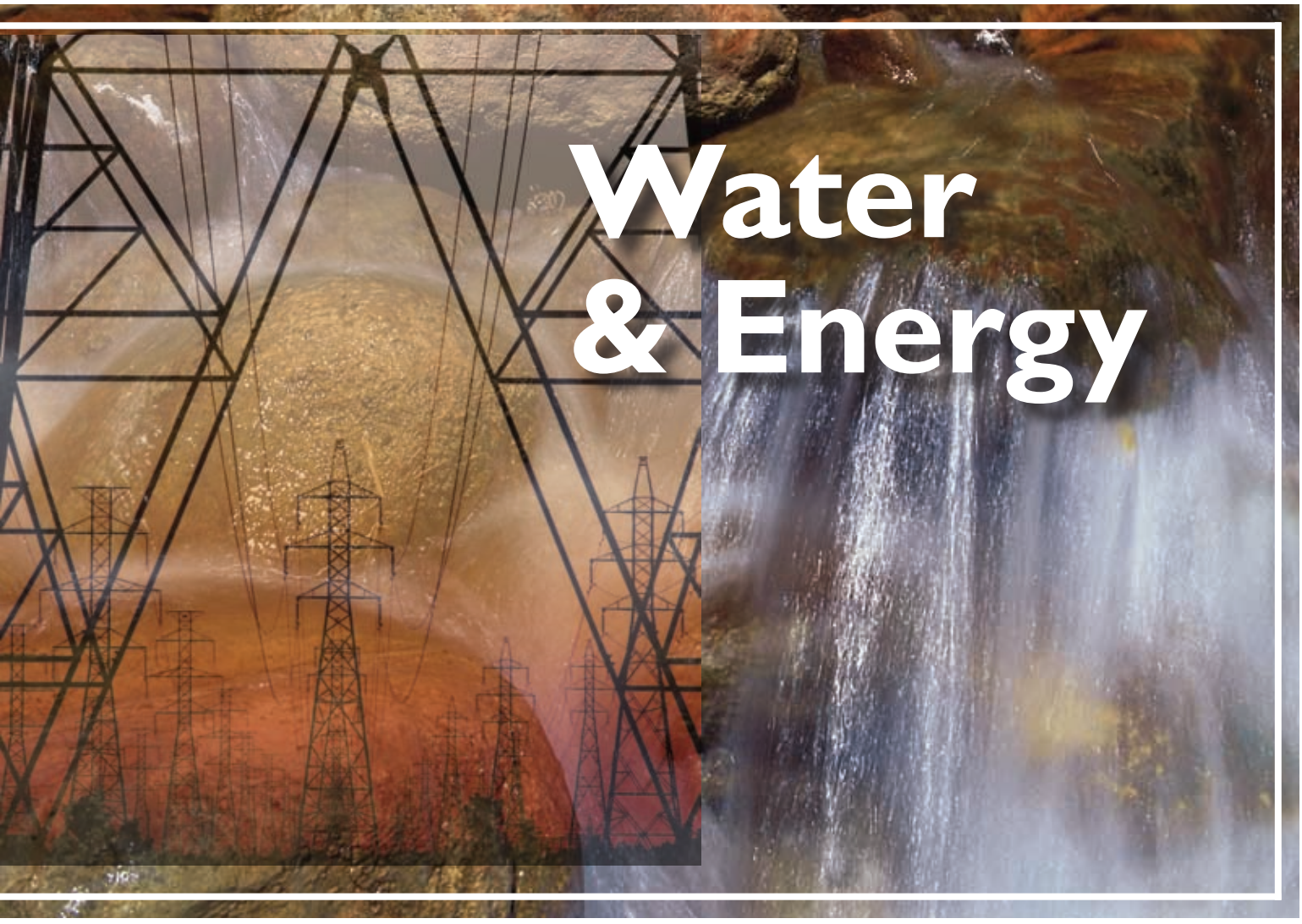
U.S. Department of Energy • Office of Fossil Energy
National Energy Technology Laboratory

Addressing the Critical Link Between the Nation's Water Resources and Reliable and Secure Energy



Water & Energy

Water and Energy

are inextricably linked. Because thermoelectric generation and fossil fuel extraction and utilization impact water resources, it is critically important to protect U.S. water supplies while providing the energy needed to power the nation through the 21st century. Through integrated water and energy-related activities, the Department of Energy/ National Energy Technology Laboratory (DOE/NETL) is responding to this challenge by developing and applying advanced technologies and supporting science. This brochure describes research, development, and demonstration activities underway at DOE/NETL that are designed to address existing and emerging water-energy issues.

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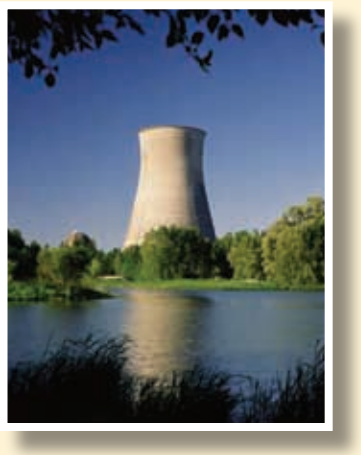
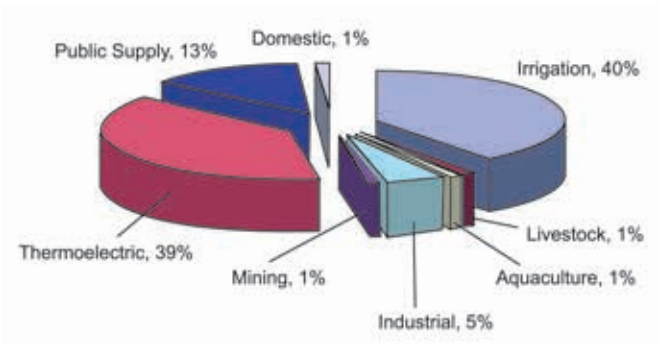


Introduction

Thermoelectric power plants (including coal, oil, natural gas, and nuclear) require large quantities of reliable, abundant, and predictable cooling water (a resource limited in parts of the United States and throughout the world) to support the generation of electricity. The United States Geological Survey estimated that U.S. thermoelectric generation accounted for approximately 136 billion gallons per day (BGD) of freshwater withdrawals in 2000, ranking only slightly behind agricultural irrigation as the largest source of freshwater withdrawals. It is important to note the difference between water withdrawal and water consumption (consumed water is not returned to the source, mostly being lost to evaporation). While thermoelectric generation accounted for 39% of freshwater withdrawal in 2000, it only accounted for approximately 3% of water consumed in 1995 (the most recent year that water consumption data is available). However, even at 3% consumption, more than 3 BGD were consumed. In addition to the water needed to condense steam in conventional thermoelectric power plants, water is a critical requirement



Annual U.S. Freshwater Withdrawals 2000

* Total greater than 100% due to independent rounding.

Source: USGS. Estimated Use of Water in the United States in 2000; USGS Circular 1268; March 2004.

for advanced power systems such as gasification, and is also necessary for the production of liquid fuels and hydrogen from fossil fuels. Thermoelectric generation also impacts water quality in the form of increased water temperature and air pollution deposition.

Fuel extraction can impact the quality and availability of the nation's water resources. Drainage of mine waters from both active and abandoned coal mining operations may compromise surface and groundwater supplies. The process of natural gas and oil production results in significant quantities of produced water. It has been estimated that approximately 14 billion barrels of produced water were generated by U.S. onshore operations in 2002. Most of this water is reinjected for disposal or to enhance production. While a large quantity of produced water has a high salt content, a substantial quantity would be suitable for other uses with little or no treatment.

As the nation's growing economy drives the need for more electricity, demands on the use of water for power generation will also increase. The direct and indirect demand for water for energy production will increasingly compete with demands from other sectors of the economy. Water shortages are a serious concern, with a U.S. Government Accountability Office survey indicating that 36 states anticipate water shortages from 2003 through 2013. Water and energy are further linked by the energy needed for water treatment and water transportation.

Section 979 of the Energy Policy Act of 2005 speaks directly to the importance of water and energy issues. The Act instructs the Secretary of the Department of Energy (DOE) to address issues related to adequate water supplies, optimal management, efficient use of water, and efficient use of energy. The Department of Energy's Office of Fossil Energy (DOE/FE) is carrying out an integrated research, development, and demonstration (RD&D) effort that cuts across its coal, oil, and natural gas programs to specifically focus on the nexus between energy and water. This brochure is a summary of the water-related RD&D and systems analyses projects currently being sponsored by DOE/FE and implemented and managed by the National Energy Technology Laboratory (NETL) in the areas of fossil-fuel-based power generation, coal mining, and oil and natural gas production.

Fossil Fuel Based Thermoelectric Power

Within NETL's Strategic Center for Coal, the Innovations for Existing Plants Program is a comprehensive R&D effort focused on the development of advanced technologies to enhance the environmental performance of the existing fleet of coal-fired power plants, with application to new plants as well. In 2002, the program was broadened to include research directed at water-energy issues, focusing specifically in the following areas: Non-Traditional Sources of Process and Cooling Water; Innovative Water Reuse and Recovery; Advanced Cooling Technology; and Advanced Water Treatment and Detection Technology.

Non-Traditional Sources of Process and Cooling Water

Work in this program area focuses on research and analysis to evaluate and develop cost-effective approaches to using non-traditional ("impaired") 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. Sponsored research includes the following: analysis of the use of water from abandoned underground coal mines to supply cooling water to power plants; analysis of the use of natural gas and oil produced waters to partially meet power plant cooling water needs; development and demonstration of mine water usage to cool thermoelectric power plants; development of membrane separation and scale-inhibitor technologies to enable power plant use of impaired waters; and pilot-scale demonstration of a variety of impaired waters for cooling.

Innovative Water Reuse and Recovery

Research is being performed under this program area to develop advanced technologies to reuse power plant cooling water and associated waste heat and to investigate methods to recover water from coal power plant flue gas. Technology advances in this area have the potential to reduce fossil fuel power plant water withdrawal and consumption. Sponsored research includes the following: development of a cost-effective liquid desiccant-based dehumidification technology to recover water from plant flue gas; analysis of power plant waste heat to dry low-rank coals; diffusion-driven desalination to allow a power plant that uses saline water for cooling to become a net producer of freshwater; investigation of the use of condensing heat exchangers to recover water from boiler flue gas; and demonstration of regenerative heat exchange to reduce fresh water use in plants with wet flue gas desulfurization systems.

Advanced Cooling Technology

The Advanced Cooling Technology program area focuses on research to develop technologies that improve performance and reduce costs associated with wet cooling, dry cooling, and hybrid cooling technologies. In addition, this research area covers innovative methods to control bio-fouling of cooling water intake structures as well as advances in intake structure systems. Sponsored research includes the following: pilot scale testing of a hybrid cooling technology; testing of an environmentally safe control method to prevent zebra mussel fouling; development of high thermal conductivity foam to be used in air-cooled steam condensers for power plants; evaluation of condensing technology applied to wet evaporative cooling towers; and development of scale-prevention technologies and novel filtration methods.

This photo shows zebra mussels densely colonizing cooling water intake pipes of power plants. Their removal causes significant power outages and expense.

Photo courtesy of: New York State Museum

Advanced Water Treatment and Detection Technology

Work in this program area is focused on detection and removal of mercury (Hg), arsenic (As), selenium (Se), and other components from the aqueous streams of coal-based power plants. Sponsored research includes the following study of the fate of As, Se, and Hg in a passive integrated treatment system for fossil plant waste water; demonstration of a market-based

approach to abandoned mine land reclamation by creating marketable water quality and carbon emission credits; utilization of anionic clay sorbents for treating and reusing power plant effluent; and evaluation of wetland use to treat plant scrubber wastewater.

For more information please visit:

http://www.netl.doe.gov/technologies/coalpower/ewr/water/index.html

Advanced Power Systems

To assist in reducing overall power plant water withdrawals and consumption, NETL is developing Integrated Gasification Combined Cycle (IGCC) advanced power systems. IGCC is a technology that efficiently converts coal to a synthesis gas that can be used in a gas turbine for power production. Roughly two-thirds of the power generated in an IGCC system is from the gas turbine. The excess heat from the gas turbine is used to produce steam in a heat recovery steam generator that produces the remaining one-third of power. Conventional pulverized coal (PC) plants, on the other hand, generate all power with a steam turbine. Since the gas turbine does not require cooling water, IGCC plants require appreciably less cooling water (up to 40 percent less) on a gallons/kWH output basis compared to similar capacity PC plants.

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

Sponsored by NETL, the University of Florida investigated an innovative diffusion-driven desalination process that allows a power plant using saline water for cooling to become a net producer of freshwater. 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.

Pictoral view of the laboratory-scale diffusion driven desalination experiment

Source: University of Florida, Innovative Fresh Water Production Process for Fossil Fuel Plants: 2004 Annual Report to NETL. September 2004.

Coal Mining

The Geosciences Division of NETL's Office of Research and Development 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 Acid Mine Drainage treatment operations and make use of the beneficial properties of mine water and produced water.

Airborne Geophysical Mapping

Understanding surface and groundwater systems requires large-scale geophysical mapping. Historically, 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 assessment of watershed-scale areas. NETL is integrating technologies developed primarily as mineral exploration tools with recent developments in global positioning satellites (GPS), geographical information systems (GIS), and improved computer technologies to create new and powerful analytical tools.

NETL expertise in this area is being applied to a number of projects including the following: an airborne frequency domain electromagnetic survey of approximately 30 square miles of the Kempton Mine Complex, which underlies portions of West Virginia and Maryland; evaluation of time domain electromagnetic conductivity for large-scale mapping of contaminated pools in abandoned underground coal mines; airborne electromagnetic surveys of 14 coal slurry impoundments for early detection of potential dam failures; and evaluation of the use of helicopters equipped with electromagnetic technologies for mapping produced waters from coalbed methane (CBM) extraction in Wyoming's Powder River Basin.

Mine Pool Treatment and Beneficial Use

Mine drainage 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 more complex, requiring 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 in this area focuses on reducing land requirements and treatment costs through the use of water-powered technologies. In addition, due to the relatively large volumes of flowing (both controlled and uncontrolled) water and its constant 55 °F temperature, NETL is pursing the development of mine pools as a geothermal energy source for heat pumps and as a small-scale hydroelectric power source.

Recent research in this area includes the following: construction and evaluation of a water-powered treatment system at an abandoned anthracite mine; demonstration of a semi-passive water treatment system consisting of an overshot water-wheel powered lime feeder installed at a standard aerobic wetland; and collaboration on a white paper addressing the potential of coupling geothermal heat pump technology with mine pools.

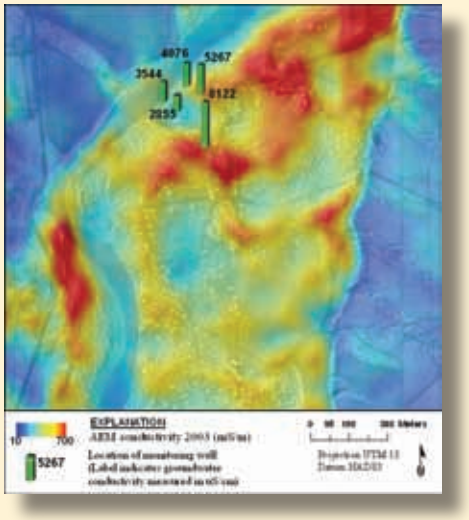
For more information please visit:

http://www.netl.doe.gov/technologies/coalpower/ewr/water/watershed.html

Applications of Airborne Electromagnetic Surveys to Improve Management of Produced Water in the Powder River Basin

A helicopter electromagnetic survey was conducted at selected study sites within the Powder River Basin of Wyoming and Montana in 2003 and 2004 as part of a hydrologic study of coalbed methane production. The purpose of this study was to evaluate the use of airborne electromagnetic methods for the large-scale mapping of geologic and hydrologic properties.

Interpretation of the apparent conductivity maps and inverted conductivity depth sections reveals geologic variations, water quality variations, and inferred hydrologic processes. Ultimately, it is hoped that the information from these surveys will be used to better manage produced waters from coalbed methane production.



Comparison of water quality data (Specific Conductance) with airborne electromagnetic data

Source: NETL, UGSG, and University of Pittsburgh. Applications of Airborne Electromagnetic Surveys to Improve Management of Produced Water in the Powder River Basin; SAGEEP Conference Publication. 2006.

Natural Gas and Oil Production

Under the Strategic Center for Natural Gas and Oil, the Oil and Gas Environmental Program addresses water-related issues such as water oil recovery, produced water and its effects on the environment, treatment of process waters, and the availability of water in arid lands.

Water Management Approaches and Analysis

Work under this program area includes a number of assessments, forecasts, and projects to address regulatory issues, evaluate methods and strategies to improve produced water management, and provide data and analyses in support of policy making. Coordination with local, state, and federal agencies is commonplace and many efforts are undertaken collaboratively.

Some examples of completed analyses include the following: development of effluent limitation guidelines for CBM produced water; study of the impacts on underground freshwater sources from hydraulic fracturing of CBM wells; evaluation of water and waste issues that could affect the gas and oil industry; research regarding a comprehensive circulation model for understanding hydrologic cycling; multi-agency investigation of the hydrology, geochemistry, microbiology, geology, and ecosystem dynamics of the Osage-Skiatook Petroleum Reserve sites; investigation of use of a variety of plants for phytoremediation and salinity reduction of CBM produced waters; investigation of produced water management practices to extend productive life of oil and gas wells; and development of a produced water quality and infrastructure GIS database for New Mexico.

Produced Water Management Technology and Beneficial Use

The primary focus of this program area is the development of new technologies to address water-handling problems. 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.

Examples of projects include: investigation of use of ionic liquids for produced water treatment; use of infiltration ponds for CBM produced water treatment; development of a handbook summarizing various aspects of CBM production; life cycle assessment of produced water and waste management practices; analysis of state programs related to the security, reliability, and growth of the nation's domestic production relating to the use of groundwater; development of hydrophobic aerogel technology to remove organic compounds from drilling and produced waters; development of reverse osmosis through molecular sieve zeolite membranes to treat CBM produced waters; development of a computational tool to predict water-soluble organic content in brines from deep-well off-shore oil production; validation of toxicity tests to evaluate the potential for beneficial use of produced water; and development of filter fouling reduction techniques for membrane filtration technology for freshwater recovery from produced waters.

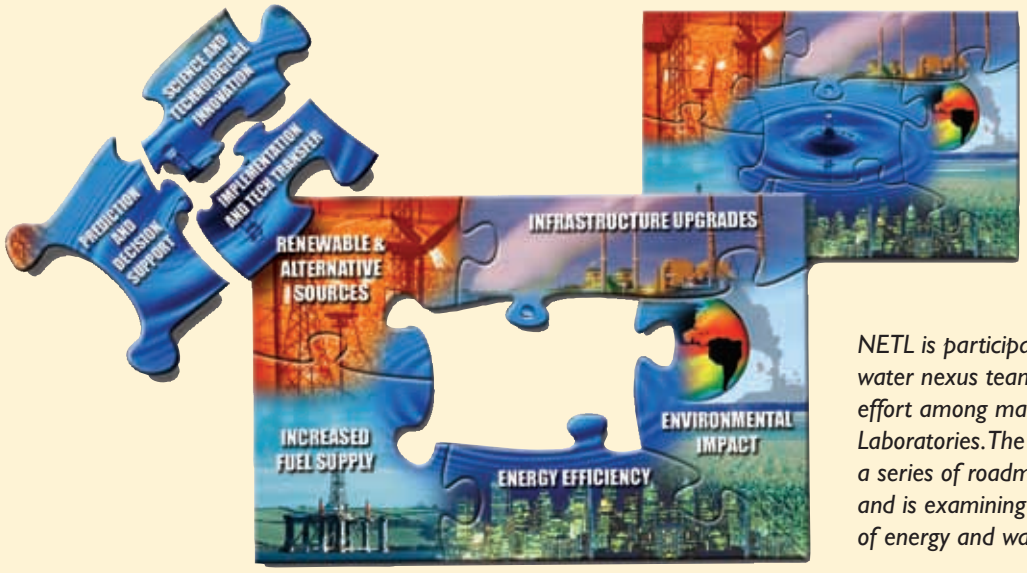
For more information please visit:

http://www.netl.doe.gov/technologies/oil-gas/EP_Technologies/

Treatment of Produced Waters Using a Surfactant Modified Zeolite/Vapor Phase Bioreactor

Sponsored by NETL, the University of Texas at Austin conducted research to develop 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 involved a series of laboratory-scale investigations as well as a field-scale demonstration of the SMZ/VPB technology.

Photo courtesy of: Mike Ranck



NETL is participating in the energy-water nexus team, a collaborative effort among many DOE National Laboratories. The team has conducted a series of roadmapping workshops and is examining issues at the nexus of energy and water.

THE ENERGY-WATER NEXUS

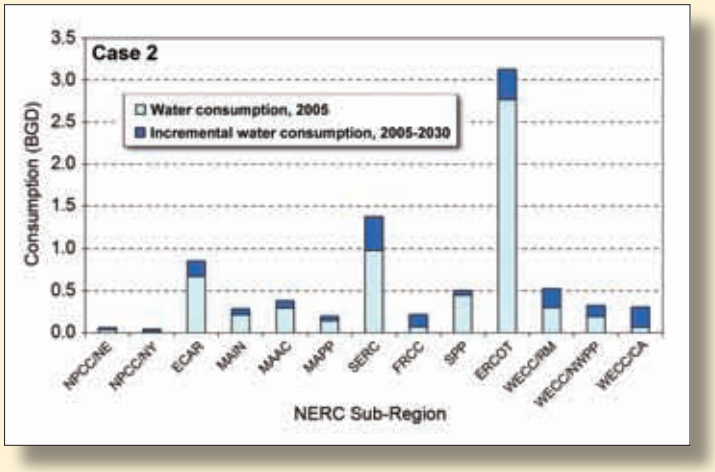
Water-Energy Studies and Assessments

NETL's Office of Systems, Analyses, & Planning (OSAP) performs studies and assessments of complex energy 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 also analyze the barriers and benefits of fossil technology research, development and deployment.

Examples of studies recently performed related to water-energy include the following: analysis and quantification of key effects of potential future climate change on the U.S. electricity sector; use of the Energy Information Administration's (EIA's) 2004 Annual Energy Outlook reference case forecast of electricity generating capacity to estimate future freshwater requirements for both total and coal-based thermoelectric generation; and study of power plant water consumption focusing on IGCC power systems.

For more information please visit:

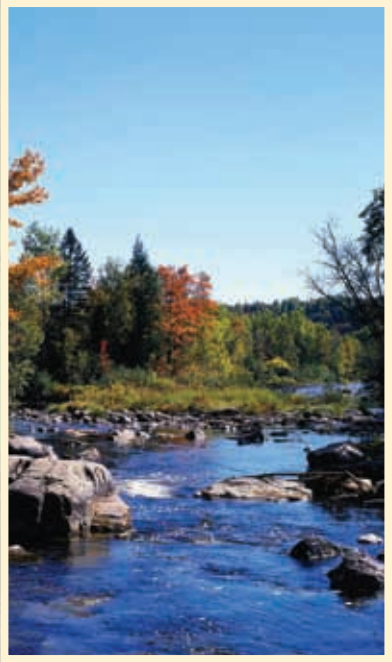
http://www.netl.doe.gov/technologies/coalpower/ewr/water/systems.html



Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirements

Completed in August 2006, this NETL report examined the freshwater needed to meet future (through 2030) electricity generating capacity based on the Energy Information Administration's 2006 Annual Energy Outlook (AEO). The study examined freshwater withdrawal and consumption on both a national and regional basis. Five cases were analyzed, each with different assumptions on a variety of factors such as what types of new plants would be built, which plants would retire, etc. Case 2 was considered the most reasonable with assumptions based on future regulations (such as 316b) requiring new plants to use recirculating cooling systems. National Case 2 consumption results showed a 32.3 percent increase in consumption. Regions were analyzed for each of the North American Electric Reliability Council's (NERC's) sub-regions and Case 2 consumption results are presented in the figure. Results ranged from a minimum of 12 percent consumption increase in NERC's SPP region (which includes portions of Arkansas, Kansas, Louisiana, Mississippi, Missouri, New Mexico, Oklahoma, and Texas), to a maximum of 352 percent consumption increase in WECC/CA (which includes California).

Summary



DOE/NETL is committed to providing the scientific, technical, and policy expertise necessary to successfully meet the challenge of balancing energy production and utilization needs with water quality and availability concerns.

DOE/NETL

The National Energy Technology Laboratory is a multipurpose laboratory owned and operated by the U.S. Department of Energy that conducts and implements science and technology development programs in energy and energy-related environmental systems.

A key component of the DOE/NETL mission is to "resolve the environmental, supply, and reliability constraints of producing and using fossil resources to provide Americans with a stronger economy, healthier environment, and more secure future."

DOE/NETL is located in Pittsburgh, Pennsylvania; Morgantown, West Virginia; Tulsa, Oklahoma; Anchorage, Alaska; and Albany, Oregon. The Laboratory has strong expertise in fossil energy technologies, nuclear cleanup, contract and project management, system analysis, and international energy issues. To learn more about DOE/NETL, please visit our website at **www.netl.doe.gov**

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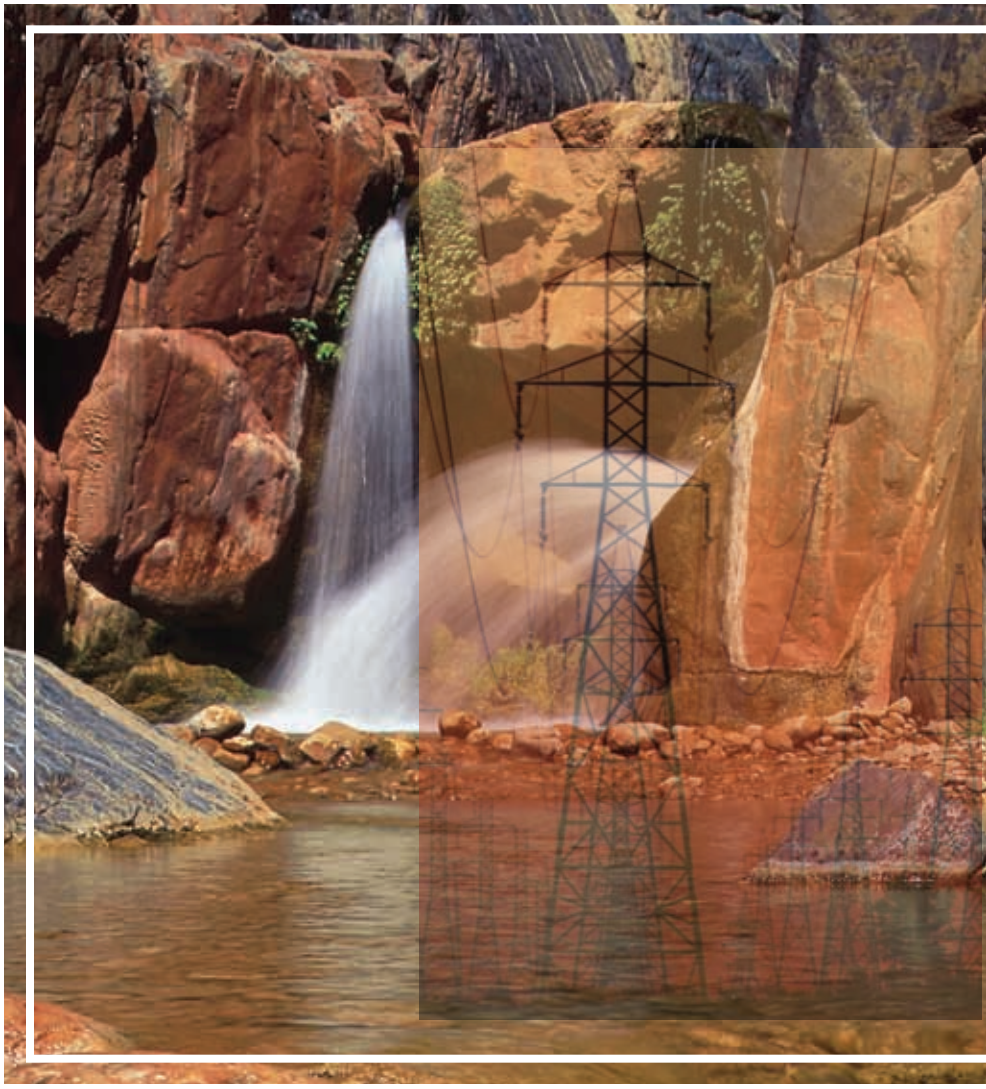

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