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Finding Technological Solutions to the Energy-Water Nexus

This article is a follow-up to the excellent summary titled "The Connection: Water and Energy Security" written by Dr. Allan R. Hoffman, published in the August 13, 2004 issue of *Energy Security*. In that article, Dr. Hoffman provided a wealth of background information highlighting the energy-water nexus and the critical need for solutions to address future water-related energy security issues.

One of the key links between energy and water is the need for sufficient water resources to drive the U.S. thermoelectric generation sector - to operate fossil-fuel and nuclear power plants. Power plants utilize significant quantities of water in generating electrical energy. For example, a 500 MW power plant requires over 12 million gallons per hour of water for cooling and other process requirements such as scrubbing sulfur dioxide from the stack gases[1]. The United States Geological Survey estimates that thermoelectric generation of electricity – including coal, oil, natural gas, and nuclear power generation – ranks only slightly behind agricultural irrigation as the largest source of freshwater withdrawals in the United States[2].

As pointed out by Dr. Hoffman, the ability of the electric-utility industry to obtain the water needed to permit new plants as well as to continue running existing facilities, particularly during periods of extended drought or in light of more restrictive environmental regulations, is being challenged. Thermoelectric generation will compete with other sectors like agriculture, domestic, industrial, mining, and in-stream use for the water that is available. Examples of the conflict between power generation and water continue to dot the pages of the popular press and trade journals. In February 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. Also in February, 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. More recently, another coal-fired power plant to be built in Wisconsin on Lake Michigan has been under attack from environmental groups because of potential impact of the facility's cooling-water-intake structures on the Lake's aquatic life. These events point towards a future of increased likelihood of conflict and competition for the water the power industry will need to operate its thermoelectric generation capacity.

The Energy Information Administration's latest forecast estimates U. S. electric power sector coal-fired generating capacity will increase from approximately 305 GW in 2003 to 389 GW in 2025[3]. Recognizing the criticality of water in meeting both current and future increases in thermoelectric power demand, DOE's Office of Fossil Energy (FE) is supporting research aimed at reducing the amount of freshwater needed to operate coal-based power systems. This research is being implemented and managed by FE's National Energy Technology Laboratory (NETL). One promising new approach to reduce power plant water withdrawals and consumption is Integrated Gasification Combined Cycle (IGCC). 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, an IGCC plant requires appreciably less cooling water on a gallons/kWh output basis compared to a similar capacity PC plant.

NETL also initiated a comprehensive research effort in 2002 directed at developing technologies and approaches to better manage how PC-based power plants use and impact freshwater resources. The overall goal of this effort is to reduce the amount of freshwater needed for power plant operations and to minimize potential impacts on water quality. The research encompasses laboratory and bench-scale activities through pilot- and full-scale demonstrations and is built upon partnership and collaboration with industry, academia, technology developers, and other government organizations. The program is built around four specific areas of research:

- **Non-Traditional Sources of Process and Cooling Water** – Develop innovative technologies to utilize lower-quality water for power plant cooling and related process needs.
- **Innovative Water Reuse and Recovery** – Develop advanced technologies to recover and reuse water from power plants including coal dewatering and flue gas dehumidification.
- **Advanced Cooling Technology** – Develop advanced wet, dry, and hybrid cooling and intake structure technologies.
- **Advanced Water Treatment and Detection Technology** –

Electricity for Transmission, Storage and Transportation
A new study titled "Carrying the Energy Future: Comparing Hydrogen and Electricity for Transmission, Storage and Transportation" by the Seattle based Institute for Lifecycle Environmental Assessment (ILEA,) evaluated the energy penalties incurred in using hydrogen to transmit energy as compared to those incurred using electricity.
The report's main premise is that since hydrogen is not an energy source but an energy carrier its economic and environmental qualities should be compared to those of electricity, the only other commonplace energy carrier. It therefore compares the actual energy available when hydrogen and electricity carriers are employed and finds that electricity delivers substantially greater end use energy, concluding that "electricity offers more energy efficient options that might preclude mass-scale emergence of hydrogen technologies."

Study: Coal based methanol is cheapest fuel for fuel cells

Develop advanced technology to detect and/or remove trace metals and other toxic components from power plant effluents.

The following is a brief summary of several recently completed and on-going R&D projects representative of these four research areas.

- **Use of Abandoned Mine Water for Power Plant Make-Up Water** - West Virginia University's Water Research Institute (WRI) recently completed 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. The amount of mine water available, the quality of the water, and the types of water treatment needed are all factors that were analyzed during this study. Non-traditional water sources such as coal mine discharges not only have the potential to reduce freshwater power plant cooling requirements, they also can improve the efficiency of the cooling process due to the lower water temperatures associated with deep-mine discharges. The study identified available mine water reserves in the region with sufficient capacity to support cooling water requirements under two scenarios for power plants equipped with recirculating cooling water systems. Under the first scenario, make-up water would be provided for plant capacities less than 600-MW. The second scenario would provide the entire cooling water requirement utilizing a flooded underground mine as a heat sink, which would eliminate the need for a wet cooling tower, for plant capacities up to 200-MW.

- **Use of Produced Water from Natural Gas and Oil Extraction for Power Plant Make-up Water** – The Electric Power Research Institute (EPRI) recently completed an evaluation of the feasibility of using produced waters, a by-product of natural gas and oil extraction, to satisfy up to 10 percent of the approximately 20 million gallons per day (MGD) of make-up cooling water demand for the mechanical draft cooling towers at Public Service of New Mexico's 1,800 MW San Juan Generating Station (SJGS) located near Farmington, New Mexico. 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

A recently completed study by University of Florida researchers for the Georgetown University fuel cell program assessed the the future overall costs of various fuel options for fuel cell vehicles. The primary fuel options analyzed by the study were hydrogen from natural gas, hydrogen from coal, and methanol from coal. The study concluded that methanol from coal was the cheapest option, by a factor of almost 50%.

Major improvement in fuel economy and range of Honda's fuel cell vehicles
The 2005 model Honda fuel cell vehicle achieves a nearly 20 percent improvement in its EPA fuel economy rating and a 33 percent gain in peak power (107 hp vs. 80 hp) compared to the 2004 model, and feature a number of important technological achievements on the road to commercialization of fuel cell vehicles.

Biodiesel fueled ships to cruise in Canada
A Canadian project will test the use of pure biodiesel (B100) as a fuel supply on a fleet of 12 boats of

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 currently collected in tanks at the wellhead and transported by truck to local saltwater disposal facilities. EPRI evaluated 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 gas and oil pipelines that are currently unused would be converted to transport produced water in the second phase.

Water quality is also a significant issue when using produced water to supplement plant cooling water requirements due to high TDS concentrations. Cooling water currently used at the SJGS is withdrawn from the San Juan River and contains only 360 mg/L of TDS compared to produced water with a TDS concentration ranging from 5,440 to 60,000 mg/L. For comparison, sea water contains 26,000 mg/L. Therefore, the produced water would have to be treated prior to use at the plant in order to reduce TDS to an acceptable level. The most economical treatment method identified was high efficiency reverse osmosis with a brine concentrator distillation unit that would process approximately 1,100 gallons per minute of produced water.

- **Water Recovery from Power Plant Flue Gas** – The University of North Dakota’s Energy & Environmental Research Center (UNDEERC) is developing a technology to extract water vapor from coal-fired power plant flue gases in order to reduce make-up water requirements for the plant’s cooling water system. The flue gas contains large amounts of water vapor produced from the coal combustion process. Coal contains in-situ water and the combustion of the hydrogen within the coal matrix also generates additional water. The amount of water that can be recovered from the flue gas is sufficient to substantially reduce the need for freshwater make-up. The first objective of this project is to develop a cost-effective liquid desiccant-based dehumidification technology to recover a large fraction of the water present in the 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. Prospects for commercial development of the process are encouraging. This project will be completed in September 2005.
- **Fate of Arsenic, Selenium, and Mercury in a Passive Integrated System for Treatment of Fossil Plant Waste**

various types and sizes, 11 boats on pure biodiesel (B100) and one on a 5-percent blend (B5).

Back Issues

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

- **Reuse of Power Plant Cooling Water Waste Heat for Coal Drying and Reduction of Cooling Water Evaporative Losses** - Lehigh University is conducting laboratory-scale testing to evaluate the performance and economic feasibility of using low-grade power plant waste heat to partially dry low-rank coals prior to combustion in the boiler. The project will be completed in December 2005. While bituminous coals have minimal moisture content (less than 10%), low-rank coals have significant moisture content – subbituminous and lignite coals range from 15-30% and 25-40% moisture, respectively. In this process, heat from condenser return cooling water is extracted upstream of the cooling tower to warm ambient air that is then used to dry the coal. Lowering the temperature of the return cooling water reduces evaporative loss in the tower, thus reducing overall water consumption. In addition, drying the coal prior to combustion can improve the plant heat rate, and in return reduce overall air emissions. Variations of this approach are also being evaluated that include using heat from combustion flue gas to supplement the condenser return cooling water to dry the coal. Information from this project is being used to design a full-scale coal drying system at Great River Energy's 546 MW lignite-fired Coal Creek Power Station located near Underwood, North Dakota. The Coal Creek project is being funded under DOE's Clean Coal Power Initiative.

- **Reuse of Power Plant Cooling Water Waste Heat for Water Desalination** - 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. Hot water from the condenser provides the thermal energy to drive the desalination process. Saline water cools and condenses the low-pressure steam and the warmed water then passes through a diffusion tower to produce humidified air. The humidified air then goes to a direct contact condenser where freshwater is condensed out. This process is more advantageous than conventional desalination technology, in that, it may be driven by low-temperature waste heat. Cool air, a by-product of this process, can also be used to cool nearby buildings. To date, a diffusion-driven desalination facility has been developed that can produce 1.03 MGD of freshwater from the waste heat of a 100 MW plant. 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 later in 2005.

- **Improving the Performance of Dry Cooling Systems for Power Plants** - Ceramic Composites, Inc. has partnered with SPX Corporation to develop high thermal conductivity carbon 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 Clean Water Act requirements through the prevention of adverse environmental impacts associated with aquatic organism intake, warm water discharge, and wet cooling tower water evaporation. This project will be completed in July 2006.

The link between energy production and water is a topic that is receiving increased attention as part of a broader discussion of the energy-water nexus. Because energy production can impact water resources, it is critically important to protect U.S. water supplies while at the same time providing sufficient water to power the nation through the 21st century. NETL is responding to this challenge with a comprehensive research effort directed at developing and applying advanced technologies and concepts to better manage how coal-based power plants use and impact freshwater resources. In addition to the projects described in this article, NETL recently closed on a competitive solicitation in which it anticipates making multiple awards for additional research on ways to reduce the amount of water needed to drive U.S. thermoelectric generation capacity.

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[1]Actual cooling water flow rate requirements for a particular plant will vary depending on type of cooling water system and design parameters.

[2] *U.S. Geological Survey. Estimated Use of Water in the United States in 2000; USGS Circular 1268; March 2004.*

[3] *Energy Information Administration. Annual Energy Outlook 2005, EIA Report No. DOE/EIA-0383(2005); January 2005.*

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