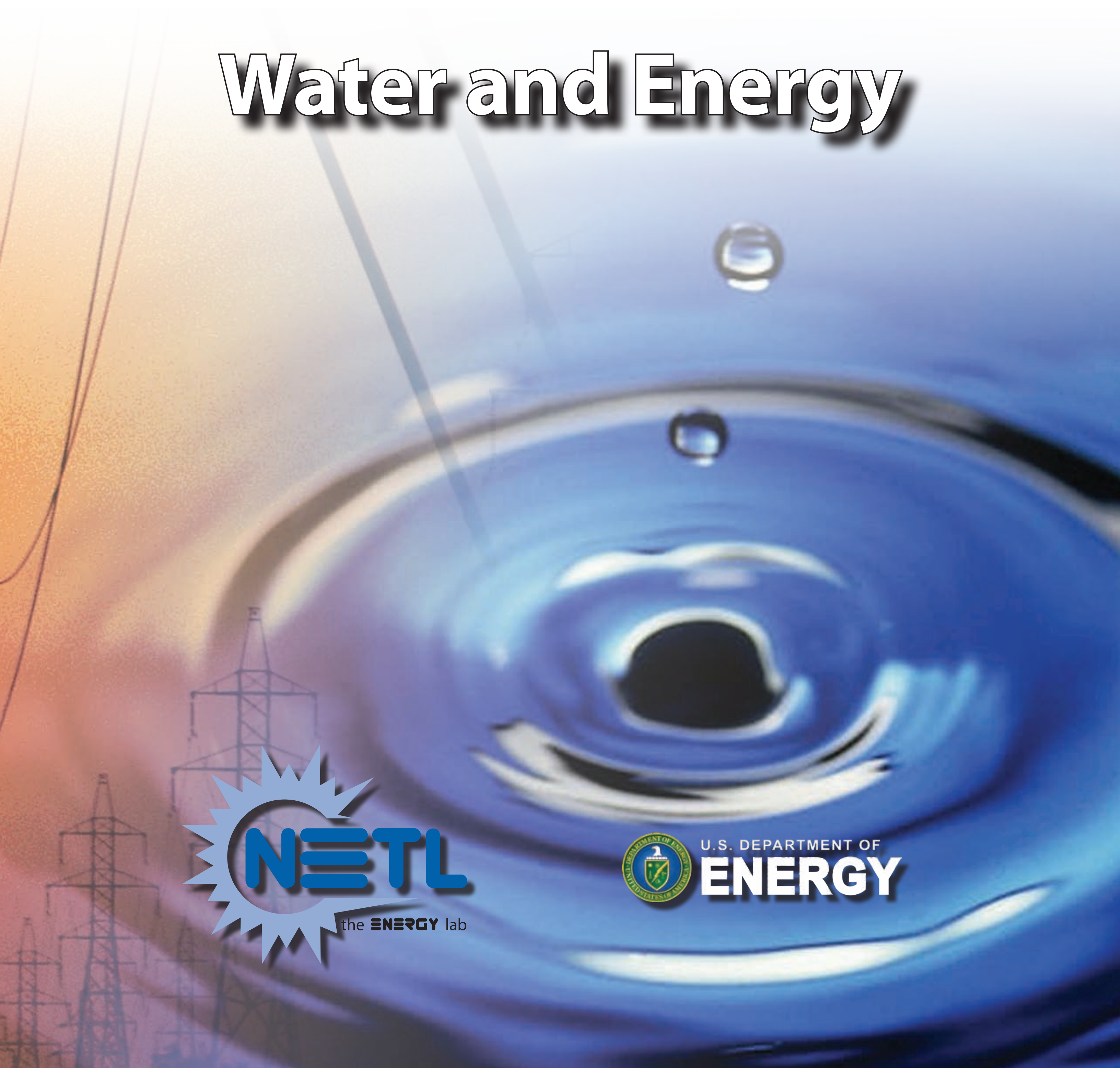
Research Addressing Power Plant Water Management to Minimize Water Use while Providing Reliable Electricity Generation

Water and Energy

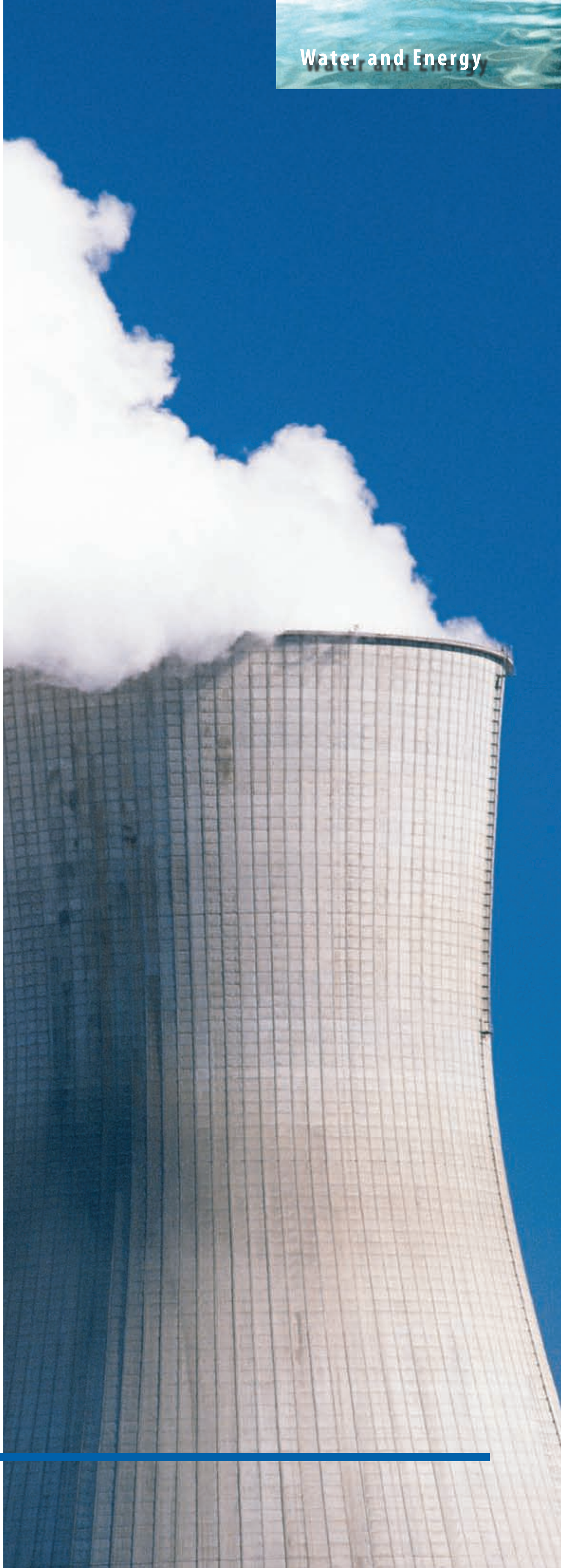


NETL the ENERGY lab

U.S. DEPARTMENT OF ENERGY

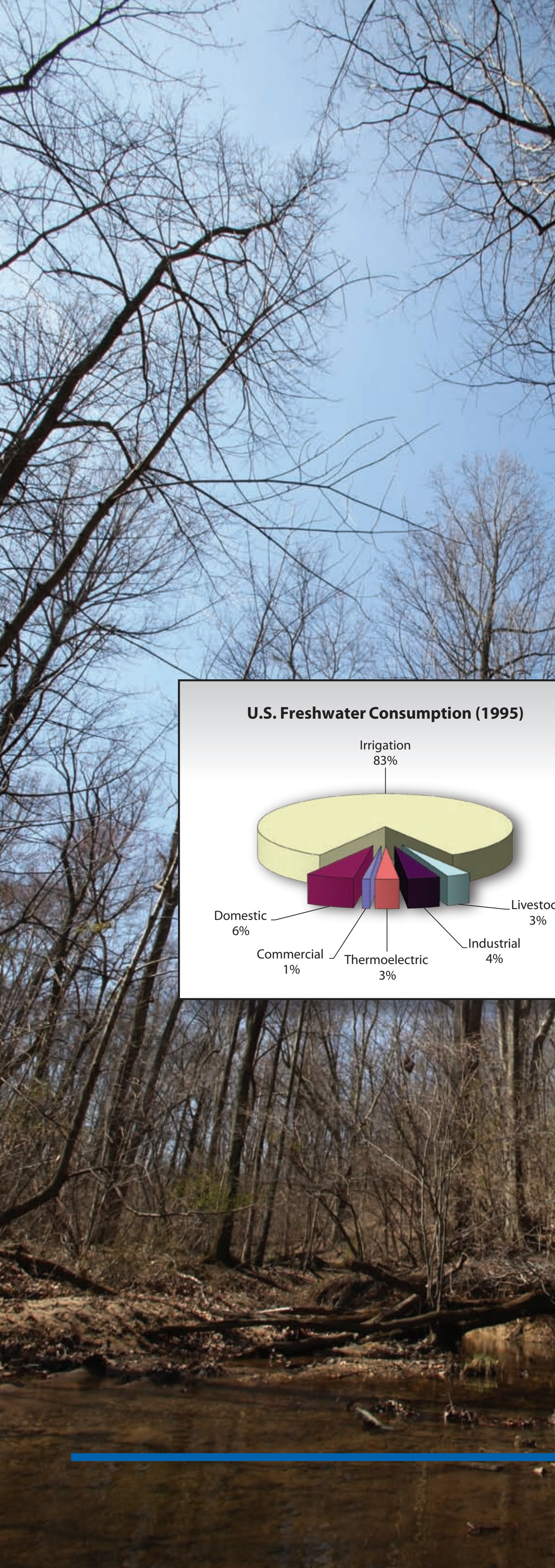
Water and Energy

are inextricably linked. Because thermoelectric generation impacts 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 energy-water issues



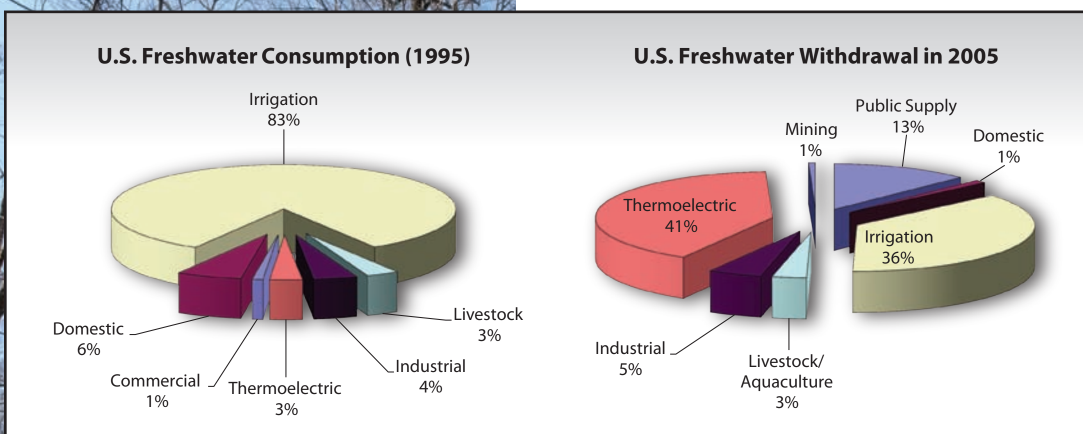
Contents

Disclaimer: This brochure was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of the authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.



Introduction

Thermoelectric power plants (including coal, oil, natural gas, and nuclear) require large quantities of reliable, abundant, and predictable water (a resource limited in parts of the United States and throughout the world) to support the generation of electricity. For example, a 500-megawatt (MW) coal-fired power plant uses more than 12 million gallons of water per hour. The largest demand for this water is process cooling. The two commonly used metrics to measure water use are withdrawal and consumption. Water withdrawal represents the total water taken from a source. Water consumption is the loss of withdrawn water, typically through evaporation.



According to water use survey data from the U.S. Geological Survey (USGS), thermoelectric generation accounted for 41 percent of all freshwater withdrawals in the U.S. in 2005, slightly ahead of irrigation. However, thermoelectric water consumption accounted for only 2.5 percent of total U.S. freshwater consumption in 1995 (the most recent year that water consumption data are available). A recent U.S. Department of Energy/National Energy Technology Laboratory (DOE/NETL) study estimated that in 2005 total U.S. freshwater withdrawals for thermoelectric power generation amounted to approximately 146 billion gallon per day (bgd), while freshwater consumption was 3.7 bgd.

Demand and Competition

One key consideration in evaluation of the relationship of energy and water is the increasing demand for both commodities over time. Thermoelectric generating capacity is projected to increase by 10 percent between 2010 and 2035. Depending upon future regulatory requirements, water withdrawal to support electricity generation is expected to stay the same or decline slightly over the same time period. However, water consumption is expected to increase by anywhere from 14 to nearly 27 percent on a national basis, depending on future regulatory changes.

Water supply concerns expressed by state regulators, local decision-makers, and the general public are already impacting numerous power projects across the United States, as indicated below. These concerns point toward a future of increased conflict

- **Water Worries Shape Local Energy Decisions**

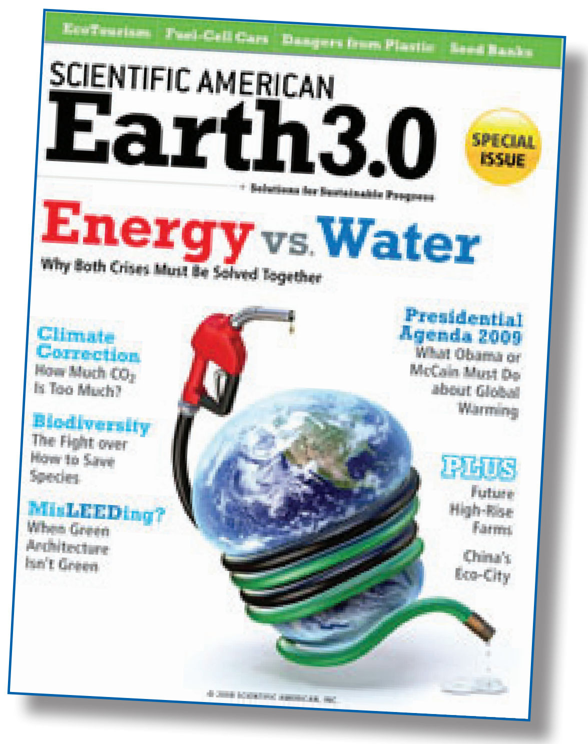
  — *Wall Street Journal, March 2009*
- **Planned power plant would take billions of gallons**

  — *Mankato Free Press, July 2008*
- **Water Shortage Works Against Kansas Coal-Fueled Power Plants**

  — *KC Tribune, May 2010*
- **New power-plant drain on rivers sparks debate**

  — *San Antonio Express News, June 2009*
- **Water Issues Behind Legal Challenges to Georgia Coal Plants**

  — Environment News Service, May 2010



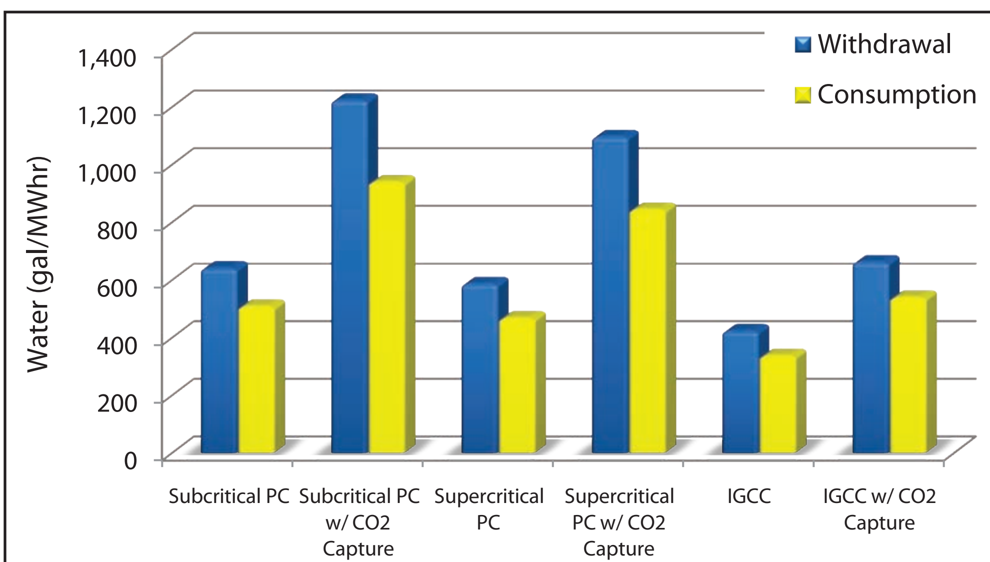
and competition for water that the power industry will need to operate their thermoelectric generation facilities.

The interface of energy and water, or the energy-water nexus, can be defined as the many relationships between energy and water that are necessary to ensure an adequate supply of both resources for every purpose. Water is needed to make use of energy, and energy is needed to make use of water. Understanding the interlocking nature of energy-water interactions is the key to determining how to make the most efficient uses of these critical resources, both for short-term economic benefit and for longer-term societal and environmental sustainability.

Water Use and Carbon Capture and Storage

Another potentially influential factor in future water use in energy generation may be carbon capture and storage (CCS). The use of carbon capture technologies in existing and future fossil fuel-fired power plants offers a mechanism for reducing carbon dioxide (CO_2) emission levels. However, carbon capture comes at an additional cost in terms of both money and resources needed to manufacture, install, and operate these technologies. The components of a power plant require a portion of the steam and electricity generated by the plant in order to operate, in addition to large quantities of fresh water for cooling, as discussed earlier. The use of currently available carbon capture techniques adds additional demands for steam, electricity and water on top of this baseline resource load.

A recent DOE/NETL study established baseline cost and performance data for a variety of power plant configurations both with and without carbon capture. Subcritical pulverized coal (PC), supercritical PC and integrated gasification combined cycle (IGCC) configurations were evaluated for a variety of factors including water withdrawal and consumption. The evaluation results in terms of water use are presented below. The results show a significant increase in overall water use by the subcritical and supercritical PC plants, while a more modest increase is present for the IGCC plant. One of the major reasons for this difference is that only one-third of the power generation of an IGCC plant is based on the steam turbine, which requires cooling water for steam condensation. The other two-thirds of IGCC power generation is from gas turbines, which don't require cooling water.



NETL Energy-Water Research Program

Under its Existing Plants Program, NETL is pursuing an integrated energy-water research and development (R&D) program that addresses water management issues relative to coal-based power generation. This initiative is intended to clarify the link between energy and water, deepen the understanding of this link and its implications, and integrate current water-related R&D activities into a national energy-water R&D program.

The research program is investigating ways to reduce the amount of freshwater needed by thermoelectric power plants and to minimize potential water quality impacts. The program sponsors research encompassing laboratory- and bench-scale activities through pilot-scale projects and is built upon partnership and collaboration with industry, academia, and other government and non-governmental organizations.

NETL Energy-Water Program Vision and Mission

Vision: A 21st century America that can count on abundant, sustainable fossil energy and water resources to achieve the flexibility, efficiency, reliability, and environmental quality essential for continued security and economic health.

Mission: To lead the critical national RD&D effort directed at removing barriers to sustainable, efficient water and energy use; develop technology solutions; and enhance understanding of the intimate relationship between energy and water resources.

The program strategy has several key elements that guide implementation:

- Work collaboratively with regulators, technology developers, utilities, academia and the public.
- Seek market-based technology solutions that maximize public benefits in a cost-effective manner.
- Respond to differences in regional requirements related to water use and availability.
- Build the program's research portfolio on projects that are competitively selected and peer-reviewed for performance results.

- Serve a facilitating role in providing the data and analysis to resolve scientific and technology issues that hinder effective regulatory and policy pathways.
- Work with stakeholders to elucidate perspectives and opportunities for improved acceptability.
- Continuing public outreach activities that provide information and educational materials about technology options.

Program R&D performers include universities, nonprofit organizations (e.g. University of North Dakota Energy and Environmental Research Center), industry, and other national laboratories (e.g. Sandia National Laboratory and Argonne National Laboratory), as well as NETL in-house research. Specific projects for the program have been funded through four competitive solicitations, with one project funded in 2002, five additional projects awarded in August 2003, seven in November 2005, and 10 in July 2008. Other projects have been funded through the Small Business Innovative Research program and the University Coal Research program.

The three principal focus areas for the Existing Plants Energy-Water R&D Program include:

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

Non-traditional sources of cooling water include waters that have previously been considered unsuitable for cooling water purposes due to some form of organic or inorganic contamination such as the presence of high dissolved solids concentrations. These non-traditional sources can include mine drainage waters, produced waters from mineral extraction processes, municipal wastewaters and other impaired waters.

Innovative water reuse and recovery involves capturing water that historically has been discharged in either aqueous or vapor form and reusing the water in the power plant. Applications here range from ash pond waters to water captured from flue gases.

Advanced cooling technology involves innovative ways to cool power plant waters while minimizing water withdrawal and consumption. Systems being evaluated range from advanced mechanical systems (i.e., cooling towers) to constructed wetlands that can help cool power plant waters and provide wildlife habitat.

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 of 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 projects involving identification, treatment and use of a variety of non-traditional waters. Projects focused on identification of non-traditional waters have included both regional and national assessments of the availability of different types of impaired waters. Mapping of distances between proposed and existing power plants has been conducted, and an ongoing project is developing a geographical information system (GIS) catalog that will identify the location and the water withdrawal and consumption demands for existing and planned coal-fired power plants in the lower 48 states. Treatment techniques being investigated to facilitate the use of impaired waters include tertiary treatment of municipal wastewaters, advanced separation techniques, chemical scale inhibitors, constructed wetlands, silica removal and nano-filtration. Specific types of non-traditional waters under study include mine pool and drainage waters, ash pond waters, cooling tower blowdown water, flue gas desulfurization (FGD) water, municipal wastewaters, and produced waters generated during oil and gas extraction, coal bed methane removal, and as a result of carbon sequestration in saline aquifers and for enhanced oil recovery.

Implementation Highlights

Successes to Date

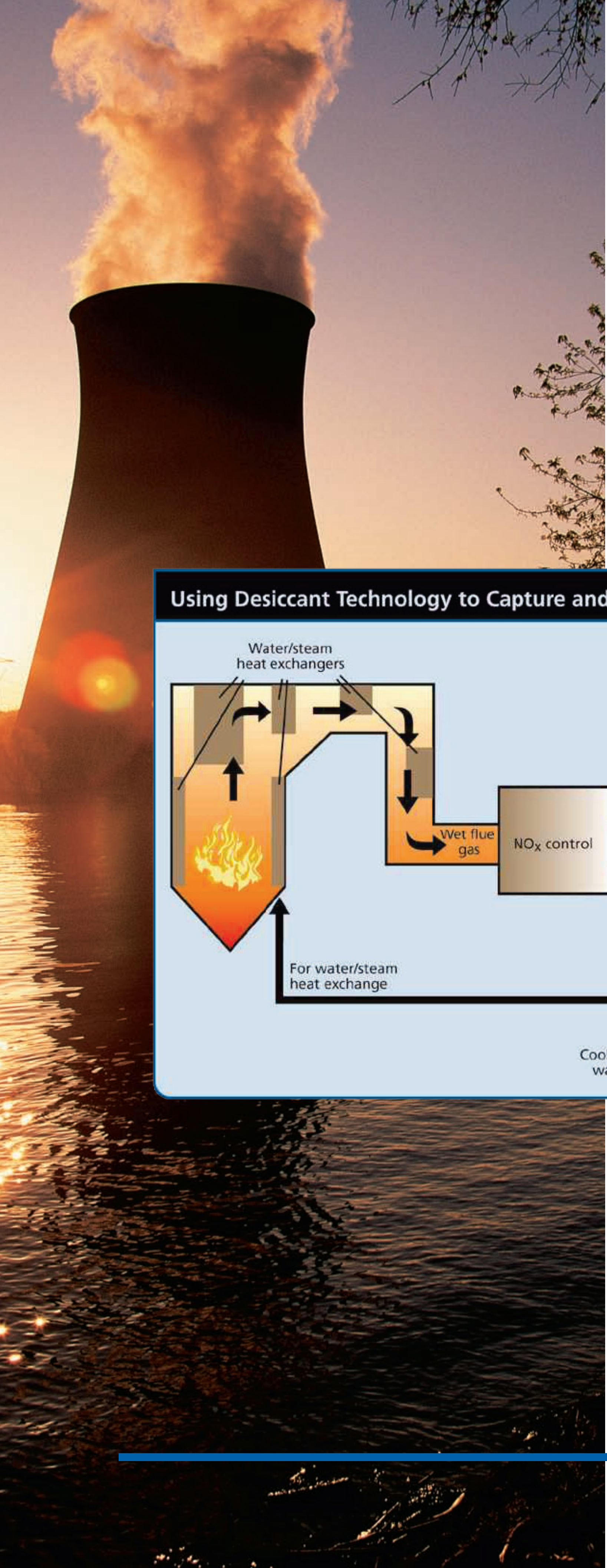
– Eight mine water sources in western Pennsylvania and northern West Virginia with sufficient capacity to support a 600 MW power plant were identified. Cost analysis concluded that depending on site conditions, utilization of mine pool water for power plant cooling could be cost effective.

– Developed pilot-scale cooling towers that can be used to evaluate the impact of multiple impaired waters in side-by side tests (see right).

– Reclaimed water (treated municipal wastewater) represents a valuable resource that can be used for cooling in electric power plants. Eighty-one percent of power plants proposed for construction by the Energy Information Administration (EIA) would have sufficient cooling water supply from one to two publicly owned treatment works (POTW) within a 10-mile radius, while 97 percent of the proposed power plants would be able to meet their cooling water needs with one to two POTWs within 25 miles of these plants.

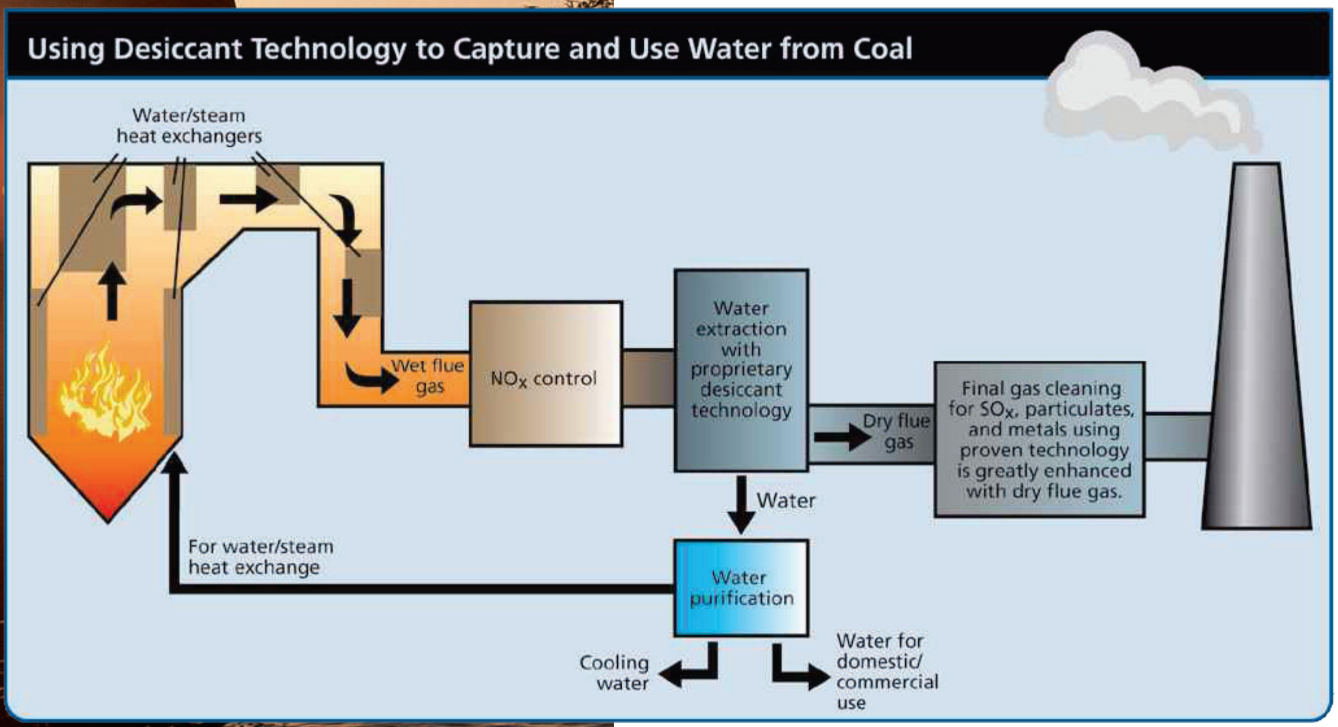
Moving Forward

– Several studies are underway evaluating methods for treating non-traditional waters so that they can be used in power plant settings. These treatments include chemical additions, advanced filtering mechanisms (electrodialysis, electrodeionization, nanofiltration), membrane separation, silica-removal technologies, and treatment in constructed wetlands. Non-traditional waters currently being evaluated for use include secondary and tertiary treated municipal wastewater, mine pool waters, passively treated coal mine drainage, ash pond effluent, and produced waters from coal bed methane capture, CO_2 enhanced oil recovery, and carbon sequestration in saline aquifers. In addition, an internet-based, GIS catalog of non-traditional waters for cooling waters is being developed.



Innovative Water Re-use 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.



Using Desiccant Technology to Capture and Use Water from Coal

Sponsored research includes investigations into the use of waste heat to drive water saving or recovery processes (including coal drying), development of condensing heat exchanger processes for extracting water from flue gases, and evaluation of the use of wetlands to treat power plant wastewaters so that they can be re-used within the plant.

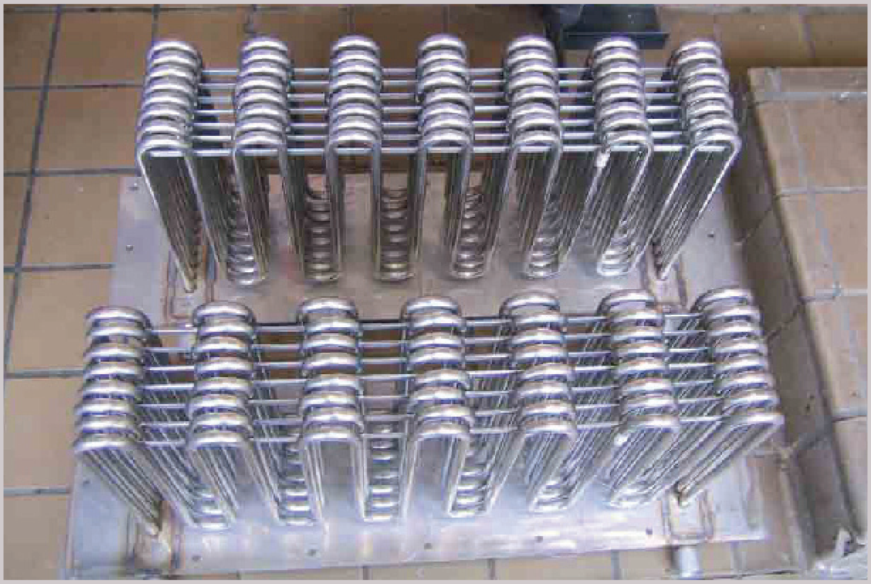
Implementation Highlights

Successes to Date

- A process that produces freshwater was demonstrated for power plants that use saltwater for cooling . Saline water cools and condenses the steam, and the warmed water from the condenser passes through a diffusion tower to produce humidified air from which freshwater is condensed. The process is cost competitive with reverse osmosis.

- Process heat from condenser return cooling water was extracted upstream of the cooling tower to warm ambient air that was used to dry coal. Lowering the temperature of the return cooling water reduced evaporative loss in the cooling tower, reducing water consumption, and led to improved plant efficiency.

- A technology was developed to extract water vapor form flue gas using a liquid desiccant. The flue gas is cooled and then sent through either a spray tower or packed bed configuration where the desiccant, calcium chloride, absorbs water from the flue gas. The wet desiccant is then heated to remove the water as vapor, which is then condensed .

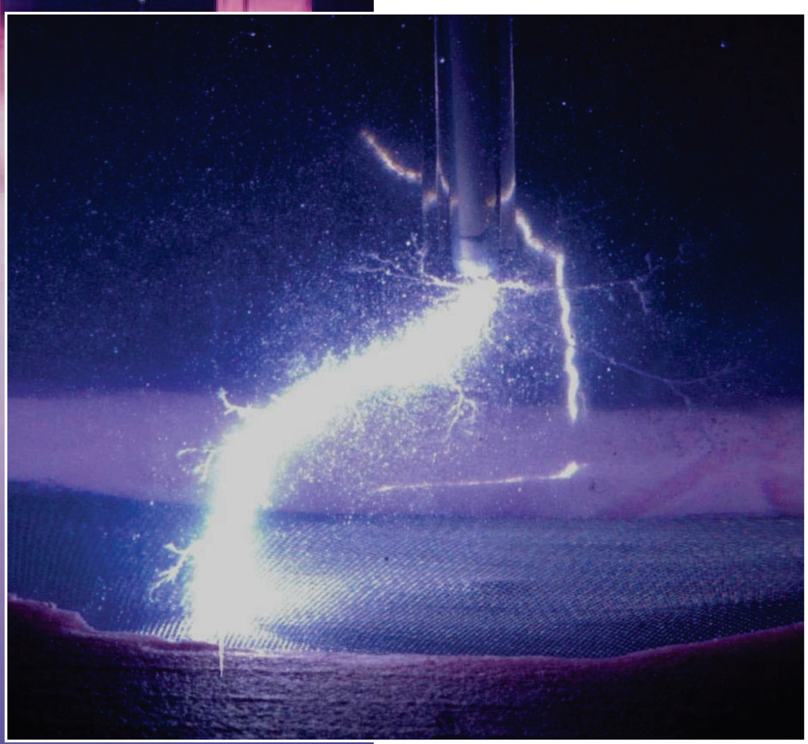


Moving Forward

Some of the earlier studies cited above are being scaled to full size. For example, results from the coal drying study are being scaled and applied to a 546 MW lignite-fired power production facility in North Dakota. The desiccant study is also being scaled to a full-sized facility. New work involves recovery of water from boiler flue gas using condensing heat exchangers (see above) and transport membrane condensers. In addition, a project is being initiated evaluating the use of constructed wetlands for treatment of aqueous power plant wastes so that the water can be reused in the plant

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. Sponsored research includes projects investigating methods to improve air flow in dry cooling systems, the use of pulsed electrical discharges (see below) to prevent scaling in wet cooling systems, methods to reduce evaporative losses of cooling water, and techniques to control zebra mussels and thus prevent the fouling of intake structures. In addition, development efforts have been undertaken with carbon foam heat exchangers and impaired water cooling systems.



Implementation Highlights

Successes to Date

– Air2Air® condensing technology has been demonstrated in a cooling tower application, as shown at right. The left-most cooling tower shown has been fitted with Air2Air® condensing technology, which has resulted in a significant reduction in the release of water vapor. This system has the potential to condense as much as 20 percent of the cooling water that would normally be evaporated. Scaled nationally, potential water savings could be over 1.5 billion gallons/day.

– Pilot-scale testing of a wet cooling system capable of using low-quality water was conducted. The unit was successful in increasing the cycles of concentration, and no scaling was observed.

– A particular strain of naturally occurring bacteria (Pseudonomas fluorescens) has been shown to be selectively lethal to zebra mussels, but benign to non-target organisms. Significant effort has been expended to reduce the cost associated with this control method, resulting in an 88 percent reduction in cost.

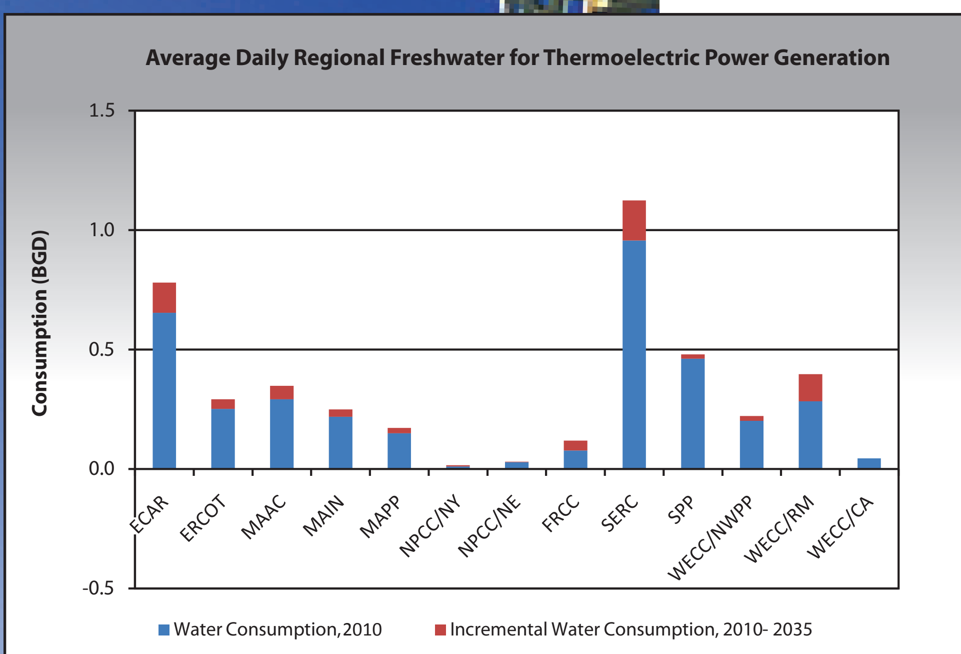
Moving Forward

– Several studies are underway evaluating methods for reducing costs for Advanced Cooling Technologies. For example, changes in geometry for the Air2Air® system have the potential to make it more efficient in capturing water. Pulse spark discharges and continuous filtration are being evaluated to determine their impact on scale formation.

In-house Research and Systems Analysis

In addition to the competitively-funded projects described above, the Existing Plants Program provides funding for in-house research performed by the NETL Office of Research and Development (ORD). ORD energy-water related projects include the following:

- Surface Coating of Condenser Tubing and CO_2 Sparging for Preventing Fouling and Water Use Reduction
- High Fidelity Computational Fluid Dynamics (CFD) Model and corresponding Reduced Order Model for General Cooling Tower and Associated Water Recovery Devices
- Topographically and Chemically Patterned Substrates for Water Recovery
- Use of the Integrated Pollutant Removal (IPR) process in oxy-fuel combustion
- Systems Modeling of Water Use



NETL's Office of Systems, Analyses, & Planning (OSAP) performs studies and assessments of complex energy systems and interactions among those systems. Examples of studies recently performed related to energy-water include an analysis quantifying key effects of potential future climate change on the U.S. electricity sector and a forecast of electricity generating capacity to estimate future freshwater requirements for both total and coal-based thermoelectric generation on a regional basis, among others.

National Energy Technology Laboratory

1450 Queen Avenue SW
Albany, OR 97321
541-967-5892

2175 University Avenue South
Suite 201
Fairbanks, AK 99709
907-452-2559

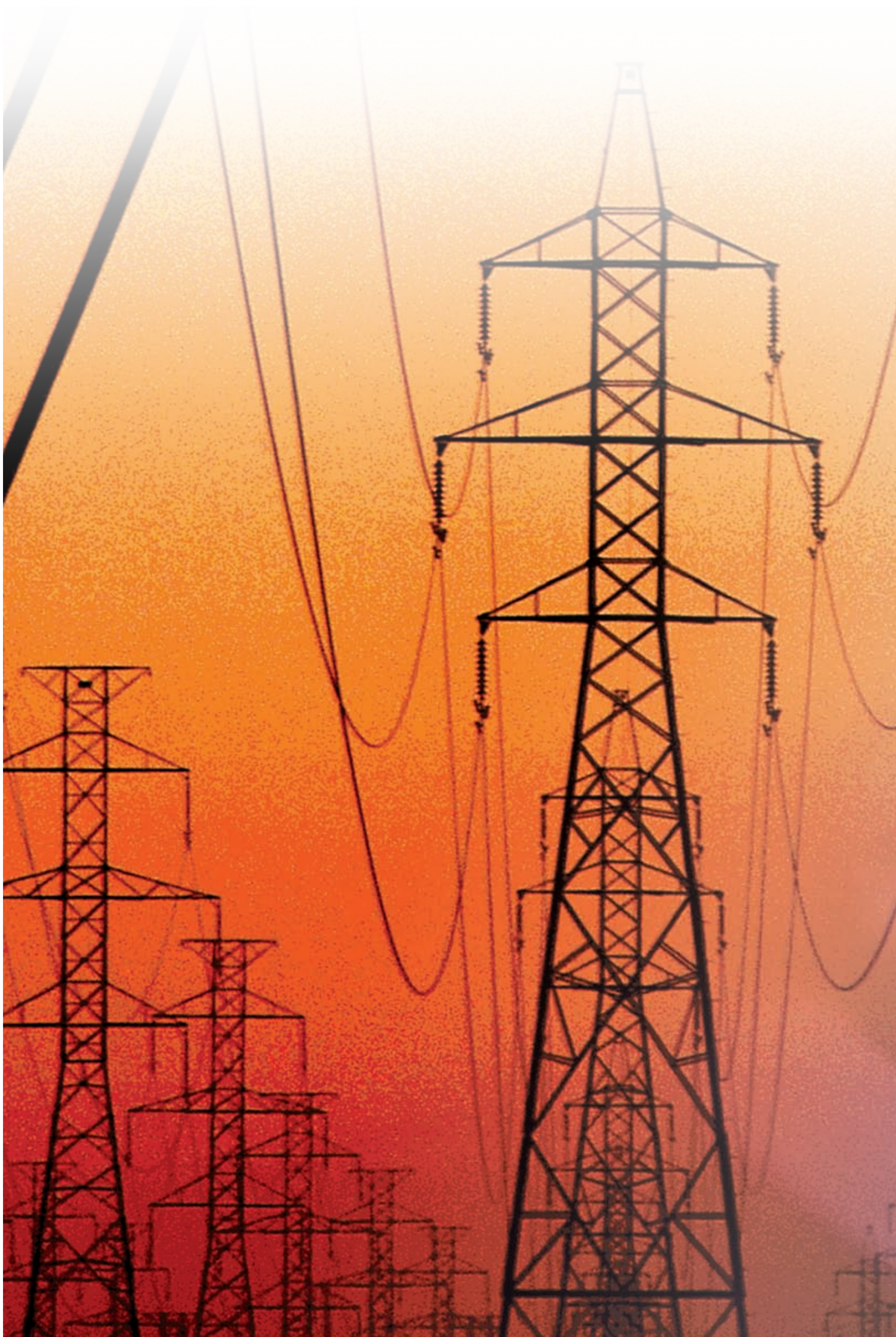
3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880
304-285-4764

626 Cochrans Mill Road
P.O. Box 10940
Pittsburgh, PA 15236-0940
412-386-4687

13131 Dairy Ashford, Suite 225
Sugar Land, TX 77478
281-494-2516

Visit the NETL website at:
www.netl.doe.gov

Customer Service:
1-800-553-7681



Printed in the United States on recycled paper
September 2010