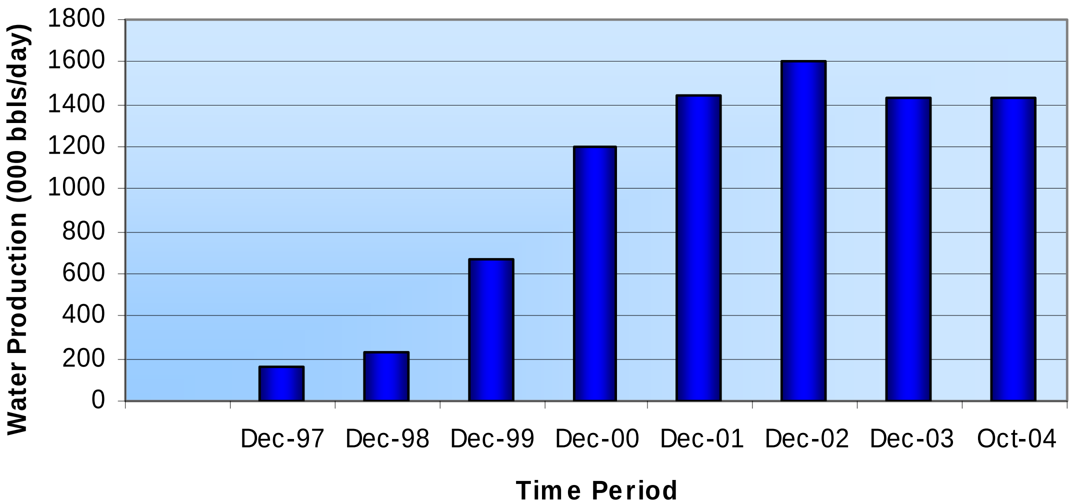
Figure 8 - Produced Water Forecast by AEO-2004 Supply Region



CBM development provides a ready illustration of the energy-water nexus. Large volumes of groundwater are pumped to the surface during CBM production in order to reduce the hydrostatic pressure in the coalbed thus allowing desorption of the natural gas, primarily methane, from coal surfaces. During 2003, 1.6 trillion cubic feet (Tcf) of CBM was produced in the United States, which amounted to slightly more than 8% of total U.S. natural gas production. More than 80% of this total was produced out of basin and plays[h] in the Rocky Mountain region – an area where water commands a premium.

The largest natural gas development project recently undertaken in the United States is drilling and production of CBM resources in the Powder River Basin (PRB) of Wyoming and Montana. To date, more than 18,000 wells have been drilled to tap trillions of cubic feet of gas locked in a dozen or so thick, water-filled coal seams.[37] With full resource development, up to 77,000 CBM wells could be drilled in the PRB and 24 billion bbls (1008 billion gallons) of water produced.[38,39] During January 2005, daily water production from CBM operations in Wyoming was 1.5 million bbls (63 million gallons).[40] Figures 9 and 10 illustrate the rapid pace of resource development in the PRB basin including volumes of produced water. Primarily because of the associated water production and the need to cost effectively manage it, CBM development has become a highly contentious issue involving industry, regulators, environmental advocates, and landowners. Such controversy is not limited to the PRB but extends to all CBM operations – especially in the arid west.

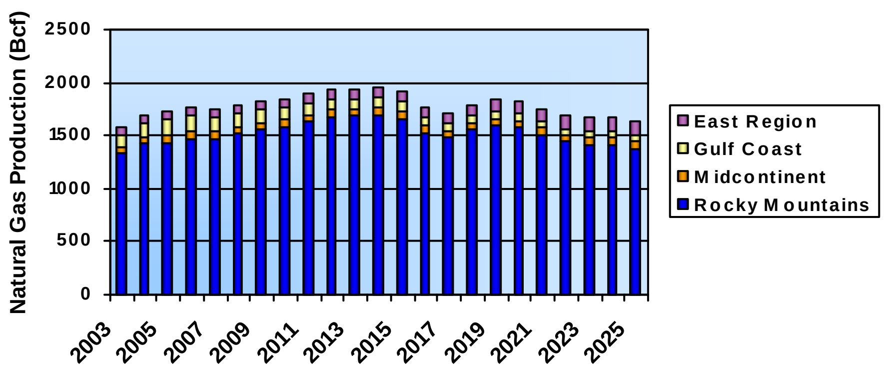
Figure 9 - Daily Water Production from Powder River Basin CBM Operations



[h] A play is a group of hydrocarbon accumulations that share a common history of hydrocarbon generation, accumulation, and entrapment.

The majority of future CBM supplies, which are projected to increase to nearly 2 trillion cubic feet per year, are expected to be produced from Rocky Mountain basins.[41] As a result, significant volumes of water will be extracted from coal seams and adjacent horizons during dewatering operations. As such, energy production and water issues should remain at the forefront.

Figure 10 - Forecast of CBM production By Supply Region through 2025



Oil and Gas Environmental Program

The Oil and Gas Environmental Program is implemented by DOE/NETL Strategic Center for Natural Gas and Oil (SCNGO) with much of the R&D based at the lab's Tulsa, OK office. The program is robust and addresses water-related issues including the injection of water for oil recovery, produced water and its effects on the environment, treatment of process waters, and the availability of water in arid lands. Individual projects fall into two general categories: 1) water management approaches and analyses and 2) water management technologies and beneficial use.

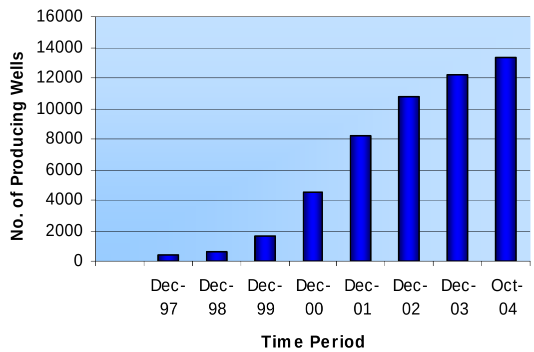
Water Management Approaches and Analysis

DOE/NETL has completed a number of assessments, forecasts, and projects to address regulatory issues, evaluate methods and strategies to improve produced water management, and to provide data and analyses in support of policy making. Coordination with local, state, and federal agencies is commonplace and many efforts are undertaken collaboratively. In some instances, impact analyses are conducted in order that all stakeholders fully appreciate and consider regulatory and policy changes affecting domestic natural gas and oil supplies. Further, these analyses also evaluate the need for new technologies and the value of their widespread adoption by industry. In some cases, technology can preclude the need for restrictive and costly regulation while providing equal or better levels of environmental protection. A brief summary of these analyses are as follows:

Coordination with U.S. EPA on Establishing Effluent Limitation Guidelines for CBM Produced Water throughout Region-8

DOE/NETL and FE are working with the U.S. EPA to develop effluent limitation guidelines (ELG's) for coalbed methane produced water in the Northern and Central Rocky Mountain Region. The initial focus of these efforts has been the PRB. Approximately one billion cubic feet of natural gas is produced from PRB coals each day. Figure 11 shows the number of producing wells in the PRB. As of January 2005, about 5,000 additional wells have been drilled but remain shut-in. Recently, a water discharge permit application was submitted for CBM operations in the Wind River Basin and DOE/NETL and FE are again collaborating with EPA and other entities.

Figure 11 - Powder River Basin CBM Development



DOE/NETL's collaborative efforts were to 1) ensure new regulations are based on sound science and engineering principles, and 2) identify resource development strategies and technologies that would preclude the need for additional regulation – yet ensure full environmental protection. These analyses and assistance are of critical importance and the efforts have attention of DOE/FE and Congress alike.[42]

Technical Assistance to US EPA – Study of the Potential Impacts to Underground Sources of Drinking Water (USDW) From Hydraulic Fracturing of Coalbed Methane Wells

Over the past decade hydraulic fracturing has become a controversial issue, especially when applied to CBM wells. The concern is whether hydraulic fracturing falls within the definition of underground injection, which is regulated under SDWA. Hydraulic fracturing is critical in meeting the U.S. natural gas and oil needs, especially when it comes to cost-effective extraction of natural gas from unconventional sources (low permeability sands, shales, and coalbeds). Recent projections indicate that natural gas production from unconventional formations is expected to increase at a faster rate, growing from 6.5 Tcf in 2003 to over 8.5 Tcf in 2025, than production from more conventional sources.[43] In recent years, about 20,000 hydraulic fracturing treatments have been pumped annually. However, since the United States will increasingly rely on natural gas as a feedstock and fuel, it is projected that 35,000 hydraulic fracturing treatments will be pumped per year through 2025. It is estimated that 75 to 80% of all new Lower-48, on-shore gas production will be produced from wells that have been hydraulically fractured.[44]

In 2004, EPA completed a study that assessed the potential impacts of hydraulic fracturing of CBM wells on USDW. The primary conclusion of that study was "that the injection of hydraulic fracturing fluids into CBM wells poses little or no threat to USDWs and does not justify additional study at this time".[45] DOE/NETL contributed substantially to the study in terms of technical expertise, data, white papers, and reviews. The current reliance of the U.S. natural gas industry on hydraulic fracturing and the projected increase in this reliance necessitate the continuation of and improvement in the safety and environmental soundness of the operation. Currently, hydraulic fracture treatments are pumped in a safe and environmentally responsible fashion in accordance with existing federal, state, and local regulations. The largest hydraulic fracturing companies voluntarily entered into a Memorandum of Agreement (MOA) with the EPA to eliminate the use of diesel fuel in fluids used to hydraulically fracture coalbed methane wells.[46] This *win-win* solution was due in large part to DOE/NETL analyses and technical assistance.

Notwithstanding the progress with respect to coalbed methane wells, myraid actions concerning hydraulic fracturing have raised stakeholder awareness and increased dialogue. Late in 2004, five members of Congress wrote to the EPA seeking an investigation of the regulation of hydraulic fracturing.[47] The decision to exempt hydraulic fracturing from UIC regulations has just recently been codified in Title III, Section 322 of the Energy Policy Act of 2005. One can only surmise that DOE/NETL's actions weighed in heavily as Congress and the Administration chose to amend the protective SDWA.

Water & Waste Regulatory Analysis - Argonne National Laboratory
There are a variety of water and waste issues that could have a significant impact on the gas and oil industry. DOE/NETL is interested in ensuring that regulatory requirements are reasonable and based on good science, while being protective of the environment. This project is designed to evaluate water and waste issues that could affect the industry, make information available to regulatory agencies, and find mechanisms to overcome regulatory barriers. Regulatory and analytical support will be provided on water and waste issues related to gas and oil exploration and production. These issues include wetlands rules, management of CBM produced water, storm water permitting, and regulations for cooling water intake structures. Argonne will review and perform a detailed technical analysis of EPA general permits and other water-related regulations proposed for gas and oil facilities, assist states with their salt cavern wastes disposal programs, and provide assistance to state and federal governments on waste management practices. This project will be completed in 2005.

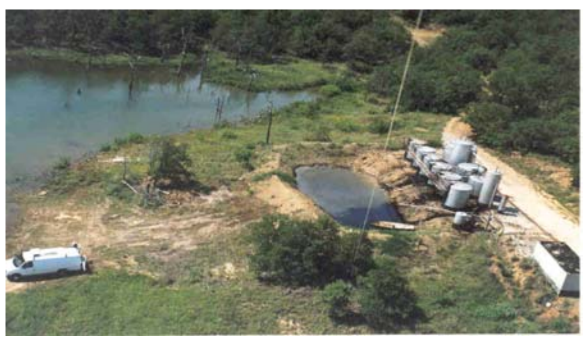
Dominquez Channel Modeling and Analysis for Pollutant Transport and Total Maximum Daily Loads - Lawrence Berkley National Laboratory
This research seeks to develop a comprehensive circulation model for understanding hydrologic cycling. The model will provide the California Environmental Protection

Agency (CAL EPA) and the State Water Quality Control Board with information leading to an improved determination of Total Maximum Daily Loads (TMDLs). Lawrence Berkley National Laboratory will implement the model for the Dominguez Channel Watershed to determine the TMDL as part of a study for CALEPA. This project will be completed in 2005.

Osage-Skiatook Petroleum Environmental Research Project – USGS

This is a multi-disciplinary, multi-agency investigation of the hydrology, geochemistry, microbiology, geology, and ecosystem dynamics of Osage-Skiatook Petroleum Reserve (OSPER) sites, shown in Figure 12, which are impacted with produced water and associated oil and chemicals. The objective of this project is to generate a credible analysis to understand the fate and ecosystem interaction of organic and inorganic contaminants at these research sites. The goal is to determine the distribution, fate and impact of contaminants released as a result of petroleum production. Project partners include DOE-NETL, USGS, EPA, Osage Indian Nation, and others. This project will be completed in September 2005.

Figure 12 - Osage-Skiatook Petroleum Reserve



Evaluation of Phytoremediation of CBM Produced Water and Water Quality for CBM Reserves in the Powder River Basin - Montana State University
The goal of this project is to investigate the use of wetland plants, selective non-wetland plants, and currently grown plants of agricultural significance for phytoremediation, and reduction of the salinity and sodicity of produced water for CBM resources in the PRB. The benefits will be to improve access to CBM resources. The research will 1) provide uses for CBM water, 2) assist regulatory agencies with good science for decision making, 3) test plant, soil and water and 4) provide symposiums to assist stakeholders to work through barriers encountered when developing the resource. This project will be completed in August 2006.

Identification, Verification & Compilation of Produced Water Management Practices for Conventional Oil & Gas Production Operations - Interstate Oil and Gas Compact Commission

The objective of this project is to improve the efficiency and reduce the cost of managing produced water from conventional production in order to extend the productive life of wells. Activities include:

- Study existing and planned changes to regulations governing produced water management practices
- Identify regulatory barriers in place for innovative and emerging technologies
- Identify current and emerging produced water management practices
- Field verifications/inspections
- Assess data and evaluate practices

This project will be completed in May 2006.

A Produced Water Quality & Infrastructure GIS Database for New Mexico Oil Producers - New Mexico Institute of Mining and Technology

The objective of this project was the design and implementation of a geographic information system (GIS) and integral tools that will provide operators and regulators with necessary data and useful information to assist in management and regulatory decisions. Accomplishments of this project include:

- Produced water quality database – integrated multiple legacy databases into a single database with over 7000 well records statewide.
- Ground water quality database
- Online GIS maps to interface with databases
- NM WAIDS web site to access the data & information.
- Online produced water corrosion & scale manual
- Web-based user tools to 1) estimate scaling composition and potential of a particular produced water, 2) estimate the composition and scaling tendencies of a mix of waters of two compositions, and 3) convert units

Produced Water Management Technology and Beneficial Use

The development of new technologies to address water-handling problems is the primary focus of DOE/NETL produced water management technology projects. These technologies are being developed through partnerships with other National Laboratories, universities, consultants, industry, and cooperating government agencies. The outcome of these projects will provide lower cost treatment technologies to turn this waste stream into a much needed resource.

Use of Ionic Liquids in Produced Water Clean-up - Oak Ridge National Laboratory

The objective of this project is to introduce a new approach to produced water clean-up through solvent extraction using ionic liquids. The major problems with produced water clean-up is separation of oil and grease from the aqueous phase, separation of the oil and grease from water-soluble organic compounds, and demonstration of successful separation to the regulatory agency. Improvements in separation can be achieved by changing physical constraints, such as temperature and pressure, or by developing a new solvent, which is the approach of this project. This project will be completed in 2005.

Treatment of Produced Waters Using a Surfactant Modified Zeolite/Vapor Phase Bioreactor – University of Texas at Austin.
The University of Texas at Austin is developing a surfactant modified zeolite/vapor phase bioreactor (SMZ/VPB) treatment system to efficiently remove the organic constituents from produced water in a cost-effective manner. The project will involve a series of laboratory-scale investigations as well as a field-scale demonstration of the SMZ/VPB technology. In the first phase, the SMZ system will be investigated with a specific focus on regeneration requirements. In the second phase, the VPB system will be optimized for the multi-component gas stream produced during SMZ regeneration.

Figure 13 - Test Field Site in Wyoming

These SMZ and VPB system components will be coupled in the third phase and the capability of the combined system to treat produced water on both a continuous and discontinuous basis will be assessed at the laboratory scale. In the fourth phase, existing SMZ and VPB pilot-scale units at the New Mexico Institute of Technology and the University of Texas at Austin will be modified as needed and tested extensively at a field site in Wyoming. Accomplishments for this research include:

- The demonstration that SMZ can be regenerated over a number of cycles without loss of sorption capacity for benzene, toluene, ethylbenzene, xylenes (BTEX)
- Development of treatment process for BTEX removal from produced water that can yield complete destruction of the BTEX compounds
- Demonstrated the capability of a vapor phase bioreactor to remove BTEX from multi-component gas streams
- Demonstrated that the VPB system can rapidly recover from downtime
- Quantified BTEX desorption from the SMZ during air stripping regeneration

This project will be completed in September 2005.

Long-Term Field Development of a Surfactant Modified Zeolite Vapor Phase Bioreactor System for Treatment of Produced Waters for Power Generation - University of Texas at Austin
This project is a continuation of the previous project and will include design, long-term operation, and post-operational testing of an SMZ/VPB prototype treatment system for produced water. The treated water will be used in process operations at the PNM San Juan Generating Station in Farmington, New Mexico. In the first phase, the SMZ will be manufactured and characterized for use and the produced water will be characterized with respect to its composition and component sorption potential. The impact of the effluent on fouling of a proposed downstream reverse osmosis system will be evaluated, and the system will be designed and built. Both the SMZ and VPB system will be optimized for the expected multi-component nature of the waste and the SMZ regeneration gas, respectively. In the second phase, the system will be installed at the PNM facility and operate for up to one year. If needed, the system will be adjusted to accommodate varying field conditions and produced water streams. Adjustments also will be made to meet treatment goals, and to regenerate the SMZ. This project will be completed in October 2007.

Coal Bed Methane Research - Arthur Langhus Layne LLC
The objective of this project is to improve the efficiency and reduce the cost of managing produced water from CBM production for beneficial use through use of infiltraition ponds. The use of unlined, infiltration ponds will provide the CBM operators a low cost option compared to deep injection and water treatment. The research will document current usage of infiltration ponds. The hydrogeological conditions at selected ponds will be characterized and numerical modeling will be performed to document the water budget of the ponds at various locations in and throughout the PRB. Geochemical modeling will also be used to forecast the future functioning of the ponds given their current characteristics. Fate and transport models will be run to forecast the changes in bedrock and percolating water as infiltration proceeds. Modeling results will be compared to published hydrogeological data and GIS derived spatial relationships of natural parameters to forecast the potential magnitude of CBM infiltration pond development. Modeling results will be collated to suggest risk-based regulatory limits for pond placement, construction, and reduction of potential impacts to soil and water resources. This project will be completed in July 2006.

Handbooks Pertinent to Coal Bed Methane Production - Arthur Langhus Layne LLC
This project developed a handbook, which was published in February 2004, that summarized various aspects essential to CBM production. It involved the review of development and mitigation practices employed in various CBM regions. The handbook encompassed existing environmental impact statements and other National Environmental Policy Act planning documents relevant to CBM areas. The handbook focuses environmental protection resources on those vulnerable environmental areas and demonstrates how operators can prepare environmental assessments and development plans that include proven mitigating technologies.[48]

Recovery of More Oil-in-Place at Lower Production Costs While Creating a Beneficial Water Resource - Aera Energy LLC
Aera Energy is working to develop a reliable, economic means of removing excess produced water from the field by converting it into a water resource for potential use in the areas of agriculure, groundwater recharge, or surface water discharge that enlarges the wildlife and habitat environment. The project is organized into three areas of activities: technical, end users, and regulatory. The first activity will identify and finalize the requirements that must be met by the demonstration study. The second is to design, construct, and operate the demonstration plant. The final activity is to summarize the findings and develop the cost and regulatory response for implementing a full-scale beneficial use of produced water project. The nine-month pilot operation will be completed summer 2005. Initial results indicate that the San Ardo produced water can be treated to meet all of the water quality criteria for various end use options. This project will be completed in July 2006.

Life Cycle Assessment, Produced Water and Waste Management Analyses - Argonne National Laboratory
Argonne National Laboratory will conduct four analyses on projects that were recommended as being valuable to the oil and natural gas industry by the Petroleum Environmental Research Forum (PERF). In the first project, a white paper will be prepared summarizing the principles of life cycle assessment (LCA), an objective, systematic process for identifying, quantifying, and assessing environmental impacts throughout the life cycle of a product, process, or activity. The white paper will focus on the applicability of LCA for the oil and gas industry. In the second and third projects, Argonne will evaluate the contributions of and risks posed by discharges of E&P wastes to the hypoxic (low dissolved oxygen) zone in the Gulf of Mexico. Because produced water is the largest volume discharge stream from offshore platforms, these two projects will primarily focus on produced water. In the fourth project, a report will be developed that compares the regulatory approaches to waste management chosen in selected international jurisdictions. Argonne will then use the comparative waste management information to distill a preliminary draft framework of guidelines for waste management at E&P sites in countries without comprehensive waste management regulations. These four projects will develop tools and data that the industry can use to improve environmental protection and interaction with regulatory agencies. This project will be completed in 2005.

Produced Water Management and Beneficial Use - Colorado School of Mines
Colorado School of Mines will provide overall management to a portfolio of technologies that will be developed through this research to address the produced water issues in a comprehensive manner. This project will include the following 10 tasks: 1) membrane-enhanced CBM to minimize produced water, 2) electrodialysis treatment of produced water, 3) isotopic evaluation of CBM-produced waters, 4) reservoir geomechanics and the effectiveness of wellbore completion methods in CBM wells in the PRB, 5) evaluating the use of produced water generated during CBM extraction for land application in the PRB, 6) regional siting criteria for CBM infiltration ponds, 7) controls on the fate of CBM co-produced waters and impacts to shallow aquifer groundwater

quality, 8) field laboratory and standard method of testing performance of water-quality treatment systems, 9) water treatment by injection, and 10) regulations/technology consistency. This project will be completed in 2007.

Energy and Environmental Information for the Protection and Conservation of Our Natural Resources - Ground Water Protection Research Foundation
The goal of this project is to analyze state programs related to the security, reliability and growth of the nation's domestic production of oil and natural gas relating to the use of groundwater. Under the Energy and Environment Initiative, the Ground Water Protection Research Foundation (GWPRF) will expand the oil and gas electronic commerce initiatives used to enhance the risk based data management system and the cost effective regulatory approach. This project will be completed in August 2008.

Identification, Verification & Compilation of Produced Water Management Practices for Conventional Oil & Gas Production Operations - Interstate Oil & Gas Compact Commission
This project is aimed at improving the efficiency and reducing the cost of managing produced water from conventional production. This will effectively extend the productive life of wells which increases the ultimate recoverable reserves while also providing improved environmental protection. Cost reductions will be achieved by identifying existing and emerging best management practices for operators to evaluate and implement. The research will evaluate produced water management practices from the standpoint of the most important issues including beneficial use, water resource impacts, pre-release treatment and regulatory burden. The research will leverage existing DOE/NETL studies and field research to identify specific parameters in environmentally significant regions which need to be considered. This project will be completed in August 2006.

Hydrophobic Membrane for the Removal of Organic Impurities in Production Water - Lawrence Livermore National Laboratory
This project will develop hydrophobic aerogel technology to remove organic compounds from drilling and production waters on oil production platforms. It is envisioned that the aerogel will be used in a granular or membrane form, be in direct contact with the waste water, remove the offending organic compounds, and yield a water that can be disposed of easily, economically, and in compliance with environmental regulations. The aerogel will be designed in a way that the organic can be extracted, allowing reuse of the aerogel. This technology will be available for use on drilling platforms, but also will be suitable to land-based production and refinery applications. This project will be completed in 2005.

Treating Coalbed Methane Produced Water for Beneficial Use of MFI Zeolite Membranes - New Mexico Institute of Mining & Technology
New Mexico Institute of Mining & Technology will work to develop reverse osmosis through molecular sieve zeolite membranes to efficiently treat high-TDS CBM produced water for beneficial use. This project will be conducted in three phases. During the first phase, investigations will be conducted to understand the mechanism of the reverse osmosis (RO) process in zeolite membranes and factors that determine the membrane

performance. During the second phase, researchers will work to improve the membranes and optimize operating conditions to enhance water flux and ion rejection. A long-term RO operation on tubular membranes will be performed during the third phase in order to test for technical and economic evaluations and system design. This project will be completed in September 2007.

Modeling of Water-Soluble Organic Content in Produced Water - Oak Ridge National Laboratory (ORNL)
The goal of this project is to develop a computational tool to predict the water-soluble organic content in brines associated with deep-well off-shore oil production. The type and amount of organics that are soluble in produced water is not well understood, leading to inefficiencies in produced water cleanup prior to its discharge into the ocean. Industry participants and ORNL will study organic solubility in produced water, including characterization of the organic component in produced water and modeling of its solubility. This model could be used prior to production from new facilities to assist in the development of a more selective and focused approach to produced water clean up, leading to cost savings and reduced environmental impact. This project will be completed in 2005.

Field Validation of Toxicity Tests to Evaluate the Potential for Beneficial Use of Produced Water — Oklahoma State University
Oklahoma State University will use a combined laboratory and field approach to determine the extent to which laboratory toxicity testing of produced water samples from an oil well on Lake Skiatook, Oklahoma, indicate the potential for effects of the water as it infiltrates the benthic zone of the lake due to subsurface transfer from a leaking evaporation pit. This study will be conducted in three phases. During the first phase, a definitive characterization of produced water infiltration into the receiving system will be performed. In the second phase, researchers will evaluate the potential for effects and temporal changes in the quality of the produced water derived from the active well through the use of standard laboratory toxicity tests. The final phase of the project will include a field assessment that will evaluate the abundance and diversity of benthic invertebrates resident in areas of the receiving system where infiltration is occurring, and augment these data with in-situ growth and survival studies using Asian clams (*Corbicula fluminea*) and freshwater amphipods (*Hyallela azteca*). This comparative approach will help indicate the efficacy of laboratory bioassays of produced water in predicting effects in receiving systems, and in turn determine how appropriate they may be to assess produced water quality for the purposes of permitting for surface discharge and beneficial reuse. This project will be completed in September 2007.

Managing Coal Bed Methane Produced Water for Beneficial Uses - Sandia National Laboratory
Sandia National Laboratory is performing an evaluation to identify produced waters that could undergo passive treatment in order to meet irrigation and rangeland rehabilitation uses. To date, an emerging capacitive deionization treatment technology has been identified that in combination with a number of emerging pre-treatment options, such as pervaporation or surface modified zeolite filtration, could provide a compact,

economical, and robust treatment system for many CBM produced waters. Preliminary laboratory testing of several types of capacitive deionization processes have been conducted in salinity levels near the mid-range of CBM produced water qualities. The results suggest that the technology requires less energy, is much less susceptible to organic fouling, and is more compact than equivalent RO systems. Combined with simple, low-cost pre-treatment technologies if needed, capacitive deionization could reduce the costs of CBM produced water treatment for irrigation and rangeland uses to 10-20% of the costs of RO treatment. Passive treatment systems may also have application for some CBM produced waters. Accomplishments for this project include:

- Compiled an extensive data base of produced water in New Mexico
- Developed relationships with oil and gas industry to work on produced water issues
- Evaluated capacitive deionization demonstration unit
- Prepared material & equipment list for hydrogen sulfide abatement equipment

This project will be completed in 2005.

Advanced Membrane Filtration Technology for Cost Effective Recovery of Fresh Water from Oil & Gas Produced Brine — Texas Engineering Experiment Station (TEES) Before oil field brine can be used for beneficial purposes, it must be processed to remove residual petroleum hydrocarbon material. An effective way of removing petroleum from produced water is the use of membrane filters. Filter fouling is one of the main reasons for the high cost of water desalination and wastewater treatment in general. The goal of this project is to improve the lifetime and operating efficiency of these filters. Researchers at Texas A&M University have been working on desalination processes to treat oil field produced brine to make it suitable for beneficial use. Results indicate that the brine treatment is feasible and can be done simply and economically. New technology has been developed having the potential to reduce the cost of desalination to be comparable with disposal by re-injection into disposal wells. Desalination of oil field brines requires a series of steps to remove contaminants and decrease salinity. A key to cost effective desalination by reverse osmosis is pre-treatment. The core tasks of this proposal focus on two new pre-treatment technologies for oil removal combined with modification of different membrane materials and membrane types. This project will be completed in September 2005.

Novel Cleanup Agents for Membrane Filters Used to Treat Oil Field Produced Water for Beneficial Purpose - Texas Engineering Experiment Station
This is a continuation of the previous TEES project. Experience has shown that substandard operating efficiency and membrane replacement are significant operating expenses of water treatment facilities. The scope of work includes the development of new cleaning agents and processes for membrane filters used in produced water desalination and in wastewater treatment. The goal is to improve operating efficiency by 25% over current practices. The program will utilize two environmentally friendly materials so that the water from the treatment process will meet EPA clean water standards. This project will be completed in October 2006.

Novel Cleanup Agents for Membrane Filters Used to Treat Oil Field Produced Water for Beneficial Purpose - University of Texas at Austin
The objective of the project is to provide new alternatives to purify produced water - removal of emulsified oil, particulates, and dissolved solids - to enable inexpensive beneficial use of produced water in applications such as agricultural and landscape irrigation, and drinking water. Such beneficial use would significantly reduce injection costs associated with current disposal practices for produced water and provide a new source of purified water in what are often water-starved regions. This objective would be achieved by improvements to the fouling resistance of polymer membranes. This project will be completed in 2006.

ENERGY-WATER STUDIES AND ASSESSMENTS

NETL's Office of Systems, Analyses, & Planning (OSAP) performs studies and assessments of complex, large systems and interactions among those systems. Such studies are conducted on issues related to national and regional plans and programs along with resource use and environmental and energy security policies. Studies are typically focused on production and processing of fossil fuels along with energy and fuel systems synthesis and design. In addition, OSAP performs studies and assessments of current, near-term and longer term trends within the energy industry and in the U.S. and world economies that may impact energy and fuels production, technologies and use. Studies of the barriers and benefits of fossil technology research, development and deployment are also conducted. The following is a brief summary of two OSAP studies related to energy and water.

Impact of Climate Variability and Change on U.S. Power Sector—Science Applications International Corporation
The objective of this project is to analyze and quantify key effects of potential future climate change on the United States electricity sector and develop a methodology for assessing the effects of climate change on the electricity sector.[49] Part of the task involves performing regional case studies in order to provide an understanding for the impacts and consequences of specific, severe climactic occurrences on the electricity sector that have already occurred in the United States. To date, case studies have been performed for the Pacific Northwest and Lake Powell/Glen Canyon Dam areas. Both are areas that have experienced extreme drought that has affected regional power generation capacity and plant operation. The studies that have been performed document specific effects of prolonged drought on the electricity sector and provide steps planners have taken to mitigate these effects and plan for future drought scenarios.

Estimating Freshwater Needs to Meet 2025 Generating Capacity Forecasts
Using the EIA's 2004 Annual Energy Outlook reference case forecast for electricity generating capacity, DOE/NETL estimated future freshwater requirements for both total and coal-based thermoelectric generation and then compared these numbers to current and past water use by the power sector.[50] The results of these case runs indicate that the

amount of freshwater needed to meet forecasted increases in thermoelectric capacity over the next two decades in the U.S. will either increase slightly or decline in terms of water withdrawal. In terms of consumption, several cases project a large increase on a percentage basis as older once-through cooling plants are replaced by new recirculating cooling system plants. However, the study does note that thermoelectric generation will most likely continue to represent only a small faction of total freshwater consumption in 2025. The project was completed in June 2004.

SUMMARY

The link between water and reliable and secure fossil-fuel-based energy is a topic that is receiving increased attention as part of a broader discussion of the energy-water nexus. Because thermoelectric generation and fossil fuel (coal, oil, and natural gas) extraction can directly impact water availability and quality, it is critically important to protect and manage U.S. water supplies while at the same time providing sufficient water to power the nation through the 21st century and beyond. The DOE's Office of Fossil Energy, through NETL, is responding to the challenge by developing a suite of advanced technologies and concepts to minimize potential impacts that fossil fuel production and use have on the Nation's water resources.

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