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ENERGY AND WATER

Preliminary Observations on the Links between Water and Biofuels and Electricity Production

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Why GAO Did This Study

Water and energy are inexorably linked—energy is needed to pump, treat, and transport water and large quantities of water are needed to support the development of energy. However, both water and energy may face serious constraints as demand for these vital resources continues to rise. Two examples that demonstrate the link between water and energy are the cultivation and conversion of feedstocks, such as corn, switchgrass, and algae, into biofuels; and the production of electricity by thermoelectric power plants, which rely on large quantities of water for cooling during electricity generation.

At the request of this committee, GAO has undertaken three ongoing studies focusing on the water-energy nexus related to (1) biofuels and water, (2) thermoelectric power plants and water, and (3) oil shale and water. For this testimony, GAO is providing key themes that have emerged from its work to date on the research and development and data needs with regard to the production of biofuels and electricity and their linkage with water. GAO's work on oil shale is in its preliminary stages and further information will be available on this aspect of the energy-water nexus later this year.

To conduct this work, GAO is reviewing laws, agency documents, and data and is interviewing federal, state, and industry experts. GAO is not making any recommendations at this time.

View GAO-09-862T or key components.
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What GAO Found

While the effects of producing corn-based ethanol on water supply and water quality are fairly well understood, less is known about the effects of the next generation of biofuel feedstocks. Corn cultivation for ethanol production can require from 7 to 321 gallons of water per gallon of ethanol produced, depending on where it is grown and how much irrigation is needed. Corn is also a relatively resource-intensive crop, requiring higher rates of fertilizer and pesticides than many other crops. In contrast, little is known about the effects of large-scale cultivation of next generation feedstocks, such as cellulosic crops. Since these feedstocks have not been grown commercially to date, there are little data on the cumulative water, nutrient, and pesticide needs of these crops and on the amount of these crops that could be harvested as a biofuel feedstock without compromising soil and water quality. Uncertainty also exists regarding the water supply impacts of converting cellulosic feedstocks into biofuels. While water usage in the corn-based ethanol conversion process has been declining and is currently estimated at 3 gallons of water per gallon of ethanol, the amount of water consumed in the conversion of cellulosic feedstocks is less defined and will depend on the process and on technological advancements that improve the efficiency with which water is used. Finally, additional research is needed on the storage and distribution of biofuels. For example, to overcome incompatibility issues between the ethanol and the current fueling and distribution infrastructure, research is needed on conversion technologies that can be used to produce renewable fuels capable of being used in the existing infrastructure.

With regard to power plants, GAO has found that key efforts to reduce use of freshwater at power plants are under way but may not be fully captured in existing federal data. In particular, advanced cooling technologies that use air, not water, for cooling the plant, can sharply reduce or even eliminate the use of freshwater, thereby reducing the costs associated with procuring water. However, plants using these technologies may cost more to build and witness lower net electricity output—especially in hot, dry conditions. Nevertheless, a number of power plant developers in the United States have adopted advanced cooling technologies, but current federal data collection efforts may not fully document this emerging trend. Similarly, plants can use alternative water supplies such as treated waste water from municipal sewage plants to sharply reduce their use of freshwater. Use of these alternative water sources can also lower the costs associated with obtaining and using freshwater when freshwater is expensive, but pose other challenges, including requiring special treatment to avoid adverse effects on cooling equipment. Alternative water sources play an increasingly important role in reducing power plant reliance on freshwater, but federal data collection efforts do not systematically collect data on the use of these water sources by power plants. To help improve the use of alternatives to freshwater, in 2008, the Department of Energy awarded about $9 million to examine among other things, improving the performance of advanced cooling technologies. Such research is needed to help identify cost effective alternatives to traditional cooling technologies.

Mr. Chairman and Members of the Subcommittee:

I am pleased to be here today to participate in your hearing on technology research and development for the energy-water linkage often referred to as the energy-water nexus. As you know, water and energy are inexorably linked, mutually dependant, and each affects the other's availability. Energy is needed to pump, treat, and transport water, and large quantities of water are needed to support the development of energy. Production of biofuels that may help reduce our dependency on oil, and the cooling of power plants that today provide the electricity we use, represent two examples where water supply is tied directly to our ability to provide energy.

However, both water and energy are facing serious supply constraints. Freshwater is increasingly in demand to meet the needs of municipalities, farmers, industries, and the environment. Likewise, rising demand for energy—fueled by both population growth and expanding uses of energy—may soon outstrip our ability to supply it with existing resources. Looking just at electricity, according to the Energy Information Administration's (EIA) most recent Annual Energy Outlook, 259 gigawatts of new generating capacity—the equivalent of 259 large coal-fired power plants—will be needed between 2007 and 2030. As the country's energy needs grow along with its population, additional pressure will likely be put on our water resources.

Given the importance of water and energy, both the federal government and state governments play key roles in monitoring, regulating, collecting information, and supporting research on energy and water issues. In general, state governments play a central role in overseeing water availability and use by evaluating water supplies and permitting water uses. However, while much of the authority governing water supply and distribution lies with state and local governments, the federal government also has a role in helping the country meet its energy needs without damaging or depleting our supplies of freshwater. For example, federal agencies, including the Department of Energy (DOE), have provided data and analysis about water use for energy production, as well as funded related research and development. These activities are important to further our understanding of how to more efficiently use such critical resources.

At the request of this committee, GAO currently has work under way related to three aspects of the energy-water nexus—water use in the production of biofuels, water use at thermoelectric power plants, and water use in the extraction of oil from shale. We expect to release reports on biofuels and thermoelectric power plants later this year. For each study, the committee asked us to identify technologies that could help reduce the amount of water needed to produce energy from these sources. My testimony today discusses key themes we have identified during our work to date on the two ongoing energy-water nexus jobs that are furthest along, specifically (1) biofuels and water use and (2) thermoelectric power plants and water use. Our work on oil shale is in its very preliminary stages and we will have further information to share with the committee on this aspect of the energy-water nexus later this year.

To identify the effects of biofuel cultivation, conversion, and storage on water supply and water quality, we are conducting a review of relevant scientific articles and key federal and state government reports. In addition, in consultation with the National Academy of Sciences, we identified and spoke with a number of experts who have published research analyzing the water supply requirements of one or more biofuel feedstocks and the implications of increased biofuel cultivation and conversion on water quality. Furthermore, we are interviewing officials from DOE, the Environmental Protection Agency (EPA), and the Department of Agriculture (USDA) about impacts on water supply and water quality during the cultivation of biofuel feedstocks and the conversion and storage of the finished biofuels. To identify the relationship of thermoelectric plants and water, we are reviewing selected reports, interviewing federal officials and experts, and examining relevant energy and water data. In particular, we are examining reports on alternative cooling technologies and water supplies and the impact they can have on water use at power plants. We are also interviewing officials from DOE, EPA, and the Department of Interior's U.S. Geological Survey, as well as state water regulators and water and energy experts at national energy laboratories and universities. In addition, we are interviewing representatives from electric power producers, sellers of electric power plant equipment, cooling technology companies, and engineering firms that design new power plants. Finally, we are examining power plant data on water source, use, consumption, and cooling technology types collected by EIA and data collected and reported by the U.S. Geological Survey. Our work is being conducted in accordance with generally accepted government accounting standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

Biofuels are an alternative to petroleum-based transportation fuels and derived from renewable resources. Currently, most biofuels are derived from corn and soybeans. Ethanol is the most commonly produced biofuel in the United States, and about 98 percent of it is made from corn that is grown primarily in the Midwest. Corn is converted to ethanol at biorefineries through a fermentation process and requires water inputs and outputs at various stages of the production process—from growth of the feedstock to conversion into ethanol. While ethanol is primarily produced from corn grains, next generation biofuels, such as cellulosic ethanol and algae-based fuels, are being promoted for various reasons including their potential to boost the nation's energy independence and lessen environmental impacts, including on water. Cellulosic feedstocks include annual or perennial energy crops such as switchgrass, forage sorghum, and miscanthus; agricultural residues such as corn stover (the cobs, stalks, leaves, and husks of corn plants); and forest residues such as forest thinnings or chips from lumber mills. Some small biorefineries have begun to process cellulosic feedstocks on a pilot-scale basis; however, no commercial-scale facilities are currently operating in the United States.[1] In light of the federal renewable fuel standard's requirements for cellulosic ethanol starting in 2010,[2] DOE is providing $272 million to support the cost of constructing four small biorefineries that will process cellulosic feedstocks. In addition, in recent years, researchers have begun to explore the use of algae as a biofuel feedstock. Algae produce oil that can be extracted and refined into biodiesel and has a potential yield per acre that is estimated to be 10 to 20 times higher than the next closest quality feedstock. Algae can be cultivated in open ponds or in closed systems using large raceways of plastic bags containing water and algae.

Thermoelectric power plants use a fuel source—for example, coal, natural gas, nuclear material such as uranium, or the sun— to boil water to produce steam. The steam turns a turbine connected to a generator that produces electricity. Traditionally, water has been withdrawn from a river or other water source to cool the steam back into liquid so it may be reused to produce additional electricity. Most of the water used by a traditional

[1]For example, Range Fuels has operated a pilot biorefinery in Denver, Colo., since 2008 that has successfully converted pine and hardwoods into cellulosic ethanol. The company plans to optimize the technologies from this pilot plant at its cellulosic biorefinery, expected to begin commercial-scale production in 2010. This biorefinery, located in Soperton, Ga., is targeted to produce approximately 100 million gallons of ethanol and mixed alcohols from wood byproducts when it is at full scale.

[2]The Energy Independence and Security Act of 2007, Pub. L. No. 110-140 (2007).

thermoelectric power plant is for this cooling process, but water may also be needed for other purposes in the plant such as for pollution control equipment. In 2000, thermoelectric power plants accounted for 39 percent of total U.S. freshwater withdrawals.[3] EIA annually reports data on the water withdrawals, consumption and discharges of power plants of a certain size, as well as some information on water source and cooling technology type. These data are used by federal agencies and other researchers in estimating the overall power plant water use and determining how this use has and will continue to change.

Information Is Limited on the Water Supply and Water Quality Impacts of the Next Generation of Biofuels

Our work to date indicates that while the water supply and water quality effects of producing corn-based ethanol are fairly well understood, less is known about the effects of the next generation of feedstocks and fuels. The cultivation of corn for ethanol production can require substantial quantities of water—from 7 to 321 gallons per gallon of ethanol produced—depending on where it is grown and how much irrigation water is used. [4] Furthermore, corn is a relatively resource-intensive crop, requiring higher rates of fertilizer and pesticide applications than many other crops; some experts believe that additional corn production for biofuels conversion will lead to an increase in fertilizer and sediment runoff and in the number of impaired streams and other water bodies. Some researchers and conservation officials have told us that the impact of corn-based ethanol on water supply and water quality could be mitigated through research into developing additional drought-tolerant and more nutrient-efficient crop varieties thereby decreasing the amount of water needed for irrigation and the amount of fertilizer that needs to be applied. Furthermore, experts also mentioned the need for additional data on current aquifer water supplies and research on the potential of biofuel cultivation to strain these water sources.

In contrast to corn-based ethanol, our work to date indicates that much less is known about the effects that large-scale cultivation of cellulosic feedstocks will have on water supplies and water quality. Since potential cellulosic feedstocks have not been grown commercially to date, there is little information on the cumulative water, nutrient, and pesticide needs of

[3]Water consumed by thermoelectric power plants accounts for a smaller percentage.

[4]Wu, M., M. Mintz, M. Wang, and S. Arora. *Consumptive Water Use in the Production of Ethanol and Petroleum Gasoline.* Center for Transportation Research, Energy Systems Division, Argonne National Laboratory, January 2009.

these crops, and it is not yet known what agricultural practices will actually be used to cultivate these feedstocks on a commercial scale. For example, while some experts assume that perennial feedstocks will be rainfed, other experts have pointed out that to achieve maximum yields for cellulosic crops, farmers may need to irrigate these crops. Furthermore, because water supplies vary regionally, additional research is needed to better understand geographical influences on feedstock production. For example, the additional withdrawals in states relying heavily on irrigation for agriculture, such as Nebraska, may place new demands on the Ogallala Aquifer, an already strained resource from which eight states draw water. In addition, if agricultural residues—such as corn stover—are to be used, this could negatively affect soil quality, increase the need for fertilizer, and lead to increased sediment runoff to waterways. Considerable uncertainty exists regarding the maximum amount of residue that can be removed for biofuels production while maintaining soil and water quality. USDA, DOE, and some academic researchers are attempting to develop new projections on how much residue can be removed without compromising soil quality, but sufficient data are not yet available to inform their efforts, and it may take several years to accumulate such data and disseminate it to farmers for implementation. Experts we spoke with generally agree that more research on how to produce cellulosic feedstocks in a sustainable way is needed.

Our work also indicates that even less is known about newer biofuels feedstocks such as algae. Algae have the added advantage of being able to use lower-quality water for cultivation, according to experts. However, the impact on water supply and water quality will ultimately depend on which cultivation methods are determined to be the most viable. Therefore, research is needed on how best to cultivate this feedstock in order to maximize its potential as a biofuel feedstock and limit its potential impacts on water resources. Other areas we have identified that relate to water and algae cultivation in need of additional research include:

- *Oil extraction*. Additional research is needed on how to extract the oil from the algal cell in such a way as to preserve the water contained in the cell along with the oil, thereby allowing some of that water to be recycled back into the cultivation process.
- *Contaminants*. Information is needed on how to manage the contaminants that are found in the algal cultivation water and how any resulting wastewater should be handled.

Uncertainty also exists regarding the water supply impacts of converting feedstocks into biofuels. Biorefineries require water for processing the fuel and need to draw from existing water resources. Water consumed in the corn-ethanol conversion process has declined over time with improved equipment and energy efficient design, according to a 2009 Argonne National Laboratory study, and is currently estimated at 3 gallons of water required for each gallon of ethanol produced. However, the primary source of freshwater for most existing corn ethanol plants is from local groundwater aquifers and some of these aquifers are not readily replenished. For the conversion of cellulosic feedstocks, the amount of water consumed is less defined and will depend on the process and on technological advancements that improve the efficiency with which water is used. Current estimates range from 1.9 to 5.9 gallons of water, depending on the technology used. Some experts we spoke with said that greater research is needed on how to manage the full water needs of biorefineries and reduce these needs further. Similar to current and next generation feedstock cultivation, additional research is also needed to better understand the impact of biorefinery withdrawals on aquifers and to consider potential resource strains when siting these facilities.

Our work to date also indicates that additional research is needed on the storage and distribution of biofuels. Ethanol is highly corrosive and poses a risk of damage to pipelines, and underground and above-ground storage tanks, which could in turn lead to releases to the environment that may contaminate groundwater, among other issues. These leaks can be the result of biofuel blends being stored in incompatible tank systems—those that have not been certified to handle fuel blends containing more than 10 percent ethanol. While EPA currently has some research under way, additional study is needed into the compatibility of higher fuel blends, such as those containing 15 percent ethanol, with the existing fueling infrastructure. To overcome potential compatibility issues, future research is needed on other conversion technologies that can be used to produce renewable and advanced fuels that are capable of being used in the existing infrastructure.

Key Efforts to Reduce Use of Freshwater at Power Plants May Not Be Fully Captured in Existing Federal Data

In our work to date, we have found (1) the use of advanced cooling technologies can reduce freshwater use at thermoelectric power plants, but federal data may not fully capture this industry change; (2) the use of alternative water sources can also reduce freshwater use, but federal data may not systematically capture this change; and (3) federal research under way is focused on examining efforts to reduce the use of freshwater in thermoelectric power plants.

Advanced cooling technologies offer the promise to reduce freshwater use by thermoelectric power plants. Unlike traditional cooling technologies that use water to cool the steam in power plants, advanced cooling technologies carry out all or part of the cooling process using air. According to power plant developers, they consider using these water-conserving technologies in new plants, particularly in areas with limited available water supplies. While these technologies can significantly reduce the amount of water used in a plant—and in some cases eliminate the use of water for cooling—their use entails a number of challenges. For example, plants using advanced cooling technologies may cost more to build and operate; require more land; and, because these technologies can consume a significant amount of energy themselves, witness lower net electricity output—especially in hot, dry conditions. However, eliminating or minimizing freshwater use by incorporating an advanced cooling technology provides a number of potential benefits to plant developers, including minimizing the costs associated with acquiring, transporting, and treating water, as well as eliminating impacts on the environment associated with water withdrawals, consumption, and discharge. In addition, the use of these advanced cooling technologies may provide the flexibility to build power plants in locations not near a source of water.

For these reasons, a number of power plant developers in the United States and across the world have adopted advanced cooling technologies, but according to EIA officials, the agency's forms have not been designed to collect information on the use of advanced cooling technologies. Moreover, the instruments the agency uses to collect these data were developed many years ago and have not been recently updated. EIA officials have told us that while some plants may choose to report this information, they may not do so consistently or in such a way that allows comprehensive identification of the universe of plants using advanced cooling technologies. Water experts and federal agencies we spoke to during the course of our work identified value in the annual EIA data on cooling technologies, but some explained that not having data on advanced cooling technologies limits public understanding of their prevalence and analysis of the extent to which their adoption results in a significant reduction in freshwater use. According to EIA officials, the agency is currently redesigning the instrument it uses to collect these data and expects to begin using the revised instrument in 2011. In addition, during the course of our work we noted that in 2002, EIA discontinued reporting water-related data for nuclear power plants, including water use and cooling technology. As we develop our final report, we will be looking at various suggestions that we can make to DOE to improve its data collection efforts.

Our work to date also indicates that the use of alternative water sources can substantially reduce or eliminate the need to use freshwater for power plant cooling at an individual plant. Alternative water sources that may be usable for power plant cooling include treated effluent from sewage treatment plants; groundwater that is unsuitable for drinking or irrigation because it is high in salts or other impurities; industrial water, such as water generated when extracting minerals like oil, gas, and coal; and others. Use of these alternative water sources can ease the development process where freshwater sources are in short supply and lower the costs associated with obtaining and using freshwater when freshwater is expensive. Because of these advantages, alternative water sources play an increasingly important role in reducing power plant reliance on freshwater, but can pose challenges, including requiring special treatment to avoid adverse effects on cooling equipment, requiring additional efforts to comply with relevant regulations, and limiting the potential locations of power plants to those nearby an alternative water source. These challenges are similar to those faced by power plants that use freshwater, but they may be exacerbated by the lower quality of alternative water sources.

Power plant developers we spoke with told us they routinely consider use of alternative water sources when developing their power plant proposals. Moreover, a 2007 report by Argonne National Laboratory indicates that the use of treated municipal wastewater at power plants has become more common, with 38 percent of power plants after 2000 using reclaimed water. EIA collects annual data from power plants on their water use and water source. However, according to EIA officials, while some plants report using an alternative water source, many may not be reporting such information since EIA's data collection form was not designed to collect data on these freshwater alternatives. One expert we spoke with told us that not having data on the use of alternative water sources at power plants limits public understanding of these trends and the extent to which these approaches are effective in reducing freshwater use. As we develop our final report, we plan to also develop suggestions for DOE that can improve this data gathering process.

Power plant developers may choose to reduce their use of freshwater for a number of reasons, such as when freshwater is unavailable or costly to obtain, to comply with regulatory requirements, or to address public concern. However, a developer's decision to deploy an advanced cooling technology or an alternative water source depends on an evaluation of the tradeoffs between the water savings and other benefits these alternatives offer and the cost involved. For example, where water is unavailable or prohibitively expensive, power plant developers may determine that despite the challenges, advanced cooling technologies or alternative water sources offer the best option for getting a potentially profitable plant built in a specific area.

While private developers make key decisions on what types of power plants to build and where to build them, and how to cool them based on their views of the costs and benefits of various alternatives, government research and development can be a tool to further the use of alternative cooling technologies and alternative water supplies. In this regard, the Department of Energy's National Energy Technology Laboratory (NETL) plays a central role in DOE's research and development effort. In recent years, NETL has funded research and development projects through its Innovations for Existing Plants program aimed at minimizing the challenges of deploying advanced cooling technologies and using alternative water sources at existing plants, among other things. In 2008, DOE awarded about $9 million to support research and development of projects that, among other things, could improve the performance of advanced cooling technologies, recover water used to reduce emissions of air pollutants at coal plants for reuse, and facilitate the use of alternative water sources such as polluted water for cooling. Such research endeavors, if successful, could alter the trade-off analysis power plant developers conduct in favor of nontraditional alternatives to cooling.

Concluding Observations

Ensuring sufficient supplies of energy and water will be essential to meeting the demands of the 21st century. This task will be particularly difficult, given the interdependency between energy production and water supply and water quality and the strains that both these resources currently face. DOE, together with other federal agencies, has a key role to play in providing key information, helping to identify ways to improve the productivity of both energy and water, partnering with industry to develop technologies that can lower costs, and analyzing what progress has been made along the way. While we recognize that DOE currently has a number of ongoing research efforts to develop information and technologies that will address various aspects of the energy-water nexus, our work indicates that there are a number of areas to focus future research and development efforts. Investments in these areas will provide information to help ensure that we are balancing energy independence and security with effective management of our freshwater resources.

Mr. Chairman that concludes my prepared statement, I would be happy to respond to any questions that you or other Members of the Subcommittee might have.

GAO Contact and Staff Acknowledgments

For further information on this testimony, please contact me at 202-512-3841 or mittala@gao.gov. Key staff contributors to this testimony were Jon Ludwigson, Assistant Director; Elizabeth Erdmann, Assistant Director; Scott Clayton; Paige Gilbreath; Miriam Hill; Randy Jones; Micah McMillan; Nicole Rishel; Swati Thomas; Lisa Vojta; and Rebecca Wilson. Contact points for our Office of Congressional Relations and Public Affairs may be found on the last page of this statement.

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