U.S. Department of Energy
Washington, DC 20585

Date: **June 18, 2014**
To: **Members of the Public**
From: **Quadrennial Energy Review Task Force Secretariat and Energy Policy and Systems Analysis Staff, United States Department of Energy**
Re: **Stakeholder Meeting on the "Water-Energy Nexus"**

1. Introduction

On January 9, 2014, President Obama issued a Presidential Memorandum establishing a Quadrennial Energy Review (QER). The Secretary of Energy will provide support to the QER Task Force, including coordination of activities related to the preparation of the QER report, policy analysis and modeling, and stakeholder engagement.

On Thursday, June 19, 2014, at 9:00 a.m. in the San Francisco City Hall in California, the U.S. Department of Energy (DOE), acting as the Secretariat for the QER Task Force, will hold a public meeting to discuss and receive comments on issues surrounding water use in the energy sector and energy use in the water sector—a relationship that is sometimes referred to as the "water-energy nexus." Two expert panels will explore the trends influencing a greater urgency to coordinate operations, policy, and planning in the water and energy sectors with the goal of identifying regional lesson learned and remaining opportunities for efficiency, conservation, and infrastructure resilience that are applicable on a national scale. While the 2015 QER will focus on transmission, storage, and distribution (TS&D), this meeting will address a broader set of issues that relate to both current and future QER research and the DOE's work on the water-energy nexus.

There will be an opportunity for public comment via an open microphone session beginning at 12:30 p.m. The session will also be webcast and written comments can be submitted to: QERcomments@hq.doe.gov.

2. Framing the Issues

Water is used in all phases of energy production and electricity generation, and energy is required to extract, convey and deliver water and then to treat wastewaters prior to their return to the environment. While undeniably interconnected, energy and water systems have historically been developed, managed, and regulated independently at the local, state, national, and international levels.

Recent developments have focused national attention on the connections between water and energy infrastructure. When severe drought affected more than a third of the United States in 2012, limited water availability constrained the operation of some power plants and other energy production activities. Hurricane Sandy demonstrated the compounding ramifications of vital water infrastructure losing power. The recent boom in domestic unconventional oil and gas development brought on by hydraulic fracturing and horizontal drilling has added complexity to the national dialogue about the relationship between energy and water resources.

Major drivers accentuating the importance of this water-energy nexus include: 1) Climate change, which is affecting precipitation and temperature patterns and potentially limiting water availability; 2) U.S. population growth and regional migration to arid areas such as the Southwest, which is bound to increase regional water consumption; 3) New technologies in the energy and the water sectors that are shifting/increasing water and energy demand.

These trends present challenges as well as opportunities for the U.S. economy and energy system. Many of the critical issues surrounding the interplay between water and energy are captured in DOE's report, issued today, *The Water-Energy Nexus: Challenges and Opportunities.*

3. Water Use for Energy Production, Generation, and Consumption

Broadly, water use can be broken down into two elements: withdrawal and consumption. "Withdrawal" designates any water diverted from a surface or groundwater source, whereas "consumption" designates withdrawn water that is not returned to its source (e.g., because it has evaporated, been transpired by plants, or incorporated into products).

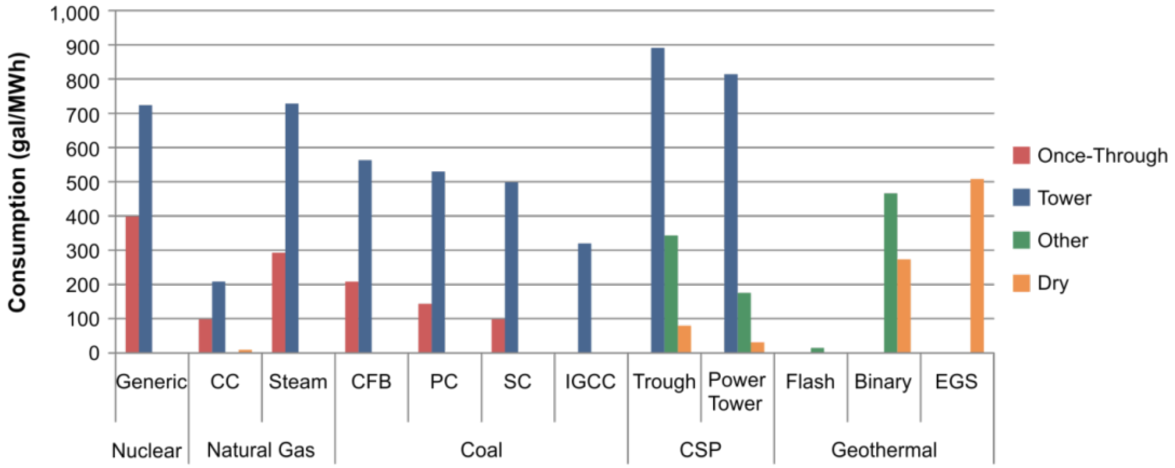

Figure 1. Operation water consumption factors for various thermoelectric generation and cooling technologies.

Abbreviations: CC: Combined Cycle; CFB: Circulating Fluidized Bed; PC: Pulverized Coal; SC: Supercritical Pulverized Coal; IGCC: Integrated Gasification Combined Cycle; CSP: Concentrating Solar Power; EGS: Enhanced Geothermal System.

In 2008, the U.S. energy sector withdrew 25 times as much water volume as it consumed, mainly using the water for cooling then returning it to the local hydrological system—though not always to the same ecosystem or in the same state.[1] This condition is somewhat unique to the United States, where many power plants were built prior to 1980. Earlier systems tended to use once-through cooling, which withdraws a great deal of water but consumes relatively little. As depicted in Figure 2, on a gallons per megawatt hour basis, freshwater withdrawals for thermoelectric generation in the United States have declined dramatically since 1975.

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[1] WEF (World Economic Forum). 2008. *Energy Vision Update 2009 Thirsty Energy: Water and Energy in the 21st Century*. Geneva, Switzerland: WEF. http://www3.weforum.org/docs/WEF_WaterAndEnergy21stCentury_Report.pdf

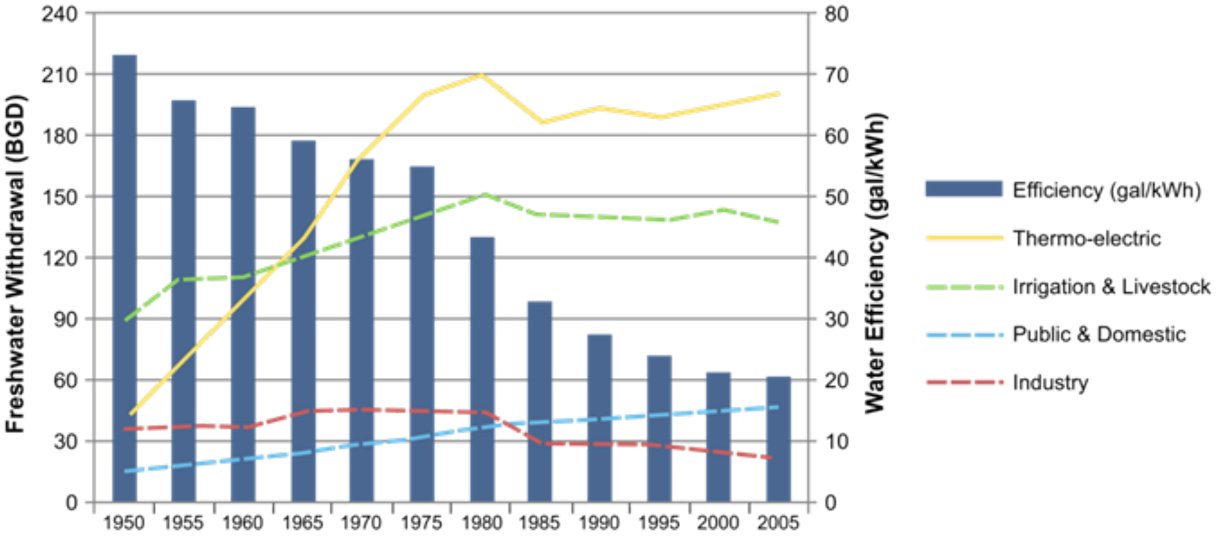

Figure 2. Water use for thermoelectric generation and other sectors.

However, even with these reductions, the United States still withdraws more water per capita than any other developed country, as shown in Table 1.

Table 1. Water Withdrawal Per Capita ,for all Uses for Selected Countries.

Country	Water Withdrawal Per Capita/Year[2]
United States	1730 cubic meters
Canada	1420 cubic meters
United Kingdom	230 cubic meters
Germany	460 cubic meters
Japan	680 cubic meters
France	530 cubic meters

Growth trajectories for withdrawn water and consumed water in the energy industry are projected to diverge dramatically over the coming decades. Internationally, withdrawal in the energy sector is projected to rise by 20 percent through 2035, while consumed water is projected increase by 85 percent.[3]

3.1 Water Withdrawals for Energy

At 196 billion gallons per day (BGD), thermoelectric electricity generation is by far the largest withdrawer of fresh water in the U.S. economy. The second largest source for fresh water withdrawals is the agriculture sector, which uses 137 billion gallons per day.

In the energy sector, water withdrawals are particularly important for Rankine cycle engines that are used for thermoelectric (e.g. coal, natural gas, oil and nuclear) generation. Within such systems, pressurized

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[2] Organization of Economically Developed Countries. 2005. "*Water Consumption*" http://www.oecd.org/publications/factbook/34416097.pdf

[3] IEA (International Energy Agency). 2012. *World Energy Outlook 2012.* http://www.worldenergyoutlook.org/resources/water-energynexus/

steam-driven turbines spin large dynamos that generate electricity. According to the U.S. Energy Information Administration (EIA), more than 86 percent of the nation's electricity comes from steam turbines in thermoelectric power generating stations.[4] Thermoelectric use currently constitutes more than 40 percent of freshwater withdrawals (138 BGD) and 4 percent of freshwater consumption (4.3 BGD).[5] And over the coming decades, carbon mitigation technologies such as carbon capture and sequestration could increase its water intensity.[6] In addition to water quantity, temperature is also important. The temperature of returned water is regulated to protect ecosystems. Although seawater has been used for once-through cooling of power plants, challenges remain in employing salt water for recirculating systems and the energy industry generally requires freshwater.

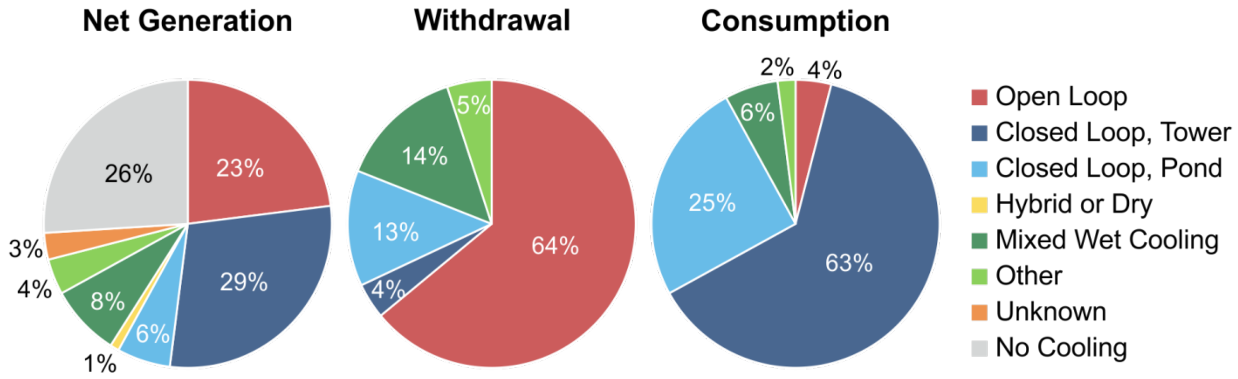

Figure 3. U.S. power generation, water withdrawal, and water consumption, by cooling type (2011).

Other important elements of the energy system that withdraw and consume large amounts of water include enhanced oil recovery, energy storage, hydraulic fracturing, and bioenergy production.

3.2 Water Consumption for Energy

The critical difference between water withdrawals and consumption is that consumed water is essentially lost to the local hydrological system. For instance, irrigation for farming consumes far more water than energy (74% of total U.S. consumption). Still energy is a major consumer of fresh water.

Irrigation for corn that is then transformed into ethanol (which makes up about 7% of the energy in America's gasoline) is one long-standing source of water consumption by the energy sector. However, there are other emerging water-intensive energy production technologies. A case in point is the practice of hydraulic fracturing, or "fracking." For shale gas and shale oil production, significant quantities of freshwater are used to fracture energy-rich shale formations. Chemicals and solid particles are added to the water to transform it into a more viscous gritty mixture. This solution includes proppants to keep fractures from closing, gels to increase the fluid viscosity, acids to help remove drilling mud near the wellbore, biocides to prevent microbial growth, scale inhibitors to control precipitates, and surfactants to

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[4] EIA (Energy Information Administration). 2013. "Electricity Explained: Electricity in the United States." www.eia.gov/energyexplained

[5] DOE (Department of Energy), 2014. *The Water-Energy Nexus: Challenges and Opportunities*. Department of Energy, Washington, DC

[6] Ibid.

increase the injected fluid recovery. The quantities of water used in this process can be substantial on a regional basis. A typical well uses between one and five millions gallons for fracturing and, unlike power generation, much of this water is “consumed”—it is permanently disposed of, or in some cases it is recycled or reused.[7]

On a national basis, the quantities of water consumed for fracking are not particularly large. However, the impacts must be analyzed at a local level. Ecosystems, farms, factories, and communities that compete with shale oil/gas producers can be negatively affected by water contamination or water scarcity in areas where supply is particularly tight. The challenges in a relatively wet climate like Pennsylvania may be primarily associated with water quality issues, whereas those in a water-scarce environment such as Colorado or New Mexico may find the water demands prohibitive. For instance, during the drought of

Water for Energy: Solutions for reducing water use in energy production in the United States

Cooling

Thermoelectric power plants are the largest single source of water withdrawals in the United States. Population pressures, drought conditions, and possible future regulations could further constrain water availability. Current alternatives to water-based cooling are expensive and impose operational penalties. More efficient and less expensive options could significantly impact water withdrawal and consumption.

Waste Heat Recovery

Thermoelectric power plants currently convert less than half of their primary energy to electricity. Most of the balance is dissipated into the atmosphere via flue gases and cooling towers. There are promising options to recover substantial amounts of this waste heat and reduce the need for cooling. Lower-grade waste heat may also be recovered from oil and gas wells for use with low temperature co-produced geothermal energy.

Process Water Efficiency and Quality

There are opportunities to improve water efficiency in industrial processes, including, but not limited to, carbon capture and storage, biorefineries, and advanced perennial feedstocks for bioenergy.

Alternatives to Fresh Water in Energy Production

There are opportunities to explore the use of substances such as supercritical carbon dioxide, nitrogen, novel nanomaterials, and liquid hydrocarbons as replacements for water in subsurface stimulation for oil and gas extraction or geothermal heat recovery. There are also opportunities to pursue entirely new and different approaches, such as using accelerants for energetic fracturing.

Hydropower

New hydropower technologies possess potential for electricity generation from unpowered dams. Additionally, human conveyances such as irrigation canals and drinking and wastewater flows provide opportunities for nontraditional hydropower technology development while minimizing civil works and environmental impact.

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[7] Ibid.

2011, the city of Grand Prairie, Texas, banned the use of city water for hydraulic fracturing and other Texas municipalities soon followed.[8]

3.3 Renewable Energy and Water

Renewable energy may also use significant quantities of water. However, water use varies depending on technology. Solar photovoltaics and wind power consume almost no water in operation. However, concentrated solar power (CSP) can consume large quantities of water (especially in the local context of the desert environments where a CSP facility is likely to be built). A more obvious example is hydropower (responsible for about 7% of U.S. electricity generation), which is reliant on large quantities of water but returns most (minus the water lost to evaporation) to the hydrological system.

4. Conveyance, Purification, and Treatment of Water Consumes Significant Amounts of Energy

While producing energy requires an enormous amount of water, delivering water of acceptable quality for geographically dispersed human activities also requires significant amounts of energy. Energy for water comprises 3 percent to 3.5 percent of total U.S. electricity consumption, including agricultural pumping and large-scale conveyance, while excluding end uses such as home water heating.[9] Some of the primary uses of energy for water include pumping for irrigation, water treatment, and desalination.

A prime example of the energy draw for water conveyance and delivery is California's State Water Project (SWP). This massive system moves water through a series of pumping stations that conveys and lifts it from Lake Oroville north of Sacramento, to consumers in the state's far south.[10] The largest single lift is at the Edmonston Pumping Plant, which pumps water nearly 2,000 feet over the Tehachapi Mountains using 14 pumps, each of which has a capacity of 80,000 hp. In total, the SWP pumps have a capacity of 2,600 megawatts, making them the single largest single user of energy in the state. The entire SWP consumes an average of 5 million megawatt hours per year, accounting for about 2 to 3 percent of

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[8] DOE (U.S. Department of Energy). 2013. *U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather*. Washington, DC: DOE. http://energy.gov/sites/prod/files/2013/07/f2/20130716-Energy%20Sector%20Vulnerabilities%20Report.pdf.

[9] Amarnath, A., B. Goldstein, et al. (2013). *Electricity Use and Management in the Municipal Water Supply and Wastewater Industries*. Palo Alto, CA, Electric Power Research Institute: 194.; CPUC (2010). *Statewide and Regional Water-Energy Relationship*. Embedded Energy in Water Studies. Sacramento, CA, California Public Utilities Commission: 155.; Marks, G., E. Wilcox, et al. (2013). *Opportunities for Demand Response in California Agricultural Irrigation: A Scoping Study*. Berkeley, CA, Lawrence Berkeley National Laboratory: 82.; Sanders, K. T. and M. E. Webber (2012). "Evaluating the energy consumed for water use in the United States." Environmental Research Letters 7(3).; Stanford (2013). "Water and Energy Nexus: A Literature Review." Stanford University. Accessed January 7, 2014, http://waterinthewest.stanford.edu/sites/default/files/Water-Energy_Lit_Review.pdf. **NOTE:** Amarnath et al. calculate slightly less than 2 percent as a total figure for water and wastewater systems, but they do not include energy required for long-distance conveyance, such as the California and Arizona Water Projects (CPUC 2010), and they also do not account for groundwater pumping for irrigation. This report estimates total electricity use for irrigation between 30 and 50 TWh/year, based on factors reported by Water in the West (Stanford 2013), and supported by (Marks et al., 2013), which estimates a figure of 10 TWh/year for irrigation in California alone.

[10] The Power Association of Northern California. 2013. "*The State Water Project and California's Electrical System*." http://www.panc.org/documents/Torres_Sep11.pdf

all electricity consumed in California.[11] At the same time, the SWP is also one of the largest energy producers in the state, with a combined hydro generation capacity of 1700 megawatts.

4.1 Water treatment

Water purification is another area in which water use draws intensively on energy resources. As high-quality fresh water becomes increasingly scarce, water purification promises to demand increasing quantities of energy for the treatment of so-called "nontraditional waters." The productive use of nontraditional waters (e.g., salt water or brackish water) is particularly significant for regions facing chronic freshwater shortages.

Nontraditional waters vary widely in quality – frequently measured by total dissolved solids (TDS) and total suspended solids (TSS). TDS is a loose measure of salinity in milligrams per liter (mg/L), and a rough proxy for toxicity to terrestrial and fresh water aquatic life forms. TSS characterizes the mass of relatively large particles, organic and inorganic, present in the water—in practical terms, it evaluates how "clear" the water is. For example, the Mississippi River below New Orleans is high in TSS (very brown), while snowmelt directly off a glacier in Alaska would score low on this scale (clear). The higher the TDS and TSS of a particular source of water, the more energy intensive it will be to purify.

4.2 Desalination

In an era of water scarcity, targeting nontraditional waters for human, industrial, and agricultural consumption will be increasingly important. Seawater constitutes a relatively infinite resource; the challenge is to utilize these waters in a fashion that is least energy-intensive. Desalination has been practiced at commercial scales for decades. Thermal methods such as multistage flash and multiple effect distillation are widely utilized in areas where energy is plentiful and freshwater is scarce (e.g., the Middle East).[12] However, techniques that depend on boiling water are energy-intensive. Reverse osmosis (RO), often in combination with nanofiltration (NF), have emerged as the predominant technologies used in desalination operations in the United States, as they are significantly less energy-intensive than traditional thermal techniques. However, both capital and energy costs are still high, thus opportunities for improvement remain.

Brackish groundwater is also an important potential resource in water-scarce regions. It requires less energy to treat than seawater, and as such could be a valuable source of water for energy operations. Additionally, produced waters from oil and gas, geothermal production, and potentially carbon capture and storage operations tend to be high in salinity. Productive use of these waters presents a significant opportunity, but it will require improved cost- and energy-efficiency of desalination solutions in order to gain market penetration.

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[11] Environmental Protection Agency. 2014. "*Water Energy Connection*." http://www.epa.gov/region9/waterinfrastructure/waterenergy.html

[12] NRC (National Research Council). 2008. *Water Implications of Biofuels Production in the United States*. Washington, DC: The National Academies Press.

4.3 Municipal and Industrial Wastewater Treatment

The second major category of opportunity in water treatment involves wastewaters. Recent estimates suggest that at least 1 percent of U.S. electricity is consumed in municipal wastewater treatment alone.[13] Although these figures are based on estimates, we do know that water treatment and delivery often comprise municipalities' largest uses of electricity.

A variety of possible mechanisms may increase the efficiency of wastewater treatment. For instance, replacing aerobic water treatment systems with anaerobic alternatives could provide significant energy savings.[14] Another opportunity is to utilize techniques that enhance the production of biogas from anaerobic digesters and reduce the volume of sludge requiring disposal. This could both decrease energy use and enhance the resilience of water treatment facilities to power outages.[15] These are just two examples of techniques that can potentially increase the efficiency and resiliency of such systems while reducing energy use.[16]

5. Climate change

The effects of climate change on U.S. energy and water use will be profound. They range from increased energy use for cooling, to decreased efficiencies for thermal power plants, to decreased fresh water supplies from traditional sources such as mountain snowpack in the Western United States. These effects are not uniform across states and regions. For instance, water scarcity is a significant issue for all states in the Southwest, but for states in the Northeast (e.g. New York and New Jersey) many of the challenges posed by climate change will have to do with rising sea levels and increased severity of storms (e.g. Hurricane Sandy).

Rising average temperatures, shifting precipitation patterns, increasing climate variability and more frequent extreme weather events alter the availability and predictability of water resources. These effects, combined with population growth, can intensify existing competition for water resources and impact energy production and distribution. As these climate impacts continue, water stress in certain constrained areas will continue to emerge. Competition for non-energy applications such as domestic water use and irrigation for food crops will increase as well.

A recent DOE report entitled *U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather* highlighted some key vulnerabilities for the U.S. energy sector. Findings from that report include:

- Thermoelectric power generation facilities are at risk from decreasing water availability and increasing ambient air and water temperatures, which reduce the efficiency of cooling, increase the

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[13] Amarnath, A., B. Goldstein, et al. (2013). *Electricity Use and Management in the Municipal Water Supply and Wastewater Industries*. Palo Alto, CA, Electric Power Research Institute: 194.

[14] McCarty, P. L., J. Bae, et al. (2011). "Domestic Wastewater Treatment as a Net Energy Producer-Can This be Achieved?" Environmental Science & Technology 45(17): 7100-7106.

[15] Neyens, E. and J. Baeyens (2003). "A review of thermal sludge pre-treatment processes to improve dewaterability." Journal of Hazardous Materials 98(1-3): 51-67.

[16] Joss, A., N. Derlon, et al. (2011). "Combined Nitritation-Anammox: Advances in Understanding Process Stability." Environmental Science & Technology 45(22): 9735-9742.

likelihood of exceeding water thermal intake or effluent limits that protect local ecology, and increase the risk of partial or full shutdowns of generation facilities.

- Energy infrastructure located along the coast is at risk from sea level rise, increasing intensity of storms, and higher storm surge and flooding, potentially disrupting oil and gas production, refining, and distribution, as well as electricity generation and distribution.
- Oil and gas production, including unconventional oil and gas production (which constitutes an expanding share of the nation's energy supply) is vulnerable to decreasing water availability given the volumes of water required for enhanced oil recovery, hydraulic fracturing, and refining.
- Renewable energy resources, particularly hydropower, bioenergy, and concentrating solar power can be affected by changing precipitation patterns, increasing frequency and intensity of droughts, and increasing temperatures.
- Fuel transport by rail and barge is susceptible to increased interruption and delay during more frequent periods of drought and flooding that affect water levels in rivers and ports.
- Increasing temperatures will likely increase electricity demand for cooling.

The report also notes that:

> *Some of these effects, such as higher temperatures of ambient water used for cooling, are projected to occur in all regions. Other effects may vary more by region, and the vulnerabilities faced by various stakeholders may differ significantly depending on their specific exposure to the condition or event. However, regional variation does not imply regional isolation as energy systems have become increasingly interconnected. Compounding factors may create additional challenges. For example, combinations of persistent drought, extreme heat events, and wildfire may create short-term peaks in demand and diminish system flexibility and supply, which could limit the ability to respond to that demand.*

6. Conclusions

To summarize, U.S. water and energy use is heavily interdependent. Over the coming decades, demographic shifts, economic growth, climate change, new energy production techniques, and other factors are likely to shift the demand for water use in the U.S. energy industry and also push many aspects of water transport and treatment to new, more energy-intensive models.

Some of the measures to address these changes include focusing on increased research, development, demonstration, and deployment (RDD&D) of water-efficient energy technologies, and also energy efficiency water technologies. A shift toward energy resources that do not depend on water for power generation (e.g., solar cells) and away from technologies that do (e.g., coal) can also improve the prospects arid regions in the United States.

7. Key Questions

- How do stakeholders view water-energy challenges, what are available tools to address them, and where is policy intervention needed?
- What are the most critical water-energy system interdependencies, how are they evolving, and how can stakeholders and policymakers address system weaknesses and vulnerabilities posed by these interdependencies in order to boost resilience?
- What future trends affecting the water-energy nexus are most important?
- What specific opportunities exist for productive synergies between energy and water systems?
- Are there specific policies, or policy gaps, that create issues in the water-energy nexus? Could these be addressed through specific executive or legislative action?
- What financial, market or other incentives are most important in shaping the water-energy decision making landscape and how are they changing?
- How much and what type of investment is needed in technology RDD&D to address water-energy challenges?
- How can government and industry accelerate appropriate technology improvements at the water-energy nexus?
- What new information do government and stakeholders need as they address water-energy challenges?
- Are there ways to strengthen industry/government partnerships around water-energy issues, improving flows of information and data that are critical to addressing these issues?
- What is the DOE's role in collaboration with state, regional, tribal, and local entities in the water-energy nexus?
- Given that water is an inherently local and regional phenomenon, what is the appropriate role of the U.S. Department of Energy in the water-energy arena?
- To what degree are lessons learned in California applicable to other states?
- What are some of the key data gaps, inconsistencies, and translation issues that impede coordination of the energy and water sectors?