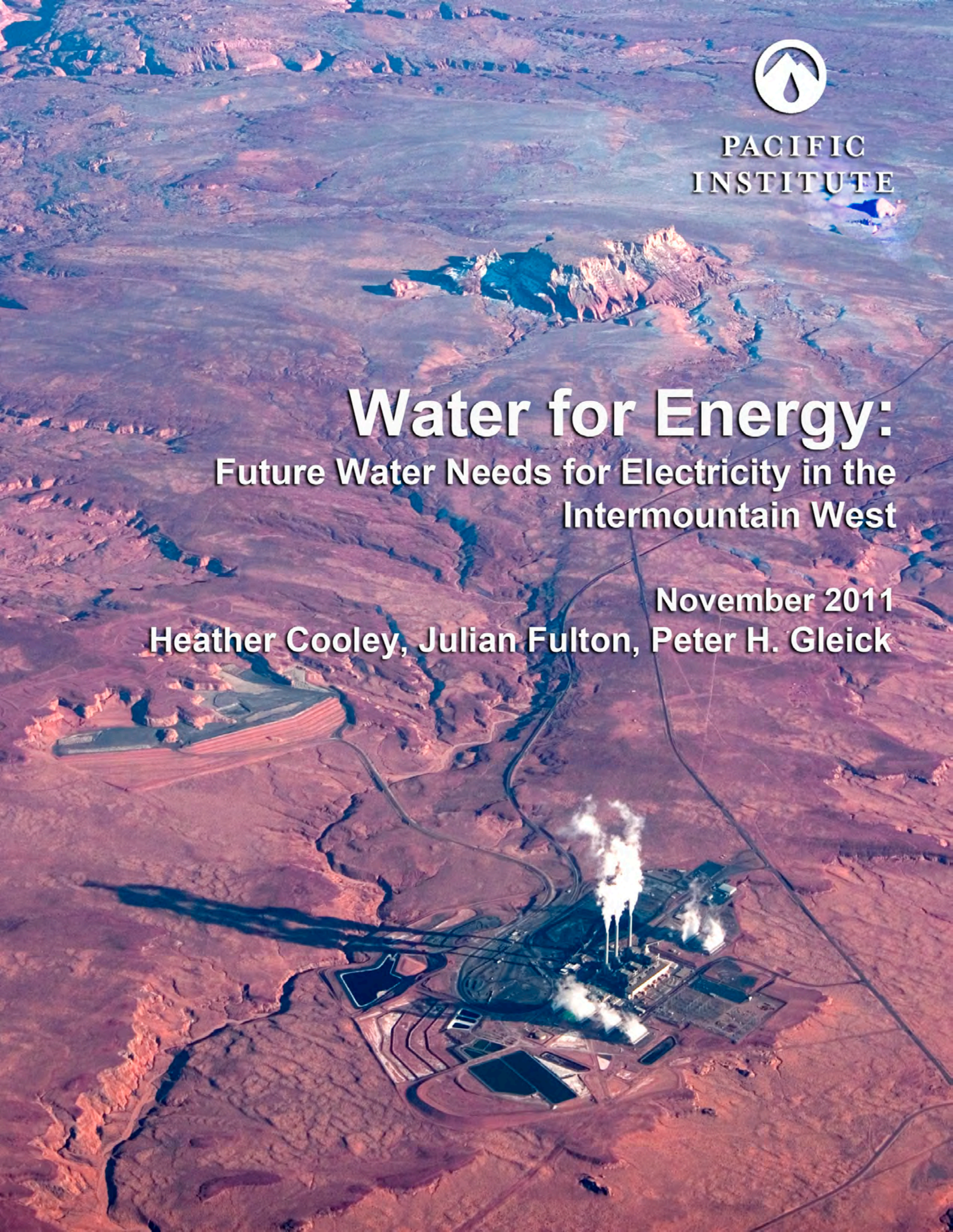

PACIFIC INSTITUTE

Water for Energy:

Future Water Needs for Electricity in the Intermountain West

November 2011

Heather Cooley, Julian Fulton, Peter H. Gleick

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The Pacific Institute is one of the world's leading nonprofit research and policy organizations working to create a healthier planet and sustainable communities. Based in Oakland, California, we conduct interdisciplinary research and partner with stakeholders to produce solutions that advance environmental protection, economic development, and social equity – in California, nationally, and internationally. We work to change policy and find real-world solutions to problems like water shortages, habitat destruction, global warming, and environmental injustice.

Since our founding in 1987, the Pacific Institute has become a locus for independent, innovative thinking that cuts across traditional areas of study, helping us make connections and bring opposing groups together. The result is effective, actionable solutions addressing issues in the fields of freshwater resources, climate change, environmental justice, and globalization. More information about the Institute and our staff, directors, funders, and programs can be found at www.pacinst.org.

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Glossary of Acronyms

ANL	Argonne National Laboratory
AEO	Annual Energy Outlook
AP	Associated Press
AZNM	Arizona-New Mexico
CCS	carbon capture and storage
CO_2	carbon dioxide
EIA	United States Energy Information Administration
EPA	Environmental Protection Agency
GAO	Government Accountability Office
IPCC	Intergovernmental Panel on Climate Change
kWh_e	kilowatt-hour of electricity
kWh_{th}	kilowatt-hour of thermal energy
UNEP	United Nations Environment Programme
NETL	National Energy Technology Laboratory
MW	megawatt
NWPP	Northwest Power Pool
RMPA	Rocky Mountain Power Area
SEG	Scientific Expert Group on Climate Change
Solar PV	solar photovoltaic
U.S.	United States
U.S. DOE	United States Department of Energy
USGCRP	United States Global Change Research Program
USGS	United States Geological Survey
WECC	Western Electricity Coordination Council

Water for Energy: Future Water Needs for Electricity in the Intermountain West

Introduction

In the past few years, there has been a growing interest in the complex connections between energy and water, typically called the energy-water nexus. For much of the 20th century, these two vital resources have largely been analyzed and managed separately, with different tools, institutions, definitions, and objectives. We now know, however, that there are very important links between water and energy and that long-term sustainable use of both resources requires more comprehensive and integrated study and management. The current report addresses the water implications of energy choices and offers some new insights into the water risks of different electricity futures.[1]

The energy sector has a major impact on the availability and quality of the nation's water resources (Table 1). Water is used to extract and produce energy; process and refine fuels; construct, operate, and maintain energy generation facilities; cool power plants; generate hydroelectricity; and dispose of energy-sector wastes. Some of this water is consumed during operation or contaminated until it is unfit for further use; often much of it is withdrawn, used once, and returned to a watershed for use by other sectors of society.

Energy use also affects water quality and ultimately human and environment health. The discharge of waste heat from cooling systems, for example, raises the temperature of rivers and lakes, which affects aquatic ecosystems. Wastewaters from fossil-fuel or uranium mining operations, hydraulic fracturing, boilers, and cooling systems may be contaminated with heavy metals, radioactive materials, acids, organic materials, suspended solids, or other chemicals (EPA 2011, Urbina 2011). Nuclear fuel production plants, uranium mill tailings ponds, and under unusual circumstances, nuclear power plants, have caused radioactive contamination of ground- and surface-water supplies (EPA 2010). Too often, however, these water-quality impacts are ignored or inadequately understood.

[1] While there are interesting challenges associated with the energy implications of our water choices, that topic is the focus of a different effort at the Pacific Institute.

Table 1. Connections between the energy sector and water quantity and quality

	Water Quantity Connection	Water Quality Connection
Energy Extraction and Production		
Oil and Gas Exploration (Conventional and Unconventional)	Water required for drilling, well completion, and hydraulic fracturing. Some unconventional oil and gas resources have especially high water demands.	Impact on shallow or deep groundwater quality.
Oil and Gas Production	Water required for enhanced oil recovery. Large volume of produced, impaired waters can be generated during production.	Produced water and spills can contaminate surface and groundwater with diverse pollutants.
Coal and Uranium Mining	Mining operations can generate large quantities of water.	Tailings and mine drainage can contaminate surface water and groundwater and destroy watersheds.
Biofuels and Ethanol	Water is used for growing biomass.	Pesticides and fertilizers can contaminate surface and groundwater.
Refining and Processing		
Traditional Oil and Gas Refining	Water used during oil and gas refinery operations.	Refinery operations can contaminate water.
Biofuels and Ethanol	Water used for refining into fuels.	Refinery wastewater produced.
Synfuels and Hydrogen	Water used for synthesis or steam reforming.	Wastewater produced.
Energy Transportation and Storage		
Energy Pipelines	Water used for hydrostatic testing.	Wastewater produced.
Coal Slurry Pipelines	Water needed for slurry transport; water not returned.	Slurry water is often highly contaminated.
Barge Transport of Energy	River flows and stages affect fuel delivery.	Spills or accidents can affect water quality.
Ocean Transport of Energy		Spills or accidents can affect water quality.
Oil and Gas Storage Caverns	Slurry mining of caverns requires large quantities of water.	Slurry disposal affects water quality and ecology. Contaminants can leak, polluting surface and groundwater.
Electric Power Generation		
Thermoelectric (Fossil, Biomass, Nuclear)	Water (surface or groundwater) is required for cooling and pollutant scrubbing operations.	Thermal and air emissions alter quality of surface waters and aquatic ecosystems.
Hydroelectric	Reservoirs lose water to evaporation.	Dams and reservoir operations alter water temperatures, quality, flow timing, and aquatic ecosystems.
Geothermal	Water (surface or groundwater) is required for cooling.	Thermal and air emissions alter quality of surface waters and aquatic ecosystems.
Solar Thermal	Water (surface or groundwater) is required for cooling.	Cooling systems can affect surface water and aquatic ecosystems.
Solar PV and Wind	Minimal water use for panel and blade washing during operation.	

Source: Modified from U.S. DOE 2006.

Conflicts between energy production and water availability are on the rise as the overall pressure on scarce water resources intensifies. Rising energy costs and concerns about greenhouse gas emissions are forcing some water managers to seek ways optimize the energy efficiency of their water systems. Likewise, water scarcity is beginning to affect energy production, even in areas not traditionally associated with water-supply constraints. Water-energy conflicts are most acute during a drought, especially in the summer, when energy demands are high and water availability is particularly low. For example:

- In September 2010, water levels in Lake Mead dropped to 1,084 feet, levels not seen since 1956, prompting the Bureau of Reclamation to reduce Hoover Dam's generating capacity by 23%. As water levels continued to drop and concerns about climate change intensified, dam operators were concerned that reductions in the electricity generating capacity would destabilize energy markets in the southwestern United States (Walton 2010).

- In August 2007, river flows and reservoir levels in the southeastern United States dropped due to drought, and in some cases, water levels were so low that power production was halted or curtailed, including at the Browns Ferry nuclear plant and at coal plants in the Tennessee Valley Authority system (Kimmell and Vail 2009).

- The Tennessee Valley Authority reported that it has curtailed operations at some of its operating nuclear plants due to drought because of temperature limits in the receiving waters below cooling water discharge pipes (Weiss 2008, Kimmell and Vail 2009).

- In 2003, rising water temperatures forced German authorities to close a nuclear power plant and reduce output at two others (AFP 2003), and high temperatures and low river levels forced the French government to shut down 4,000 megawatts of nuclear generation capacity (The Guardian 2003).

Despite these concerns, water and energy policies are rarely integrated. Federal policies are being developed with little understanding or concern about the impacts on water resources. In particular, the federal government, through subsidies for corn production, has massively increased the production of ethanol, with little concern for the water supply and quality implications of this policy. Similarly, efforts to promote "clean" coal have ignored the water-intensity of capturing carbon. Likewise, most water managers are pursuing water-supply options such as desalination or interbasin transfers with little concern about the energy implications of their water management decisions. A number of new trends, including rising electricity demands, the application of carbon capture and storage technologies, and the pursuit of increasingly energy-intensive water-supply options, suggest that the conflict between energy and water resources might intensify in coming years and pose a serious risk to the future availability and quality of our nation's water and energy resources. In combination, these concerns and new trends highlight the need to better integrate water and energy policy.

The disconnect between water and energy policy is driven in large part by the failure of water and energy practitioners to engage with and fully understand one another. Each has been working within their own silo and is only aware of one another when conflict arises, such as when water availability constrains energy production or energy prices affect the financial stability of the water provider. This analysis offers some new insights into the water implications of electricity generation. Transportation fuels are not covered here, although we note that the water implications of transportation fuels are of growing concern due to a shift toward domestic fuel sources, especially biofuels. We also do not address the water implications of extracting and processing the primary fuels used to generate electricity, such as hydraulic fracturing, oil shale production, or other segments of the energy fuel cycle. Some of these impacts will be addressed in later work.

Figure 1. Intermountain West
Source: Produced by Matthew Heberger, Pacific Institute

Here, we focus on current and projected electricity generation within the Intermountain West, which is the area bound by the Rocky Mountains in the East and the Sierra Nevada and Cascade Mountains in the West (Figure 1). States entirely or partially within this region include Washington, Oregon, Idaho, Montana, Wyoming, Nevada, Utah, Colorado, Arizona, New Mexico, and California. We note that water and energy concerns are not limited to the West, and examples of water-energy hotspots can be found throughout the United States. However, the Intermountain West is of particular interest for this study because it has a growing population (and demand for energy and water), a diverse fuel mix for power generation, and existing water resource constraints that are expected to worsen.

We divide the report into four sections. Section 1 provides a brief introduction to how electricity is generated in the Intermountain West, and estimated water use for that generation. In Section 2, we provide examples of how water availability has constrained the operation and siting of power plants in the region and how climate change and continued population growth are projected affect water availability. In Section 3, we analyze the future requirements associated with six different electricity-generation scenarios. In Section 4, we discuss future research needs, including the impacts of climate change on the water requirements for electricity generation and the water requirements for fuel extraction and processing. Finally, we conclude with a set of recommendations for reducing the water-related risks of energy generation.

Section 1: Defining the Water-Energy Connection

Overview of Electricity Generation Technologies

Electricity is one of our most widely used forms of energy. Electricity, however, is a secondary form of energy, meaning that it is created from other primary energy forms, such as the combustion of fossil fuels, nuclear fission processes, or renewable systems that harness wind and solar energy. Generating electricity occurs in many ways. Thermoelectric generation – driven largely by fossil fuel combustion or nuclear reaction – converts heat to mechanical energy and then into electricity. Kinetic processes through the movement of water (hydroelectricity) and wind are the second most common methods for generating electricity. Other electricity generation methods include the direct conversion of solar energy into electricity using photovoltaic panels. Each method is described briefly, below.

Thermoelectric Power Generation

Thermoelectric power plants use a fuel source to generate heat that spins a turbine and generator to produce electricity. A small number of thermoelectric power plants use combustion turbines, where the fuel is combusted to produce a superheated gas that drives a turbine and generator. The vast majority of thermoelectric power plants use steam turbines. With steam-electric turbines, heat generated from fuel combustion or nuclear reaction boils water to create steam (or other vapor in lower-temperature systems) that drives a turbine and generator to produce electricity. Energy sources for steam-electric generation include fossil, nuclear, and biomass fuels; geothermal energy; or in the case of solar thermal systems, the sun. Once the steam has passed through the turbine, it is then transferred to a heat exchanger where it is cooled – typically using water as the coolant – so that the boiler fluid can be reused. Many different cooling technologies are in use, including once-through cooling, wet and dry cooling towers, and cooling ponds (see Box 1 for a description of these cooling technologies).

Hydropower and Wind Generation

Broadly speaking, hydropower is the production of power from the kinetic energy of moving water. Hydropower has been used around the world for nearly a thousand years. In early days, the mechanical power of water was captured by water wheels and water mills to produce flour or for textile and lumber production. Today, the vast majority of hydropower in the United States is used to produce electricity through hydroelectric dams. Hydroelectric systems typically consist of a dam, a reservoir, and a powerhouse (Figure 2). Water released from the dam passes through the powerhouse where the movement of water spins a turbine and generator, producing electricity.

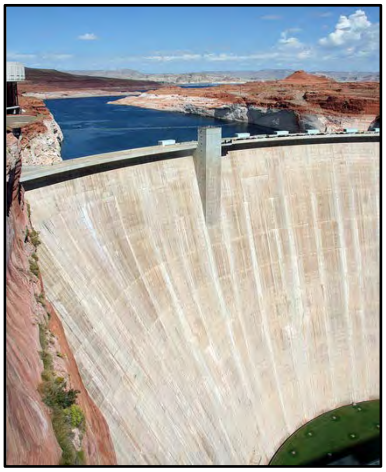

Figure 2. Glen Canyon Dam in Page, Arizona
Source: Redeo/Flickr.com

Wind power is similar in concept to hydropower in that it is derived from kinetic energy. The kinetic energy of atmospheric circulation, as air moves from areas of high pressure to low pressure, is manifested as wind. A wind turbine, which consists of a rotor with blades and an electricity generator, is typically mounted on a tower high above the ground surface where wind speeds are higher and more constant. The pressure of the wind turns the blades, driving a generator and producing electricity.

Solar Photovoltaic Power Generation

Figure 3. Solar photovoltaic system in New Mexico
Source: Worklife Siemmens/Flickr.com

Solar photovoltaic (PV) technologies use solar cells that directly convert sunlight into electricity. Solar panels are made of cells containing semiconductors – most commonly silicon – that can absorb photons from the sun, emitting an electron that becomes part of an electric current. Solar PV systems are easily scalable using modular panels and have been used for hundreds of different applications from powering spacecraft to transportation infrastructure to commercial and residential buildings. Utility-scale solar PV uses large arrays of solar panels that feed electricity into transmission grids (Figure 3).

Solar power is gaining an increasing amount of attention in recent years, and the industry is experiencing rapid growth. It is important to note that solar PV systems are distinct from solar thermal energy systems. Both systems use the sun as the primary energy source. As described above, solar PV systems generate electricity directly. By contrast, utility-scale solar thermal systems use heat from the sun to boil water, generating steam that then drives a turbine and generator. As a result, solar thermal systems are considerably more water-intensive that solar PV systems.

Box 1. Cooling Technologies for Thermoelectric Power Generation

The amount of water withdrawn and consumed by thermoelectric power plants depends on several factors, including plant efficiency, fuel source, power cycle, and, especially, the cooling system. Prior to 1970, most thermoelectric plants were built with once-through cooling systems, which have a low capital cost and higher energy efficiency than other cooling systems in use. Since 1970, however, most new plants have been built using recirculating cooling systems. Dry cooling systems are still fairly uncommon, although in areas where water is especially scarce, they are in use. The major technical characteristics of these systems are described here.

Once-through cooling systems withdraw large volumes of water from a water body, circulate it once through heat exchangers to condense steam leaving the turbine, and then discharge the warmed cooling water into a nearby water body (Figure 5). Because most of this water is returned to the environment, only a small fraction of the water withdrawn is consumed through evaporation. Once-through cooling systems have been shown to have significant environmental impacts (Kelso and Milburn 1979, Barnthouse 2000, Bamber and Seaby 2004, Greenwood 2008, and Kesminas and Olechnoviciene 2008). The withdrawal of large amounts of water kills organisms on the intake screen (referred to as impingement) or within the cooling system (referred to as entrainment) and can substantially alter flows in natural systems. Discharge of warm water can also adversely affect aquatic ecosystems. Requirements by the Environmental Protection Agency under Section 316(b) of the Clean Water Act are making the permitting requirements for once-through cooling systems in new power plants increasingly difficult, and existing systems are being phased out. Additionally, regions with limited water resources have, out of necessity, moved away from this water-intensive cooling technology.

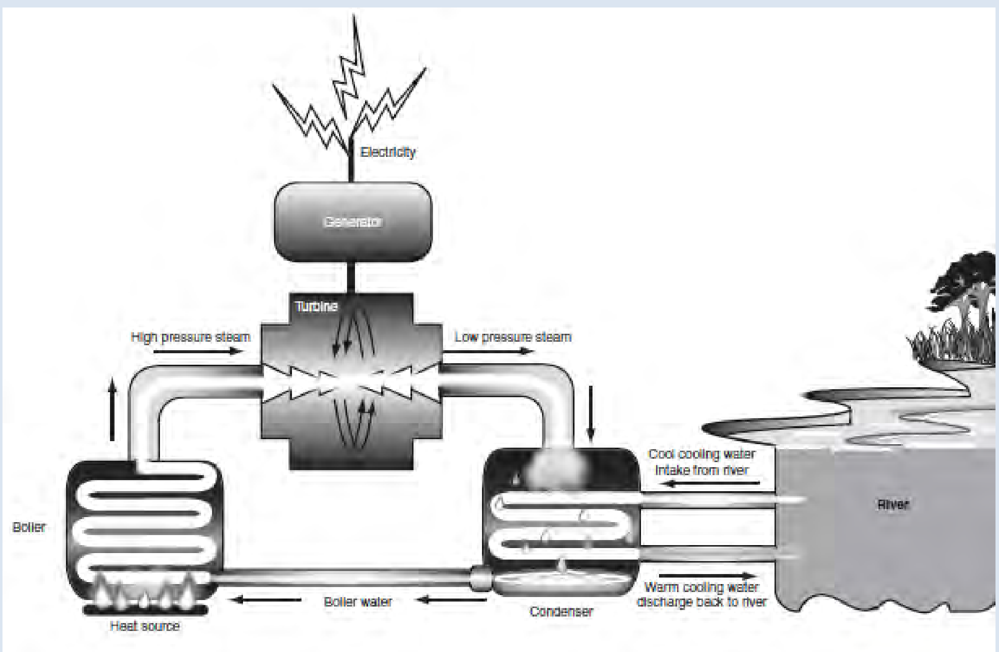

Figure 4. Diagram of a once-through cooling system

Source: GAO 2009

Box 1. Cooling Technologies for Thermoelectric Power Generation (continued)

Recirculating cooling systems withdraw water from a water body and circulate it through heat exchangers to condense the steam exiting the turbines. The warmed cooling water is then cooled using a cooling tower or on-site pond and is reused. These systems are also referred to as closed-loop cooling systems. With wet recirculating towers, the cooling water is exposed to air within the cooling tower (Figure 6). Most of the cooling water is returned to the condenser for reuse, although some of it evaporates and is discharged through the top of the tower (Figure 6). With pond systems, the cooling water is discharged into an on-site pond, where the excess heat is dissipated into the atmosphere. Once cooled, the water is returned to the condenser and is reused. Recirculating systems withdraw less water than once-through cooling systems per unit of energy produced, although most of the water withdrawn is consumed through evaporation. Some amount of water, referred to as blowdown, is periodically discharged due to the accumulation of minerals and dissolved solids in the cooling water.

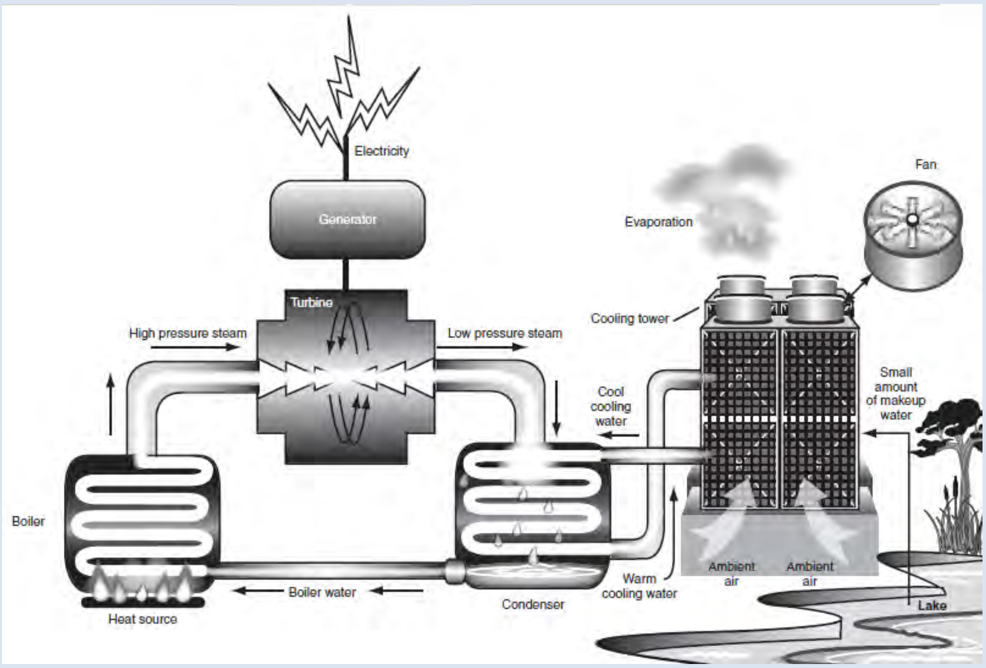

Figure 5. Diagram of a wet recirculating cooling system
Source: GAO 2009.

Figure 6. Photo of wet cooling tower
Source: Christopher Stokes/iStock.com

Box 1. Cooling Technologies for Thermoelectric Power Generation (continued)

Dry cooling systems rely on air flow in cooling towers rather than water to cool the steam produced during electricity generation. Steam from the boiler is routed through a heat exchanger. Air is blown across the heat exchanger to condense the steam back into liquid, which is then returned to the boiler and is reused (Figure 8). Plants that use dry cooling withdraw and consume a small amount of water to maintain and clean the boiler, including replacing boiler water lost through evaporation. Dry cooling has a higher capital cost than recirculating systems and reduces the overall efficiency of the power plant. Additionally, dry cooling does not operate effectively at high temperatures, although it can be coupled with a wet cooling tower to produce a hybrid system. With a hybrid system, wet cooling can be used during warm periods, and dry cooling can be used during cooler periods. Although still fairly infrequent, dry cooling systems are becoming more common due to ongoing water scarcity concerns and pressure to phase out once-through cooling systems.

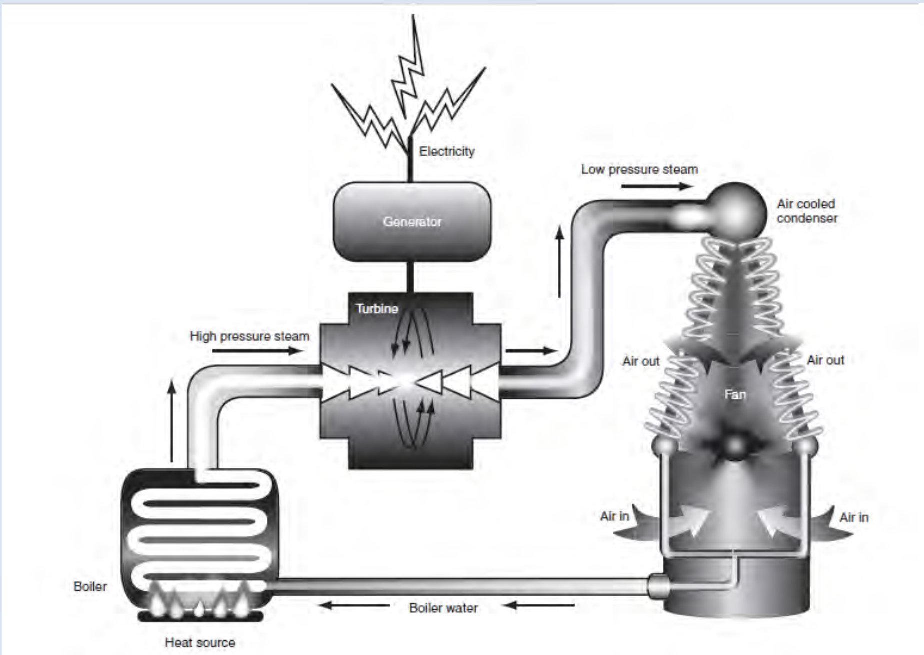

Figure 7. Diagram of a dry cooling system
Source: GAO 2009.

Electricity Generation in the Intermountain West

Thermoelectric power plants produce two-thirds of the electricity generated in the Intermountain West. Coal and natural gas are the primary fuels used to power these systems, with an additional 6% coming from nuclear plants (Figure 4). Hydropower produces another 28% of the electricity in the region, while wind provides 3% and solar, geothermal, and biomass each produce around 1%. Compared to the nation as a whole, the Intermountain West is less dependent on coal and nuclear energy but is more reliant on hydropower to meet its electricity needs.

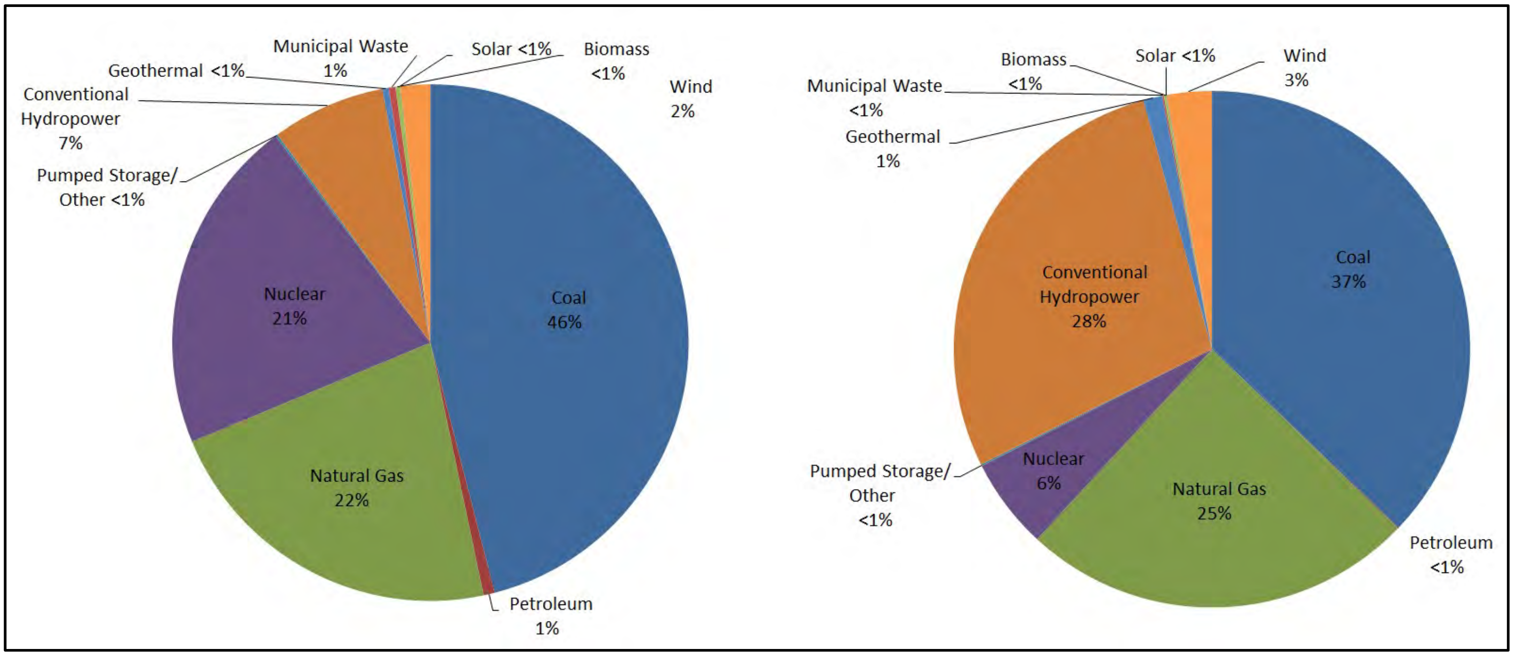

Figure 8. Electricity generation in the United States (left) and in the Intermountain West (right) by primary energy source, 2009

Note: Generation in the Intermountain West is based on estimates for the following EIA Electricity Market Model Supply Regions: Northwest Power Pool, Arizona-New Mexico, and Rocky Mountain Power Area.
Source: EIA 2011a.

Water Requirements for Electricity Generation

The water literature is rife with confusing, and sometimes misleading, terminology. Within the power sector, the terms "water withdrawal" and "water consumption" are among the most commonly encountered. Water withdrawals refer to water taken from the environment. Some of the water withdrawn may be returned to the environment in a different, sometimes degraded condition. Some water withdrawn, however, can be lost through evaporation and made unavailable for reuse in the same water basin. This phenomenon is usually referred to as "water consumption." Based on data from 1995, the United States Geological Survey (USGS) estimates that only 2% of the total water withdrawn for thermoelectric generation was consumed. There are, however, significant regional differences based on the mix of cooling systems employed in a particular area, as we shall see below (Solley et al. 1998).

It is commonly believed that consumption is a more important indicator of water use than water withdrawal because it reduces the amount of water that can be recovered to satisfy additional basin demands. This is indeed an important consideration, especially where total water availability is constrained. But under some conditions, the total volume of water withdrawn can also be a vital indicator of water use. During a drought or in water-constrained regions, for example, there simply might not be enough water available to sustain the operation of energy facilities. In addition, surface water temperatures tend to increase as water levels in a stream or river decline, in which case power-plant efficiencies might be reduced. In more extreme circumstances, the water withdrawn is too warm to effectively cool the plant, or the temperature of the return flow is too high for ecosystems. During an extreme heat wave in 2003, for example, energy utilities in France were forced to scale-back or shut down operations at nuclear power plants because water levels were too low in some areas and water temperatures too high for effective cooling in others. At the same time, electricity demand for refrigerators and air conditioners was high. France is particularly dependent on nuclear power, and limits on electricity production played a role in the 14,000 deaths that occurred in France during the extreme heat (UNEP 2004). In these cases, it may be crucial to consider implementing energy options that reduce total water withdrawal volumes, not just consumptive use.

A comprehensive evaluation of the water requirements for the production of electricity would include both the water withdrawn and consumed in every phase of the fuel cycle, including to extract, process, and refine fuels; construct, operate, and maintain generation facilities; generate electricity; and dispose of wastes. For almost all energy systems, the vast majority of water is used in the operation of the energy generation facilities, specifically cooling the power plant and replacing boiler feed water (Gleick 1993). While electricity generation represents the largest use of water on a regional basis, water requirements for fuel extraction and waste disposal may represent the largest use of water for a given locale. For example, Wyoming's Powder River Basin produces a large amount of coal that is then processed and transported to other regions for electricity generation. Within this basin, water requirements for fuel extraction and processing represent the dominant use of water. In this assessment, we focus on the water requirements for electricity generation, although as noted above, ongoing work at the Pacific Institute is evaluating the impacts of fuel extraction and processing on water resources more broadly, especially given the rapid expansion of hydraulic fracturing and other water-intensive fuel extraction processes.

Water Requirements Per Unit of Electricity Generated

Electricity generation can require substantial amounts of water, depending on the fuel source, power generation technology, and cooling technology employed (Table 2). Water requirements for solar PV panels and wind are negligible, as these systems require only small amounts of water for periodic cleaning. Hydroelectricity also uses and consumes water, although the consumptive requirements are a complex function of climate, reservoir design and operation, location, and more (see Box 2 on this topic). Water requirements for geothermal power generation are highly variable, depending upon the cooling technology employed and for wet cooling towers, whether geofluids or freshwater are used as the coolant.

Water requirements for thermoelectric power plants are largely driven by the type of cooling system employed at the plant and the efficiency of the plant in converting thermal energy to electrical energy, although fuel type is also important (Table 2; Figures 9 and 10). Steam power plants with once-through cooling typically withdraw between 10 and 60 gallons per kilowatt-hour of electricity generated (kWh) (Macknick et al. 2011).[2] Combined cycle power plants operate at higher thermal efficiency and thus produce less waste heat per unit electricity produced. As a result, combined-cycle power plants with once-through cooling withdraw between 7.5 and 20 gallons of water per kWh, considerably less than traditional steam plants (Macknick et al. 2011). Little of the water withdrawn for once-through cooling systems, however, is actually consumed.

Water requirements for pond cooling systems are typically higher than tower systems and are much more variable. Macknick et al. (2011) note “pond-cooled systems can be operated in manners that resemble both recirculating systems and once-through systems as well as in hybrids of these technologies…different configurations and operating practices of pond-cooled systems can lead to widely different reported water withdrawal and consumption values.” In a survey of power-plant operators, Dziegielewski and Bik (2006) found that differences in the way that water withdrawals are reported or estimated are also a factor in the large variability associated with these systems. As described in Box 1, dry cooling systems only require water to replace a small amount of water from the boiler that is lost to evaporation, although all of this water is consumed.

Water requirements for cooling also vary according to the thermal efficiency of the plant (for more on this, see Gleick 1993, Dziegielewski and Bik 2006). A high-efficiency power plant requires less water per unit of energy generated than a less efficient power plant, because the water requirement is a direct function of the temperature difference between the top and bottom end of the cooling system and whether other heat sinks (such as the atmosphere) are available for absorbing waste heat.

Furthermore, fuel type is also a determinant of cooling water requirements. A coal power plant, for example, sheds some of the waste heat generated during combustion through its smokestack. Natural gas combustion turbines shed almost all the waste heat through the smokestack. Nuclear power plants, however, cannot shed heat through a smokestack and therefore must shed more of the waste heat through water cooling loops, effectively increasing cooling water requirements (Webber 2011).

[2] In this report, we use kWh (kilowatt-hour) to represent a unit of electricity, unless otherwise noted. In other literature, this may be written as kWh_e. By contrast, a kWh_{th} represents a unit of heat and does not account for efficiency losses in the conversion of heat to electricity; e.g., for a typical power plant operating at 33% efficiency, there are 3 kWh_{th} per kWh_e.

Table 2. Water withdrawal and consumption factors, in gallons per kWh_e

		Once-Through[a]	Recirculating (Tower)	Recirculating (Pond)	Dry
Steam	Withdrawal	10 – 60	0.46 – 2.6	0.30 – 24	0.0039 – 0.079[b]
	Consumption	0.064 – 0.4	0.39 – 1.2	0.004 – 0.8	
Combined Cycle	Withdrawal	7.5 – 20	0.15 – 0.61	6	0 – 0.004
	Consumption	0.020 – 0.1	0.13 – 0.44	0.24	
Geothermal	Withdrawal[c]	-	0.0067 – 6.8	-	0 – 1.8
	Consumption	-	0.005 – 5.1	-	
Solar PV	Withdrawal	0 -0.033[d]			
	Consumption				
Wind	Withdrawal	0 – 0.001			
	Consumption				

Source: These estimates are based on various data sources, as summarized in Macknick et al. (2011), unless otherwise noted.

Notes: We use the units of kWh_e to refer to units of electrical energy. By contrast, kWh_{th} represent a unit of heat and does not account for efficiency losses in the conversion of heat to electricity; e.g., for a typical power plant operating at 33% efficiency, there are 3 kWh_{th} per kWh_e.

a: Consumption estimates for once-through cooling do not include downstream evaporation of discharged cooling water. This additional consumption should be included, although few data are available to quantify it.

b: Withdrawal and consumption factors for dry-cooled coal power plants were for boiler makeup water only and are provided by Stiegel et al. (2007).

c: Macknick et al. (2011) only provided water consumption factors for geothermal power plants. To estimate water withdrawals for these systems, we assume that 75% of the water withdrawn is consumed, which is consistent for average values for other thermoelectric power plants using cooling towers.

d: The upper end of this range assumes some water is regularly used for washing dust off of panels (Gleick 1993, Leitner 2002, Meridian Corp. 1989). Some of this water could be recaptured, but we know of no actual efforts to do so, so we assume consumption equals withdrawal for solar and wind systems.

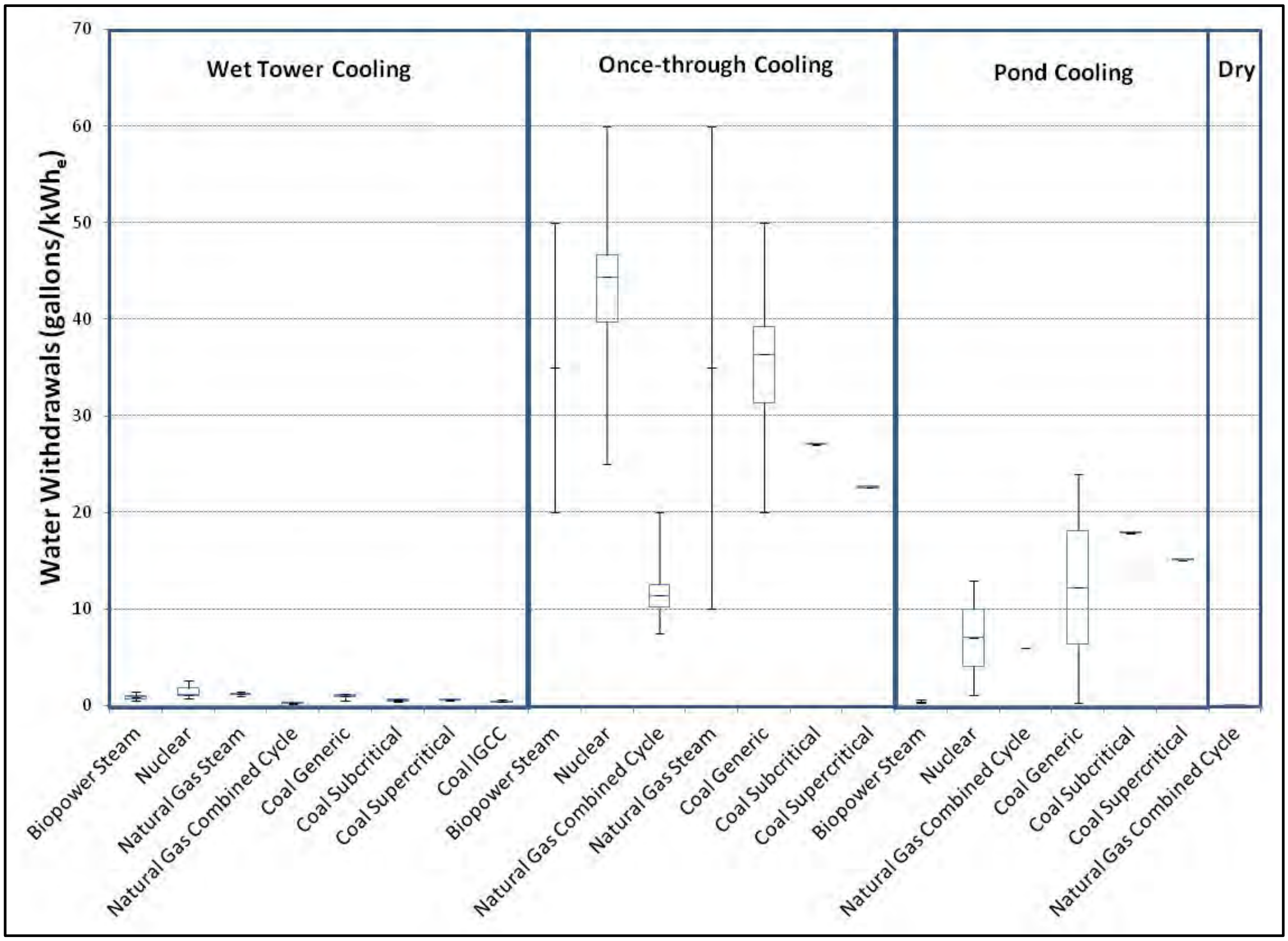

Figure 9. Operational water withdrawal factors, in gallons per kWh_e, for electricity generating technologies

Notes: Whisker ends represent maxima and minima. Upper and lower ends of boxes represent 75th and 25th percentile, respectively. Horizontal lines in boxes represent medians. These estimates are based on a variety of data sources, some of which are decades old, and are summarized in Macknick et al. (2011). We use the units of kWh_e to refer to units of electrical energy. By contrast, kWh_{th} represent a unit of heat and does not account for efficiency losses in the conversion of heat to electricity; e.g., for a typical power plant operating at 33% efficiency, there are 3 kWh_{th} per kWh_e.

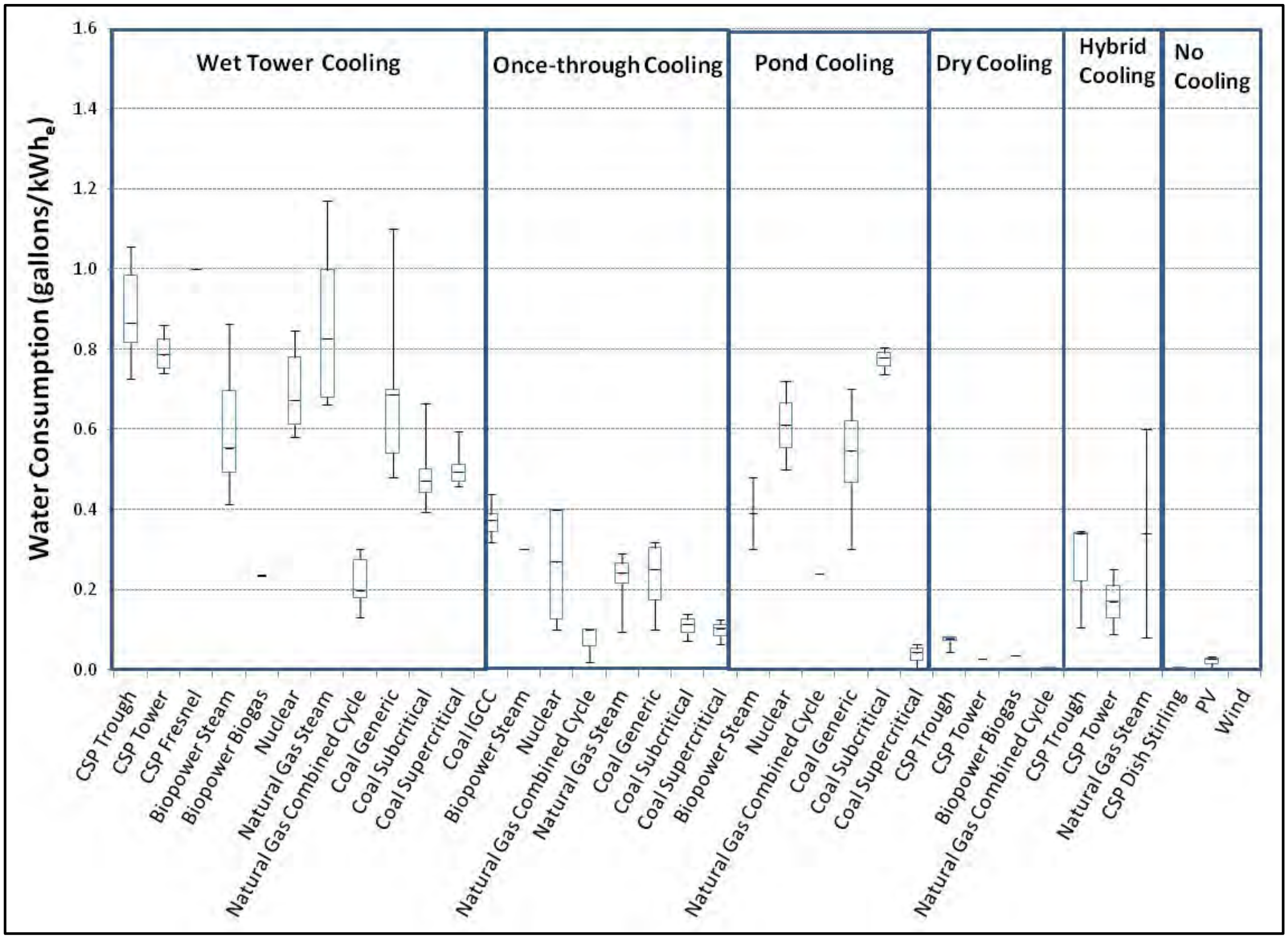

Figure 10. Operational water consumption factors, in gallons per kWh_e, for electricity generating technologies

Notes: Whisker ends represent maxima and minima. Upper and lower ends of boxes represent 75th and 25th percentile, respectively. Horizontal lines in boxes represent medians. These estimates are based on a variety of data sources, some of which are decades old, and are summarized in Macknick et al. (2011). We use the units of kWh_e to refer to units of electrical energy. By contrast, kWh_{th} represent a unit of heat and does not account for efficiency losses in the conversion of heat to electricity; e.g., for a typical power plant operating at 33% efficiency, there are 3 kWh_{th} per kWh_e.

Box 2: Does Hydropower Use and Consume Water?

Hydroelectricity has a relatively simple fuel cycle. Unlike with fossil fuels, there are no water requirements associated with extracting or processing the raw materials for hydroelectric generation, except for water that might be associated with building facilities. Early work on energy and risk life-cycle assessments suggests such material demands are a small fraction of demands from the rest of the fuel cycle (Holdren et al. 1979) and as a result, most assessments exclude them. With hydroelectricity, the greatest impact on water resources is associated with the generation of electricity. In theory, all of the water that flows through hydroelectric turbines is “withdrawn” for energy production. (Continued)

Box 2: Does Hydropower Use and Consume Water? (continued)

The USGS estimates that in 1995, nearly 3,200 billion gallons of water flowed through hydroelectric turbines each day (Solley et al. 1998), or about 440 gallons of per kWh. Water that flows through the turbine is returned to the river downstream of the powerhouse. These numbers dwarf the withdrawal figures for all other energy systems. Like other "withdrawals," however, the actual impacts vary. When stretches of rivers are completely dewatered to feed hydroelectric turbines through long penstocks, there are serious ecological costs. Similarly, major dams can alter the temperatures in downstream river stretches, also causing ecological harm. Finally, some reservoirs lose water through seepage. When these losses are returned through groundwater recharge of streamflow, there may be water quality impacts from leached minerals, even if no water is lost to the system. These impacts are rarely quantified and rarely included in comprehensive energy-water assessments, but they are real and deserve more attention and analysis.

Some water, however, is lost or consumed through evaporation from the reservoir or through seepage that is not recovered. Evaporative losses from hydroelectric generation facilities are highly variable and depend on a number of local factors, including the surface area of the reservoir compared to the normal size of the river, its depth and temperature, and climatic conditions. In hot, dry regions such as the American Southwest, evaporative losses from reservoir surfaces can be up to 2 meters per year. Gleick (1992) found that the diverse set of California hydroelectric facilities consume 0.0095 to 55 gallons per kWh, with a median value of 1.4 gallons per kWh. The large variation among facilities is associated with generator capacity and the ratio of dam height to hydraulic head. Some hydropower plants have a very large reservoir area and a relatively low gross static head (i.e., the height the water "falls" in moving through the turbine). Others have a very small reservoir area but a very large gross static head, when water is put into a penstock and transported downslope from the dam to a powerhouse, often hundreds or even thousands of feet below the dam itself. In the former case, high evaporative losses are associated with relatively lower energy generation; in the latter case, the same amounts of energy might be generated from facilities with very low evaporative losses, because of small reservoir surface areas (Gleick 1992).

In a more recent assessment, Torcellini et al. (2003) estimate that hydroelectric facilities in the United States consume an average of 18 gallons per kWh – again with a large range depending on facility type. These figures indicate that hydropower has the highest consumptive water use among the electricity generation technologies. However, because reservoirs often serve multiple purposes in addition to electricity generation, such as flood control, water supply, and recreational uses, attributing withdrawals and evaporative losses among the different uses is challenging. In a recent analysis, Pasqualetti and Kelley (2007) proposed allocating evaporative water losses to the various uses of the reservoirs based on the economic value of those different uses. This is one possible solution, although additional work is needed in this area.

Aside from water consumption, hydroelectric facilities can have significant impacts on freshwater systems. First, most facilities affect the geomorphology of a water body, altering flow rates, erosion patterns, and sediment loads. As a result, animal and plant species whose life cycles and population dynamics depend on those features may be detrimentally affected. For example, insufficient flows at critical times of the year can inhibit fish migration and actively kill fish when they pass through hydroelectric turbines. Other potentially negative downstream effects include changes in temperature, turbidity, and nutrient loads due to reservoir construction and management. Dams can also dramatically alter upstream and downstream habitat where rivers become inundated by reservoirs. These water-related impacts are not incorporated into simple estimates of water withdrawn or consumed per unit energy generated and rarely discussed in prior assessments, but they represent real consequences at the intersection of energy and water.

Total Water Requirements for Electricity Generation

Total water requirements for U.S. electricity generation remain largely unknown due to limits on the quantity and quality of the available data. The USGS compiles and reports national water use data for various sectors, including domestic, mining, irrigation, and thermoelectric power plants. These data include (1) total water withdrawals; (2) the type of water (fresh or saline); and (3) the source of the water (surface or groundwater). Water consumption was reported in the past but has not been available since 1995. Water-use data are compiled from multiple sources and are released every five years. The first USGS report, *Estimated Use of Water in the United States – 1950*, was released in 1951, and the most recent report, *Estimated Use of Water in the United States in 2005,* was released in October 2009 (Kenny et al. 2009). Numerous reports and analyses have identified shortcomings with the USGS datasets and the state-level data on which the USGS datasets are based and point to the need to obtain more accurate data (Dziegielewski and Bik 2006, Macknick et al. 2011, GAO 2009).

Even the limited data suggest that water requirements for thermoelectric power production in the United States are substantial. In 2005, thermoelectric power plants, which include those fueled by fossil, geothermal, nuclear, and biomass fuels , withdrew around 200 billion gallons of water each day. This represents nearly half of all saline and freshwater withdrawals in the United States (Kenny et al. 2009) and includes water used for cooling purposes and make-up water that replenishes boiler water lost through evaporation. About 70% of the total amount of water withdrawn by thermoelectric power plants, or 143 billion gallons per day, is fresh water and the remaining 30% is saline (Kenny et al. 2009). The use of saline water is largely confined to coastal regions, as nearly all of this water was withdrawn from the ocean. On average, thermoelectric power plants in the United States withdrew 23 gallons of water, both fresh and saline, for every kWh generated in 2005.

Water withdrawals for thermoelectric power generation in the Intermountain West are substantially lower than in the rest of the United States. In 2005, thermoelectric power plants in the region withdrew around 1,150 million gallons of water each day (Kenny et al. 2009).[3] This is equivalent to more than two times the annual water use of the City of Los Angeles or nearly 10% of the annual flow in the Colorado River. Nearly all of the water withdrawn by thermoelectric power plants is fresh water, with only a small amount of saline groundwater withdrawn in Utah.

Water withdrawals vary by state, driven largely by differences in total thermoelectric power generation, relative reliance on thermoelectric power verses hydropower, and type of cooling technology employed. For example, hydropower accounts for the vast majority of electricity in Idaho and Oregon. But because water withdrawals for hydropower are not included in the USGS estimates, it appears that water withdrawals for electricity generation are low in these states. Similarly, water withdrawals are high in Wyoming because thermoelectric power plants, most of which are powered by coal, account for the vast majority of generation in the state, and many use once-through cooling systems. Although hydropower is a major source of electricity in Washington, nuclear generation is also high and many of these nuclear plants use once-through cooling, resulting in a relatively large amount of water withdrawn (Figure 11).

[3] This estimate is for the 10-state Intermountain West.

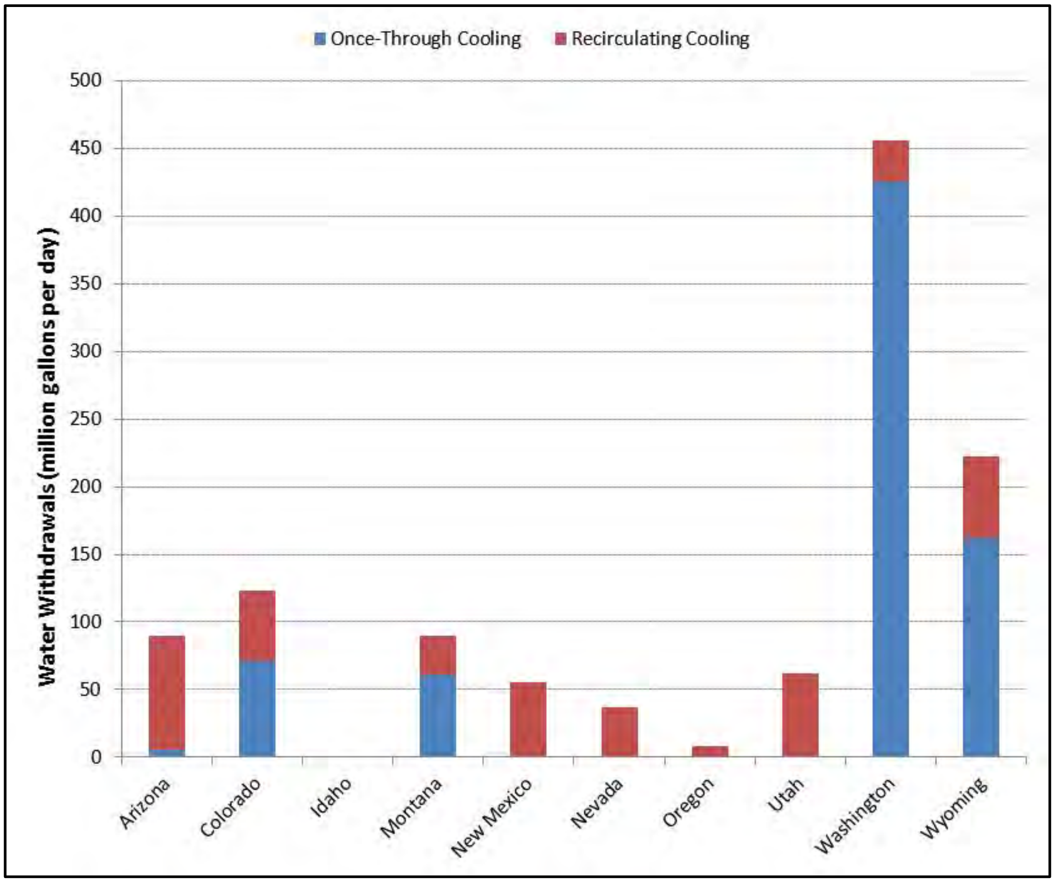

Figure 11. Water withdrawals, in million gallons per day, for thermoelectric power generation, by state, in 2005.
Note: The difference between states reflect differences in total power generation and the types of generation and cooling systems used.
Source: USGS 2009.

The USGS estimates that in 2005, thermoelectric power plants withdrew, on average, 1.4 gallons of water, both fresh and saline, for every kWh generated in the Intermountain West. As is shown in Figure 12, however, there is considerable variation among states. This variation is driven largely by differences in the type of cooling technology employed, along with the fuel source and generation technology. According to the USGS, once-through cooling systems account for about 7% of total power generation in the region. In Washington, however, once-through cooling accounts for more than 40% of power generation and, as a result, 8.4 gallons of water are withdrawn per kWh. In comparison, once-through cooling is not used in Utah, Nevada, and New Mexico, and consequently, water withdrawals are considerably less than 1 gallon of water per kWh.

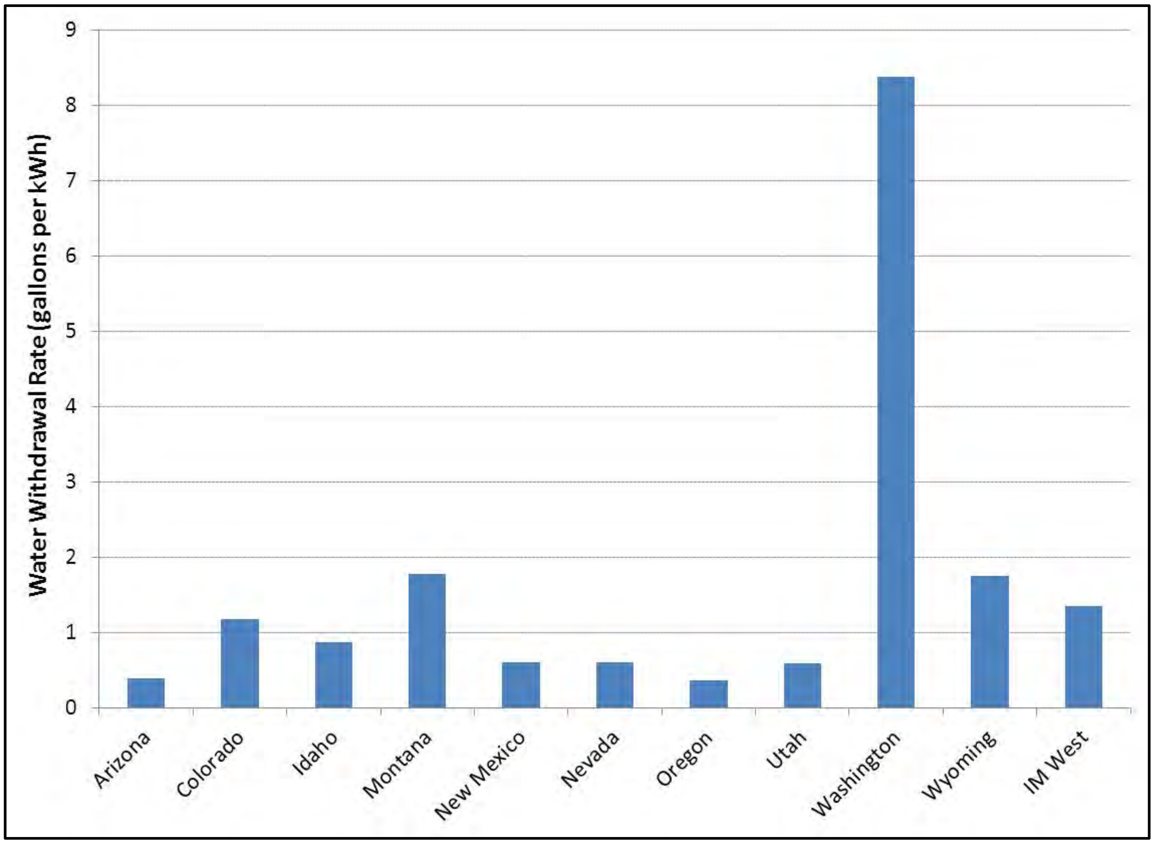

Figure 12. Water withdrawal rates, gallons per kilowatt-hour of electricity produced, for thermoelectric power plants in 2005

Note: This does not include water withdrawn or energy generated from hydroelectric plants.

Source: USGS 2009.

Differences in water withdrawals for thermoelectric power generation in the Intermountain West and in the United States as a whole are driven largely by significant regional differences in the systems used to cool these plants. Once-through cooling systems, which require large volumes of water, are uncommon within the Intermountain West, accounting for about 7% of generation, according to the USGS. These systems, however, represent 50% of generation across the United States as a whole (Kenny et al. 2009). In the water-constrained western United States, recirculating cooling systems are the most commonly used (Figure 13). Dry cooling systems are still fairly uncommon, although their use is growing (Table 3).

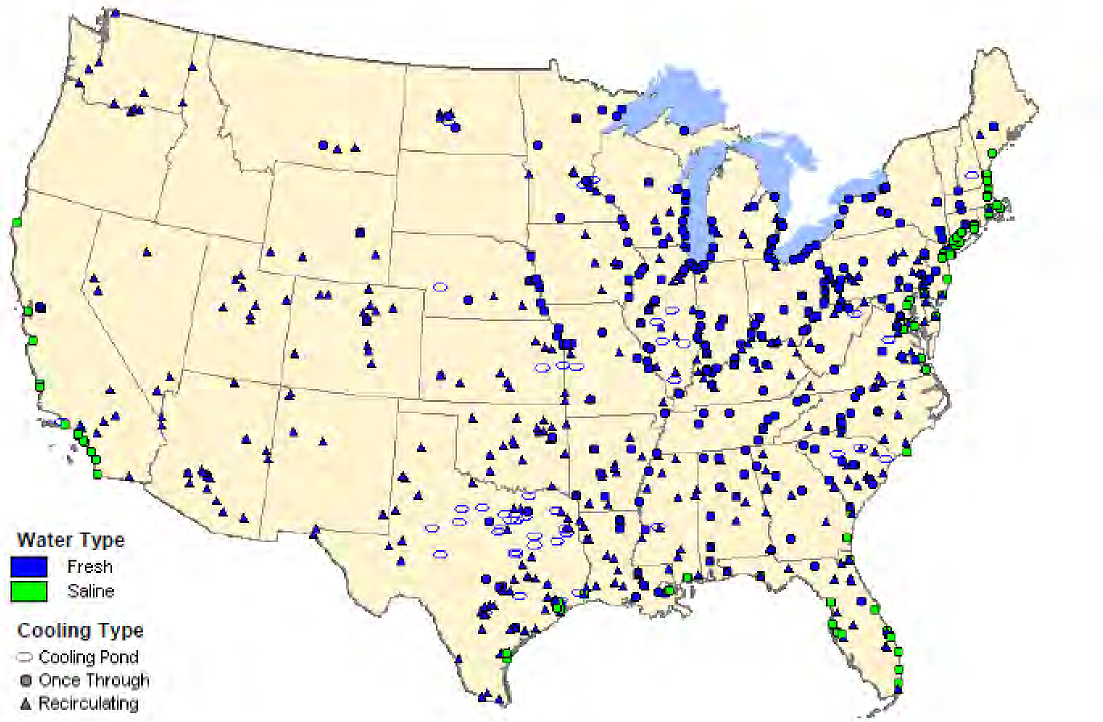

Figure 13. Cooling systems by technology and water source
Note: Dry cooling systems are not included in this figure.
Source: NETL 2010a.

Table 3. Power plants using dry cooling systems in the Intermountain West.

Plant Type	Location	Fuel Source	Capacity (megawatt)	Date Constructed
Wyodak Station	Gillette, Wyoming	coal	335	1978
Rosebud Power Plant	Colstrip, Montana	coal	41.5	1990
Harry Allen Generating Station	Las Vegas, Nevada	natural gas	484	1995
Wygen Station	Gillette, Wyoming	coal	88	2003
Silverhawk Generating Station	Las Vegas, Nevada	natural gas	520	2004
Walter M. Higgins Generating Station	Primm, Nevada	natural gas	530	2004
Chuck Lenzie Generating Station	Las Vegas, Nevada	natural gas	1,102	2006
Currant Creek Power Plant	Juab, Utah	natural gas	540	2006
Hobbs Generating Station	Lea, New Mexico	natural gas	526	2008
El Dorado Power Plant	Boulder City, Nevada	natural gas	465	2009
Dry Fork Station	Campbell, Wyoming	coal	385	2011

Note: There are also likely a large number of dry cooling systems in use in smaller power plants that are not included here.

Analysis of USGS Data

Because of constraints and limitations to the data on total water use for electricity that is collected and produced by the USGS, we have developed more comprehensive estimates on total water withdrawals using U.S. Energy Information Administration (EIA) data on electricity generation and cooling technology for thermoelectric power plants in the Intermountain West in 2005 and average water withdrawal factors by fuel type and cooling technology from Macknick et al. (2011). The purpose of this analysis is to obtain a clearer understanding of the magnitude of the water requirements for electricity generation. Additional detail on the methodology employed in this analysis can be found in Appendix A.

According to the EIA, total thermoelectric power generation in 2005 in the Intermountain West was 356 billion kWh, about 15% higher than that reported by the USGS (Figure 14). With both the EIA and USGS datasets, recirculating cooling systems are the dominant cooling technology used in this region, accounting for more than 90% of the generation in 2005. USGS data underestimate total generation because their estimates do not include electricity generated by plants supplied by public water systems and small peaking plants using groundwater (Susan Hutson 2010). Additionally, the USGS does not report generation, or water requirements, for plants using dry cooling, wind, or solar PV. As the use of these systems increases, efforts should be made to include the generation and water requirements for these systems.

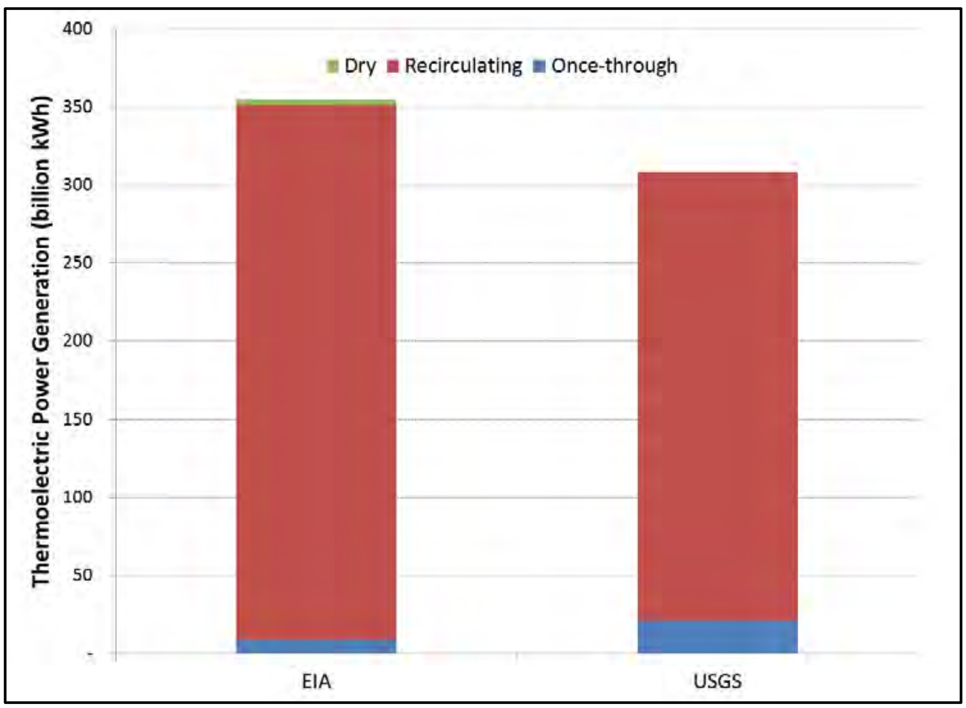

Figure 14. Thermoelectric power generation, in billion kilowatt-hours, in 2005 in the 10-State Intermountain West, as reported by USGS and EIA

Note: Based on total generation for the following states: Washington, Oregon, Idaho, Montana, Wyoming, Nevada, Utah, Colorado, Arizona, and New Mexico.

Source: USGS data from Kenny et al. (2009); EIA data calculated based on electricity generation from EIA Form 767 and 860

Although overall thermal generation estimates can be reconciled between the two data sources, the water withdrawal estimates are dramatically different. Based on EIA data and average water withdrawal factors, we estimate that water withdrawals for thermoelectric generation in the Intermountain West in 2005 were 2,330 million gallons per day, more than double that estimated by the USGS of 1,150 million gallons per day (Figure 15).

We have identified two key factors that may explain the discrepancy in thermoelectric water withdrawals in the Intermountain West between our analysis and the USGS estimate. First, the USGS estimate for the water requirements for plants using once-through cooling systems is too low. According to the USGS, plants using once-through cooling withdrew an average of 725 million gallons of water each day to generate 20.8 billion kWh in 2005 (Kenny et al. 2009). Based on these data, then, these systems withdrew an average of 13 gallons per kWh. According to our analysis, however, once-through cooling systems typically withdraw nearly double that amount (an average of nearly 24 gallons per kWh), which is more consistent with values found in other studies, as shown in Table 2.

Second, the USGS underestimates water requirements for plants using recirculating cooling and ignores differences between tower and pond cooling systems. There is tremendous variability associated with water requirements for pond cooling systems. Indeed, the available data, as summarized in Table 2, indicate that water withdrawals for pond cooling systems range from 0.3 to 24 gallons per kWh. Water requirements for tower systems are considerably lower and less variable, ranging from 0.15 to 3.5 gallons per kWh. Yet, the USGS combines pond and tower recirculating systems into a single category. Additionally, they report that these systems withdraw an average of 0.5 gallons of water per kWh, at the extreme low range reported in other data sources. In combination, these errors suggest that USGS underestimates water withdrawals for electricity generation in the Intermountain West by about 50%.

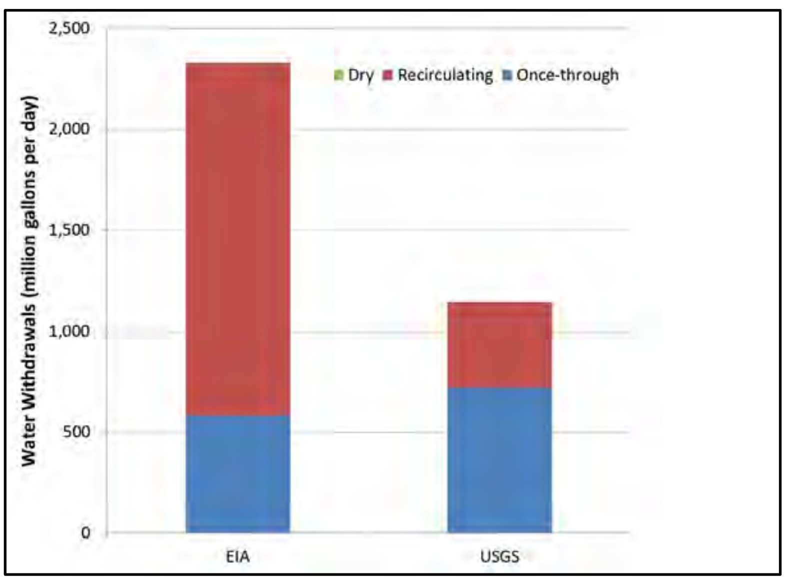

Figure 15. Daily thermoelectric power sector water withdrawal, in million gallons per day, in 2005 in the 10-State Intermountain West, as reported by USGS versus our analysis

Note: Based on water withdrawals for the following states: Washington, Oregon, Idaho, Montana, Wyoming, Nevada, Utah, Colorado, Arizona, and New Mexico.

Source: USGS data from Kenny et al. (2009); EIA data calculated based on electricity generation from EIA Form 767 and 860 and water withdrawal factors from Macknick et al. (2011).

Section 2: Water and Energy Conflicts in the Intermountain West

Despite uncertainty in the data, water withdrawals for thermoelectric power generation in the Intermountain West represent a relatively small fraction of total withdrawals in the region. The USGS estimates that about 1% of total of withdrawals in the region are for electricity generation (Figure 16) (Kenny et al. 2009). Our estimate, as described above, suggests that it may be twice that amount. But these figures alone underestimate the threat that water availability poses to energy security in the Intermountain West today and in the future. In the following section, we provide some clear examples of how water availability constrains the operation and siting of power plants today and how climate change and continued economic and population growth may serve to intensify these constraints.

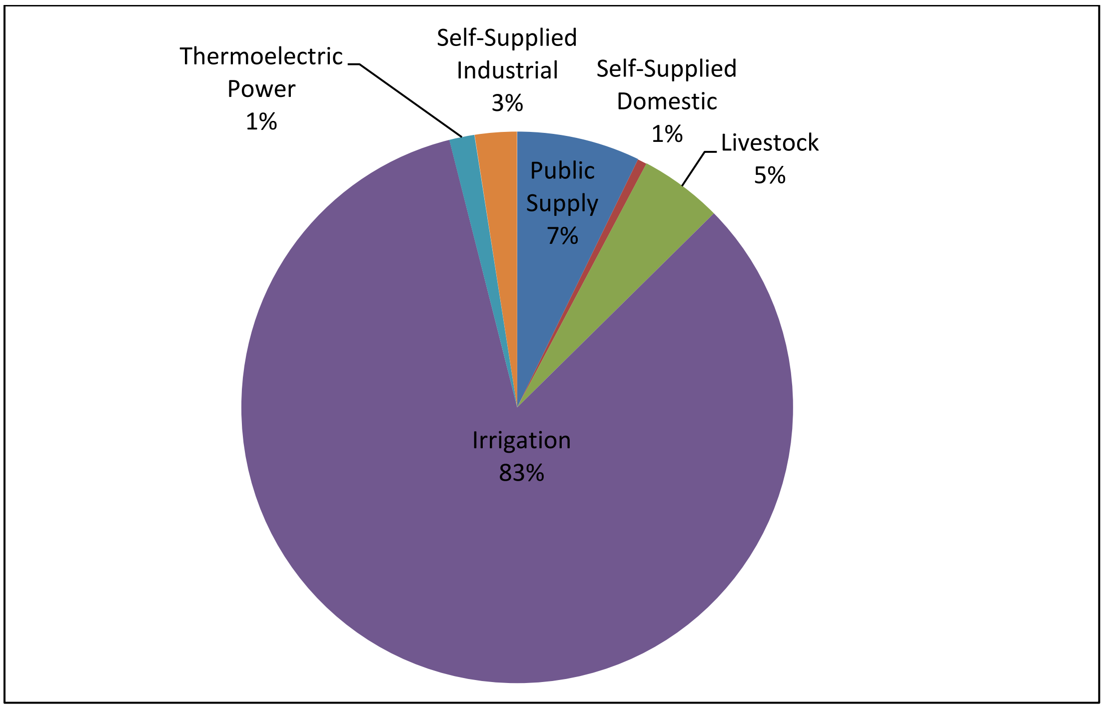

Figure 16. Water withdrawals in the Intermountain West, 2005
Source: USGS as reported in Kenny et al. 2009.

Making the Link Between Water and Energy Security

There is growing concern that water availability threatens energy security. Dr. Allan Hoffman, a senior analyst with the U.S. Department of Energy, noted back in 2004 that “we can no longer take water resources for granted if the U.S. is to achieve energy security in the years ahead.” Soon thereafter, Congress approved the 2005 Energy Security Act, which directed the U.S. Department of Energy to develop a National Energy-Water Roadmap. The Roadmap was developed through a series of workshops and was designed to evaluate the effectiveness of federal programs in addressing water-energy issues and provide recommendations in defining the direction of research, development, demonstration, and commercialization efforts. The Roadmap was supposed to be finalized in September 2006 and made available in March 2007. But even after 22 rewrites, the Department of Energy has not released the final report (Schneider 2010).

Despite some acknowledgment of the potential threat that water availability poses to energy security, these threats persist and are especially acute in the Intermountain West. For example:

- In 2005, Arizona's Mohave Generating Station ceased operations in part due to objections from the Navajo and Hopi tribes about the impacts of pumping water from the Black Mesa aquifer to transport coal to the power plant (Lesle 2006, Randazzo 2009).

- A seven-year drought reduced power production from the North Platte Project – which includes a series of dams and hydropower plants along the North Platte River from Nebraska to Wyoming – by about 50%, according to the executive director of the Wyoming Municipal Power Agency. The drought also reduced production in other thermo- and hydroelectric plants along the river (LaMaack 2006).

- The proposed Ely Energy Center, a 1,500-megawatt coal-fired power plant, would have consumed over 7.1 million gallons of water each day. Local residents and environmental groups opposed the proposal due, in part, to concerns about water consumption (WRA n.d.). NV Energy abandoned the plan in 2009, citing economic and environmental uncertainties (NV Energy 2009).

- Hualapai Valley Solar LLC proposed building a 340-megawatt solar power plant in Mohave County, Arizona. This plant would require more than 2.1 million gallons of groundwater each day from the Hualapai Valley Aquifer. Mohave County residents expressed concern about the effects of the power plan on water availability (Arizona Center for Law in the Public Interest n.d.). In 2010, the Arizona Corporation Commission ruled that the facility would have to use dry-cooling or treated wastewater, as a condition of their certificate of environmental compatibility (Adams 2011).

- Sempra Energy proposed building a 1,450-megawatt coal-fired power plant in the Smoke Creek Desert in Northern Nevada. The Granite Fox Power Project, proposed in 2004, received quick criticism from residents of Gerlach, Nevada where the plant was to be built (Voyles 2006). Opponents cited air pollution, habitat destruction and water consumption as their main concerns (AP 2004). Sempra Energy withdrew its permit and put the $2 billion project plans up for sale in 2006 (Voyles 2006).

- In September 2010, water levels in Nevada's Lake Mead dropped to 1,084 feet, levels not seen since 1956, prompting the Bureau of Reclamation to reduce Hoover Dam's generating capacity by 23% (Figure 17). As water levels continued to drop and concerns about climate change intensified, dam operators were concerned that reductions in the electricity generating capacity would destabilize energy markets in the southwestern United States (Walton 2010).

Figure 17. Low water levels in Lake Mead threaten hydropower generation
Source: Florian Ziegler/Flickr.com

Climate Change

Climate change will exacerbate water resource challenges in the Intermountain West. Rising greenhouse gas concentrations from human activities are causing large-scale changes to the Earth's climate. Because the water and climate cycles are inextricably linked, these changes will have major implications for our nation's water resources, including both natural hydrology and the infrastructure we have built to manage the water cycle (Compagnucci et al. 2001, SEG 2007, Kundzewicz et al. 2007, Bates et al. 2008). The movement of water is the primary process by which heat is redistributed around the planet, and as temperatures rise, the movement of water will accelerate through increases in both evaporation and precipitation. In short, climate change will intensify the water cycle. As shown in Figure 18, current climate models suggest that wet areas will become wetter and dry areas will become drier across the United States (USGCRP 2009), and while many uncertainties remain, the scientific confidence in these results has been growing as models improve and as physical evidence from the real world accumulates.

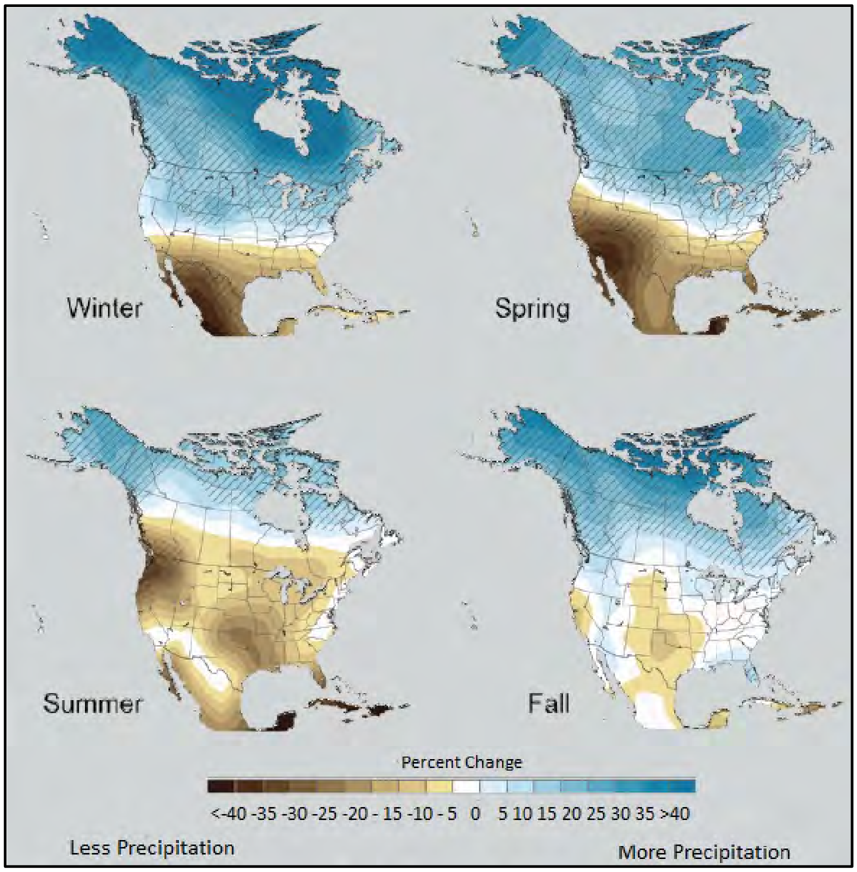

Figure 18. Projected change in North American precipitation by 2080-2099
Source: USGCRP 2009
Note: The maps show projected future changes in precipitation relative to the recent past as simulated by 15 climate models. The simulations are for late this century under a higher emissions scenario.

Climate change impacts on water resources are already evident across the United States (Bates et al. 2008) (Table 4). For example, annual precipitation over the past century has increased for most of the United States but declined in the Central Rockies and southwestern United States. As a result, runoff and streamflow have increased for most of the eastern United States but declined for the Columbia and Colorado River basins. Snowpack has begun to diminish in mountains as temperatures rise. The climate has also become more variable: the number of heavy precipitation events has increased whereas the frequency and intensity of droughts have also increased, particularly in the western United States.

Table 4. Observed changes in water resources during the past century across North America

Observed Water Resource Change	Region Affected
↑ Annual precipitation	Most of North America
↓ Annual precipitation	Central Rockies, southwestern U.S., Canadian prairies, eastern Arctic
↑ Frequency of heavy precipitation events	Most of U.S.
↑ Periods of drought	Western U.S., southern Canada
↓ Proportion of precipitation falling as snow	Western Canada and prairies, U.S. West
↓ Duration and extent of snowcover	Most of North America
↓ Glacial extent	U.S. western mountains, Alaska, and Canada
↓ Ice cover	Great Lakes, Gulf of St. Lawrence
↓ Mountain snow water equivalent	Western North America
↓ Runoff and streamflow	Colorado and Columbia River basins
↑ Streamflow	Most of the eastern U.S.
← 1-4 week earlier peak streamflow due to earlier warming-driven snowmelt	U.S. West and New England regions, Canada
↓ Thawing of permafrost	Most of northern Canada and Alaska
↑ Water temperature of lakes (0.1 – 1.5 C)	Most of North America
↑ Salinization of coastal surface waters	Florida, Louisiana

Source: Bates et al. 2008

Climate models find that the impacts and economic consequences of climate change will accelerate, particularly if efforts to reduce greenhouse gas emissions continue to be delayed. Climate change will exacerbate challenges already facing the water sector, especially given that much of the projected population growth is in areas that are projected to become drier (Figure 19). The Intergovernmental Panel on Climate Change concludes that “climate change will constrain North America’s already over-allocated water resources, thereby increasing competition among agricultural, municipal, industrial, and ecological uses” (Bates et al. 2008). Because of the water intensity of electricity generation, the U.S. Global Change Research Program finds that “energy production is likely to be constrained by rising temperatures and limited water supplies in many regions” (USGCRP 2009). Thus, climate change, along with continued population and economic growth, suggest that the future in the Intermountain West will be characterized by increased conflict and competition for limited water resources.

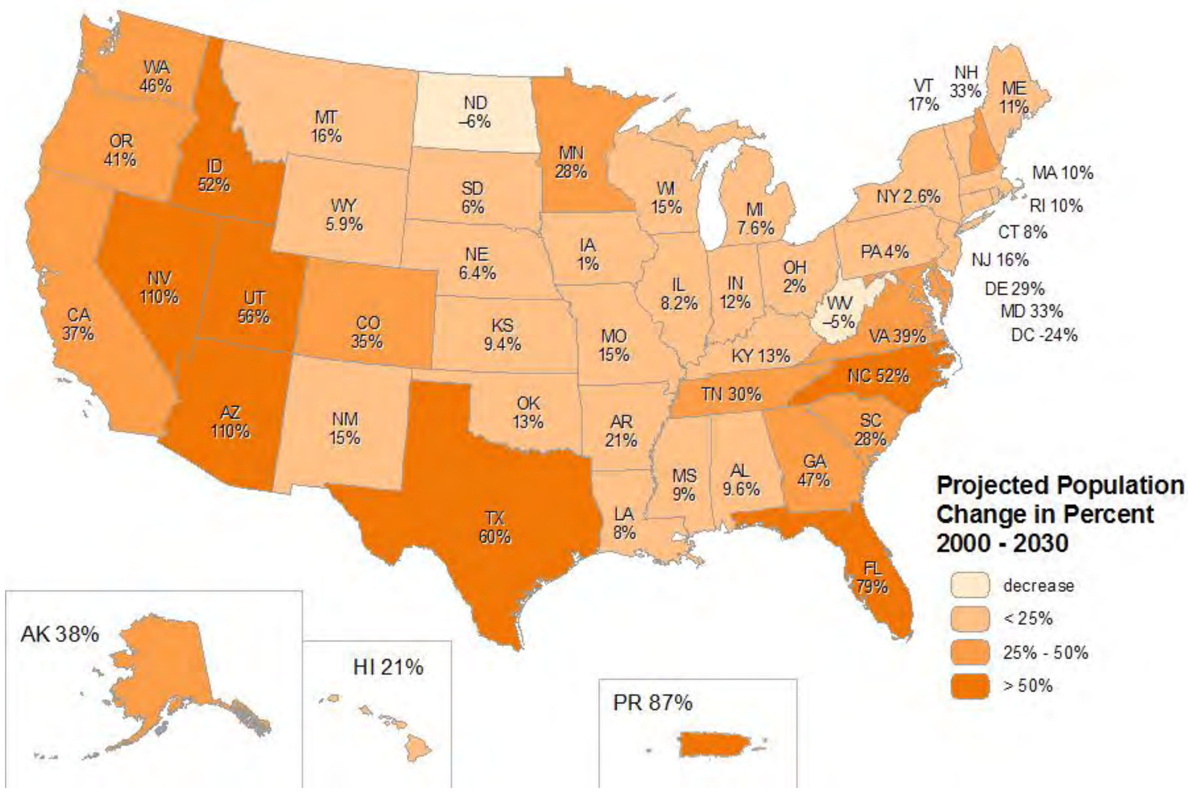

Figure 19. Projected population change from 2000 to 2030
Source: Based on U.S. Census 2005. Map by Matthew Heberger, Pacific Institute.

Section 3: Analysis of the Future Water Requirements for Electricity Generation in the Intermountain West

Amidst growing concerns about water availability and energy security, the National Energy Technology Laboratory (NETL), which is owned and operated by the U.S. Department of Energy, began assessing future water requirements for thermoelectric power generation in 2004. These studies are conducted annually and are based on future electricity scenarios produced by the EIA and assumptions about cooling technologies and the use of carbon capture and storage. In the most recent assessment, released in 2010, national freshwater withdrawals for thermoelectric power generation are projected to decline in 2035 by 2% to 23% from their 2010 levels, depending on assumptions about cooling technologies and water sources. Water consumption, on the other hand, is projected to increase by 14% to 27% over the same time period. These increases are especially dramatic within the western United States. For example, nearly all scenarios project that water consumption within the Rocky Mountain region will increase by 40% or more by 2035 (NETL 2010a).[4]

The NETL assessments suggest that the quantity and quality of water will continue to constrain future electricity generation in the region and that these constraints may become more acute. In the next section, we perform a more detailed analysis of the water implications of alternative electricity generation and cooling technology scenarios in 2035. Unlike the NETL assessments, however, we evaluate a broader range of future electricity scenarios, including one based on more rapid expansion of renewables. Furthermore, while the NETL assessments are generally limited to conventional (fossil and nuclear) energy systems, we include an analysis of water requirements for a broader range of energy technologies. Water requirements for hydroelectric power plants, however, are not included in this analysis; additional work is needed in this area, especially given projected increases in temperature and evaporation associated with climate change.

Methods

Study Area Boundary

The focus of this analysis is the Intermountain West. As described in earlier sections of this report, the Intermountain West includes the area bounded by the Rocky Mountains to the East and the Sierra Nevada and Cascade Mountains to the West. States entirely or partially within this region include Washington, Oregon, Idaho, Montana, Wyoming, Nevada, Utah, Colorado, Arizona, New Mexico, and California. There are eight regional entities that coordinate electric system reliability within the United States. The Intermountain West lies within areas served by the Western Electricity Coordinating Council (WECC). The WECC region is further divided into four subregions: Northwest Power Pool (NWPP); Arizona-New Mexico (AZNM); Rocky Mountain Power Area (RMPA); and California-Mexico (CAMX) (Figure 20). Given our focus on the Intermountain West, we evaluate electricity generation in all of the WECC subregions except CAMX.

[4] In the NETL analysis, the Rocky Mountain region includes all of Colorado and Arizona, most of New Mexico, and a small areas of Nevada and Texas.

Our analysis is limited to the quantitative dimensions of water use during power plant operations, e.g., water used for driving turbines and for cooling purposes. As we have noted elsewhere, water is also used, consumed, and contaminated during construction and decommissioning of power plants and to extract, process, and dispose of the fuels and wastes as part of the overall fuel cycle of any energy system. Additional analysis is needed to evaluate these water-related impacts in the Intermountain West and elsewhere, especially given widespread interest in expanding natural gas production from unconventional sources.

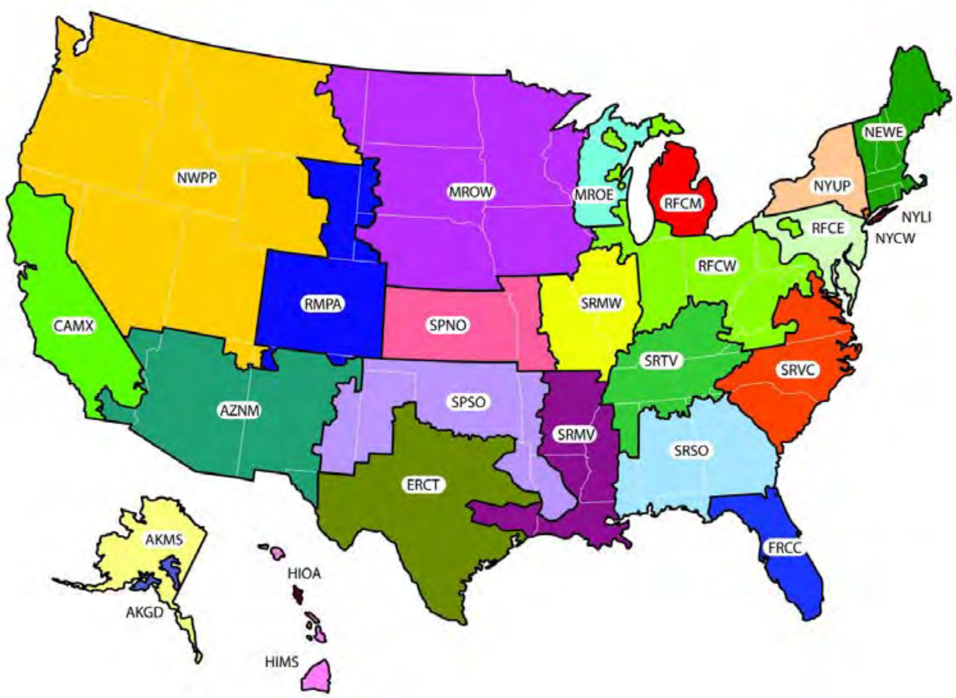

Figure 20. Map showing NERC subregions
Source: U.S. EPA

Quantifying Future Water Requirements

In this assessment, we estimate water requirements for power generation in 2010 and in 2035 based on:

(1) published water withdrawal and consumption factors;
(2) current and projected total electricity generation for each fuel type (coal, natural gas, solar thermal, wind, etc.); and
(3) the type of cooling system employed.

In the following sections, we provide additional detail on each of these factors.

Water Withdrawal and Consumption Factors

As described earlier, data on the water requirements for electricity generation are limited and in some cases, decades old. NETL uses data reported by power plant operators to the EIA (on Form 860) to estimate water withdrawal and consumption factors per unit of electrical output – gallons per kWh – for coal, natural gas, and nuclear power plants. These data, along with estimates from other published primary data sources, were compiled and summarized in a recent report by the U.S. Department of Energy's National Renewable Energy Laboratory (Macknick et al. 2011). Although the data on water use are known to "have numerous gaps and methodological inconsistencies," they are currently the best estimates available and "are good proxies for use in modeling and policy analyses, at least until power plant level data improve" (Macknick et al. 2011). The estimates from Macknick et al. (2011) form the basis of our study, supplemented with other data sources where indicated.

Electricity Generation Scenarios

Current electricity production in the region is estimated using data sets from the EIA, the statistical and analytical agency within the U.S. Department of Energy, and the Environmental Protection Agency (EPA). Future projections of electricity demand and the fuels used to generate that electricity are driven by a range of social, environmental, political, and economic factors. For this analysis, we rely on electricity projections developed by the EIA. The EIA uses the National Energy Modeling System to provide energy production and consumption forecasts based on a range of factors. These forecasts are published in the EIA Annual Energy Outlook (AEO), the most recent of which was released in April 2011 and includes forecasts to the year 2035 (EIA 2011a). Forecasts are available for the entire United States and for each of the 22 subregions, including the three WECC subregions included in this analysis: the Northwest Power Pool, Rocky Mountain Power Area, and Arizona-New Mexico.

AEO 2011 includes 47 electricity generation scenarios in five-year increments to the year 2035. For our analysis, we use the "Reference" case to examine water-use trends between 2010 and 2035. The Reference case is a business-as-usual trend estimate, given known technology and demographic trends. It represents current legislation and environmental regulations as of January 31, 2011. For example, state level Renewable Portfolio Standard policies, which have been adopted by many states in the Intermountain West, are included in the Reference case. In addition to the Reference case, we use the "Greenhouse Gas Price Economywide" case, which reflects an increasing price on carbon dioxide (CO_2) emissions nationwide and as a result, increased adoption of low- or non-CO_2-generating energy sources, e.g., wind and nuclear power. The assumptions in the Greenhouse Gas Price case are consistent with the provisions of some proposed federal legislation that limits the emissions of greenhouse gases and encourages expansion of renewable energy systems. As such, it should be considered a lower water-using scenario, but just one of many different possible future paths.

Cooling Technology Scenarios

Cooling technology is a primary determinant of the water requirements for power plant operations. The cooling technology employed at a particular facility depends upon a range of factors, including air temperature, water availability, land prices, date of construction, cost, etc. The current makeup of generation technologies was estimated from EIA databases with records on existing power plants that are updated annually with information provided by power plant operators. Data from EIA Forms 860 and 923 were merged into a single database, allowing us to determine electricity generation by fuel type, generation technology, and cooling technology. Data on cooling systems are available for a total of 79 plants in the Intermountain West that represent 59% of the total generation in the region. In some cases, a single power plant may have multiple cooling systems. Plants with multiple cooling systems were assigned to a single system type based on the dominant cooling systems using information from EIA Form 860.

Each power plant in the combined EIA database was then assigned to the appropriate WECC subregion using data from the Environmental Protection Agency eGRID database. In some cases, the location of the facility was not known because it was not included in the eGRID database or there was conflicting information among different databases. For these plants, we identified the physical location of the plant using its zip code and compared that to the EPA eGRID subregion map. We note that plants often are physically located in one subregion but generate electricity for other subregions. For the purposes of this assessment, we assign the water demands to the place of electricity generation, not use. Brief descriptions on the data used for this analysis are included in Table 5.

Table 5. Data sources used

Data Source	Type of Data	Plants Included	Number of plants within study area
EIA 2009 Form 860	• Power plant location • Primary cooling type	Capacity ≥ 1 MW Capacity ≥ 100 MW	763 plants, 81 reporting cooling type
EIA 2009 Form 923	• Power plant generation by fuel type and prime mover	Capacity ≥ 1 MW	751 plants; combined generation 518,019 GWh
EPA eGRID2010 V1 (2007 data)	• Power plant by WECC subregion	Capacity > 1 MW	687 plants

For each WECC subregion within the Intermountain West, we quantified the percent generation by cooling technology in 2009, the most recent date for which data are available. These data are summarized in Table 6. Note that cooling technologies are not provided for solar thermal and geothermal power plants. Operators are only required to submit information on cooling type if the capacity of the plant exceeds 100 MW. Because solar thermal and geothermal plants in these regions are currently less than 100 MW, EIA data are not suitable for classifying the cooling systems. We assume all solar thermal and geothermal plants in the region use wet cooling towers (Wilshire 2010).

The EIA data show that recirculating systems are the most common type of cooling systems employed at coal, nuclear, and natural gas power plants in the Intermountain West, with 73 of the 79 plants reporting using either wet tower or pond recirculating systems. An estimated 84% of the electricity generated from coal-fired power plants use recirculating wet cooling towers. Wet cooling towers are even more common at natural-gas fired power plants, accounting for nearly 90% of generation in 2009. Once-through and dry cooling are fairly uncommon in the Intermountain West, although the number of dry cooling systems is growing.

There is some variability among regions in the Intermountain West. Not surprisingly, wet cooling towers, which tend to use less water than once-through or pond cooling systems, are more common in the drier portions of the Intermountain West, i.e., the Rockies and Southwest, than in the Northwest. For example, nearly 100% of the electricity generated from natural-gas-using steam turbines in the Southwest and Rockies use wet cooling towers compared to only 43% in the Northwest. Surprisingly, dry cooling accounts for a larger fraction of total generation in the Northwest than in the drier regions of the Intermountain West. However, the number of dry cooling systems is still small and is difficult to draw robust conclusions from such a small number of facilities.

For this analysis, we evaluate three cooling technology scenarios. In the first scenario, we assume that the cooling technologies employed in 2035 are proportionally the same as those in 2009, e.g., there is no shift in cooling technology preferences over time. In the second and third scenarios, we assume that once-through cooling systems are phased out and convert some recirculating cooling of fossil-fuel plants to dry cooling such that dry cooling comprises 25% and 50%, respectively, of total generation within each WECC subregion by 2035. For these scenarios, dry cooling may be the only cooling system at a given power plant or may be combined with a wet cooling tower as hybrid system. We assume that all nuclear plants, in current and future scenarios, use recirculating wet cooling towers.

Table 6. Percent of generation by cooling type and fuel source in 2009 for the Intermountain West

Region	Primary Cooling Type	Coal	Natural Gas (Steam)	Natural Gas (Combined Cycle)	Nuclear	Number of plants
Intermountain West - Total	Once-through	3.2%	0.03%	1.0%	-	3
	Wet tower	84%	87%	90%	100%	67
	Pond	12%	13%	5.1%	-	6
	Dry	1.4%	-	3.6%	-	3
Arizona-New Mexico	Once-through	-	-	2.1%	-	1
	Wet tower	78%	99%	98%	100%	29
	Pond	22%	1.4%	-	-	1
	Dry	-	-	-	-	1
Northwest Power Pool	Once-through	7.7%	-	-	-	2
	Wet tower	85%	43%	78%	100%	24
	Pond	4.1%	57%	13%	-	3
	Dry	3.5%	-	9.1%	-	2
Rocky Mountain Power Area	Once-through	-	-	-	-	0
	Wet tower	92%	99%	100%	-	14
	Pond	8.1%	1.4%	-	-	2
	Dry	-	-	-	-	0

Note: The number of plants reporting is shown in the column on the far right. Only plants with a generation capacity in excess of 100 MW are required to submit data on cooling type. Thus, these data may underrepresent the total number of plants using dry cooling systems. The percentages are based on the fraction of generation for those plants reporting these data. Percentages by region may not add to 100 due to independent rounding to two significant figures.

Scenario-Based Planning

Analysts and decision makers often construct scenarios to better understand the consequences of choices or policies on a wide range of plausible future conditions. This is particularly useful when there are great uncertainties about how the future may evolve, or when the stakes are especially high. Sometimes scenarios explore outcomes that are unlikely or incongruent with current decisions and policies. Sometimes these scenarios are purely descriptive and are designed to study outcomes that had not previously been considered. Sometimes the scenarios are quantitative and represent discrete outcomes drawn from a range of possible futures.

In any effort to look into the future, it is critical to keep in mind that no matter how thoughtful any scenario analyst is, there will be surprises and unexpected events. Despite this, as Peter Schwartz has noted, we can make pretty good assumptions about how many of them will play out (Schwartz 2003). Ultimately, the point – and power – of scenarios is not to develop a precise view or prediction of the future, but to enable us to look at the ***present*** in a new and different way and to find new possibilities and choices we might have previously overlooked or ignored.

In this analysis, we evaluate water withdrawals and consumption for current (2010) electricity generation and for six future electricity generation scenarios. These scenarios include the following:

1. **Current Trends Scenario**: EIA "Reference" electricity generation scenario for 2035 with the current mix of cooling technologies;

2. **Current Trends + 25% Dry Cooling Scenario**: EIA "Reference" electricity generation scenario for 2035 with 25% dry cooling and 75% recirculating cooling;

3. **Current Trends + 50% Dry Cooling Scenario**: EIA "Reference" electricity generation scenario for 2035 with 50% dry cooling and 50% recirculating cooling;

4. **Expanded Renewables Scenario**: EIA "Greenhouse Gas Price Economywide" electricity generation scenario for 2035 with current mix of cooling technologies;

5. **Expanded Renewables + 25% Dry Scenario**: EIA "Greenhouse Gas Price Economywide" electricity generation scenario for 2035 with 25% dry cooling and 75% recirculating cooling; and

6. **Expanded Renewables + 50% Dry Scenario**: EIA "Greenhouse Gas Price Economywide" electricity generation scenario for 2035 with 50% dry cooling and 50% recirculating cooling.

Results

Electricity Generation Scenarios

Electricity demands and the type of fuel used to generate that electricity vary over time. Under the Current Trends scenario, annual electricity generation in the Intermountain West increases from 475 billion kWh in 2010 to 563 billion kWh in 2035, or by about 20% (Figure 21). Conventional hydropower and wind are expected to show the largest growth during this period, with annual generation increasing by 37 billion kWh and 27 billion kWh, respectively.[5] By 2035, wind is projected to represent 8% of total electricity generation, compared to only 4% in 2010. Modest growth is also projected for coal, natural gas, and geothermal power, with annual generation for each projected to increase by about 4.5 billion kWh by 2035. Growth in nuclear and solar power is relatively minor.

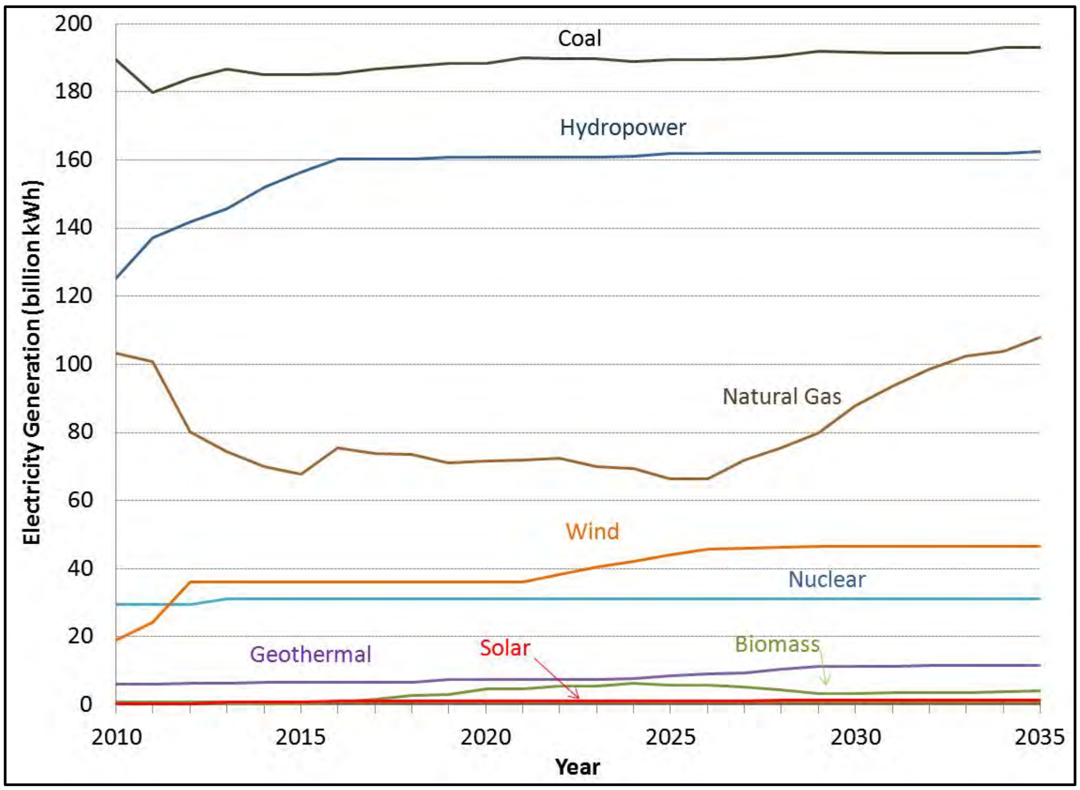

Figure 21. Electricity generation projections for the Intermountain West in the Current Trends scenario
Source: Based on generation in the NWPP, RMPA, and AZNM subregions for the Reference scenario in EIA 2011a.

[5] Increases in hydropower generation are largely driven by return to normal hydrologic conditions in the region and retrofitting of existing sites with more efficient turbines.

The Expanded Renewables scenario, by contrast, is characterized by more robust efficiency improvements and more rapid expansion of wind power. Under this scenario, annual electricity generation in the Intermountain West increases from 475 billion kWh in 2010 to 514 billion kWh in 2035, an 8% increase (Figure 22). Thus, total generation in 2035 under the Expanded Renewables scenario is 50 billion kWh less than in the Current Trends scenario, suggesting more aggressive implementation of energy efficiency improvements. These scenarios also have a substantially different mix of energy generation technologies. Under the Expanded Renewables scenario, coal generation is projected to decline by more than 75% while wind and conventional hydropower generation are projected to increase dramatically. By 2035, wind is projected to represent 19% of total electricity generation, compared to only 4% in 2010. Significant expansion is projected for natural gas, as well. Growth in nuclear power in the Expanded Renewables scenario are larger than projected under the Current Trends scenario, although it is still fairly modest and is not projected to occur until after 2030.

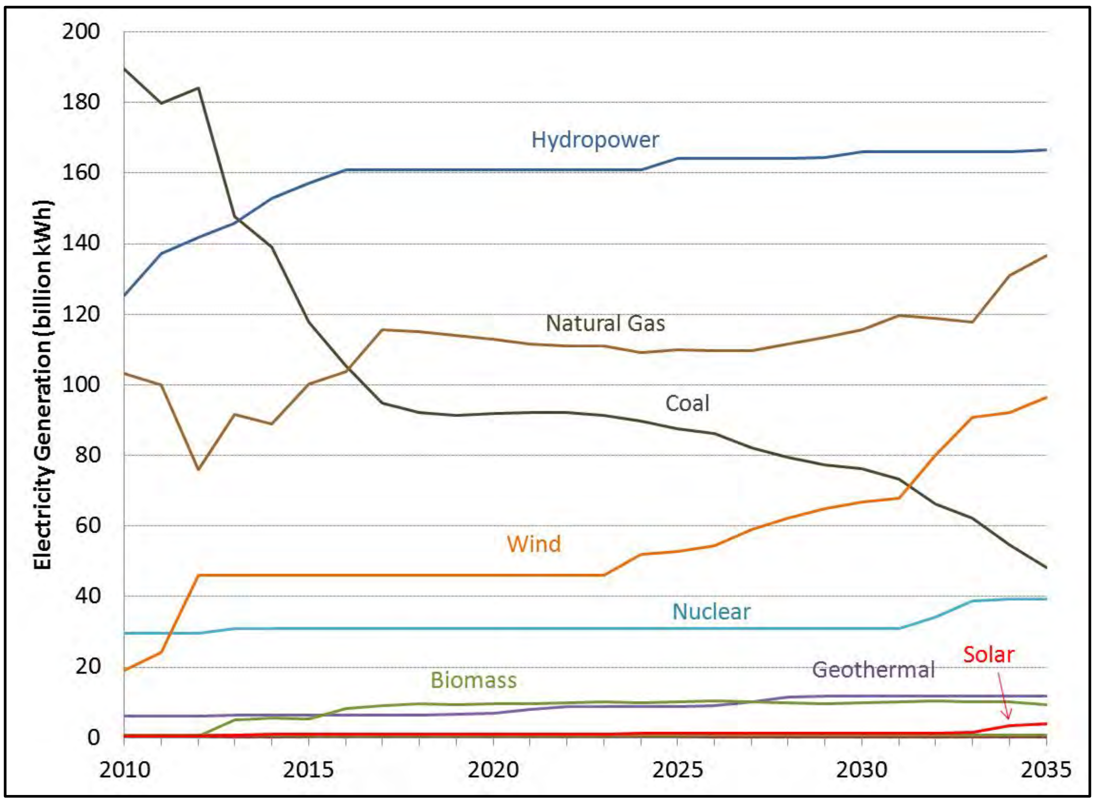

Figure 22. Electricity generation projections for the IM West in the Expanded Renewables scenario
Source: Based on generation in the NWPP, RMPA, and AZNM subregions for the Greenhouse Gas Price Economywide scenario in EIA 2011a.

Future Water Requirements for Electricity Generation

We estimate that average water withdrawals for electricity generation in the Intermountain West in 2010 were 1,940 million gallons per day,[6] equivalent to a withdrawal of 1.5 gallons of water per kWh (Figure 23). Of the total amount withdrawn, approximately 20%, or 373 million gallons per day, was consumed (Figure 25). Coal-fired power plants accounted for 37% of generation but 84% of water withdrawals and 65% of water consumption. On a regional basis, the Arizona-New Mexico subregion had the highest levels of water withdrawals and consumption, followed by the Northwest Power Pool (Table 7).

Table 7. Water withdrawal and consumption, in million gallons per day, in the Intermountain West in 2010

	Rocky Mountain Power Area	Northwest Power Pool	Arizona-New Mexico	Intermountain West
Withdrawals	277	830	838	1,940
Consumption	72.5	133	168	374

Note: All numbers rounded to three significant figures.

Under the Current Trends scenario, water withdrawals and consumption are projected to increase across the Intermountain West. While average withdrawals would decline to 1.3 gallons per kWh, total water withdrawals increase to 1,980 million gallons per day by 2035, an increase of 2% over 2010 levels (Figures 23 and 24). Water consumption increases by 20 million gallons per day to 393 million gallons per day (Figures 25 and 26). This represents a 5% increase in total water consumption. The Rocky Mountain Power Area experiences the largest increases in withdrawals whereas the Northwest Power Pool experiences the largest increases in consumption. These results suggest that the impact of electricity generation on water resources will intensify under the Current Trends scenario.

Installing dry cooling systems, however, dramatically reduces both water withdrawals and consumption. By expanding the deployment of dry cooling to 25% of generation, water withdrawals in 2035 decline to 1,440 million gallons per day, equivalent to an average withdrawal of 0.9 gallons per kWh. Consumptive water use declines to 310 million gallons per day. This effectively reduces water withdrawals by nearly 30% and water consumption by nearly 20% below 2010 levels. The largest reductions in both water withdrawals and consumption are in the Arizona-New Mexico subregion, a region that faces severe water supply constraints. Expanding dry cooling systems to 50% of total generation – the Current Trends + 50% Dry Cooling scenario – could provide additional water savings. Under this scenario, water withdrawals decline by 48% across the region, while water consumption declines by 38%, relative to 2010 levels.

[6] Note that this estimate is considerably less than the 2.33 million gallons per day that we calculated for the USGS comparison due to differences in the study area and scope. The USGS reports water use by state, so for that analysis we included generation in the entire 10-state Intermountain West. Here, we focus exclusively on the three WECC subregions: NWPP, RMPA, and AZNM.

Changes in the future electricity mix also produce significant water savings. Energy efficiency improvements, which effectively reduce total electricity demand, combined with large reductions in coal generation and the expansion of generation from wind and combined cycle natural gas, results in large reductions in both water withdrawals and consumption throughout the Intermountain West, as demonstrated in the Expanded Renewables scenario. Under this scenario, water withdrawals decline to 853 million gallons per day, 56% below 2010 levels. On average, 0.6 gallons of water are withdrawn per kWh generated. Water consumption declines by about a third to 247 million gallons per day. These changes are larger than would occur by simply installing dry cooling systems, as modeled in the Current Trends + 25% Dry Cooling and Current Trends +50% Dry Cooling scenarios. The largest reductions in both water withdrawals and consumption would occur in the Northwest Power Pool subregion, although savings in the other regions are also quite large.

The most significant reductions in water use are achieved through a combination of changes in the electricity mix plus more widespread adoption of dry cooling systems. Under the Expanded Renewables + 25% Dry Cooling scenario, water withdrawals for electricity generation in the Intermountain West decline to 573 million gallons per day, or 71% below 2010 levels. Under this scenario, average water withdrawals decline to 0.4 gallons of water per kWh. This represents a reduction in water withdrawals of 1,370 million gallons per day, enough water to supply the domestic needs of 13.7 million people.[7] Under this scenario, water consumption declines to 206 million gallons per day, or 45% below 2010 levels.

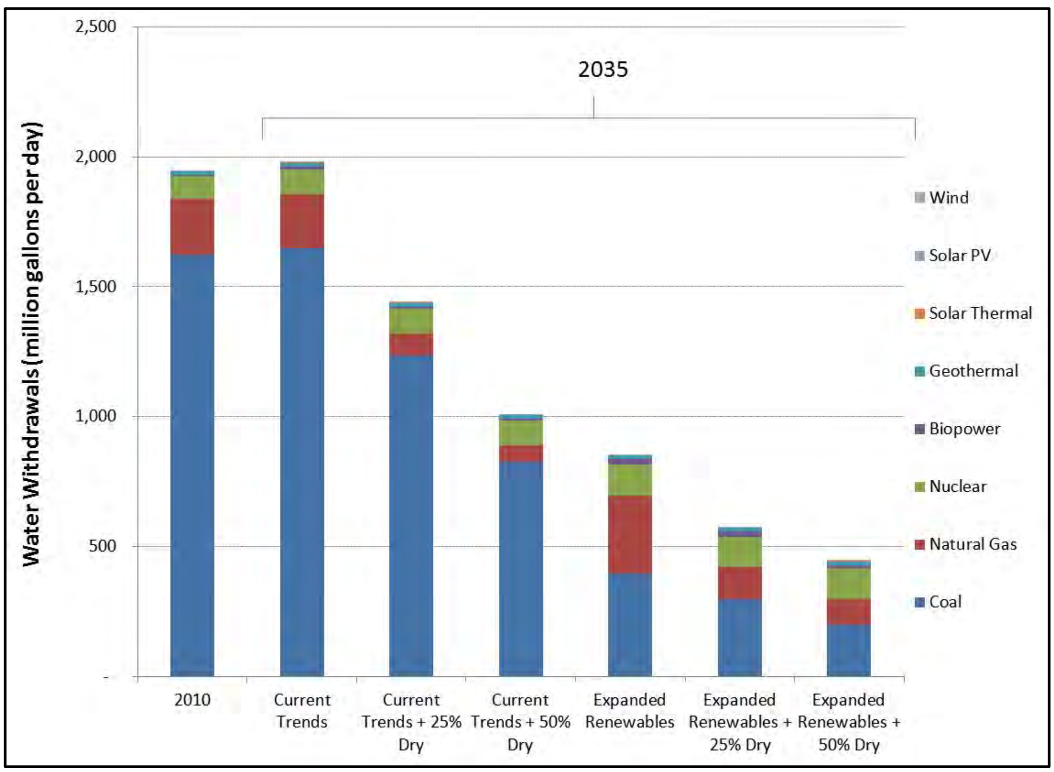

Figure 23. Water withdrawals, in million gallons per day, for electricity generation in the Intermountain West in 2010 and in 2035 under six scenarios

[7] We assume average residential water use is 100 gallons per person per day.

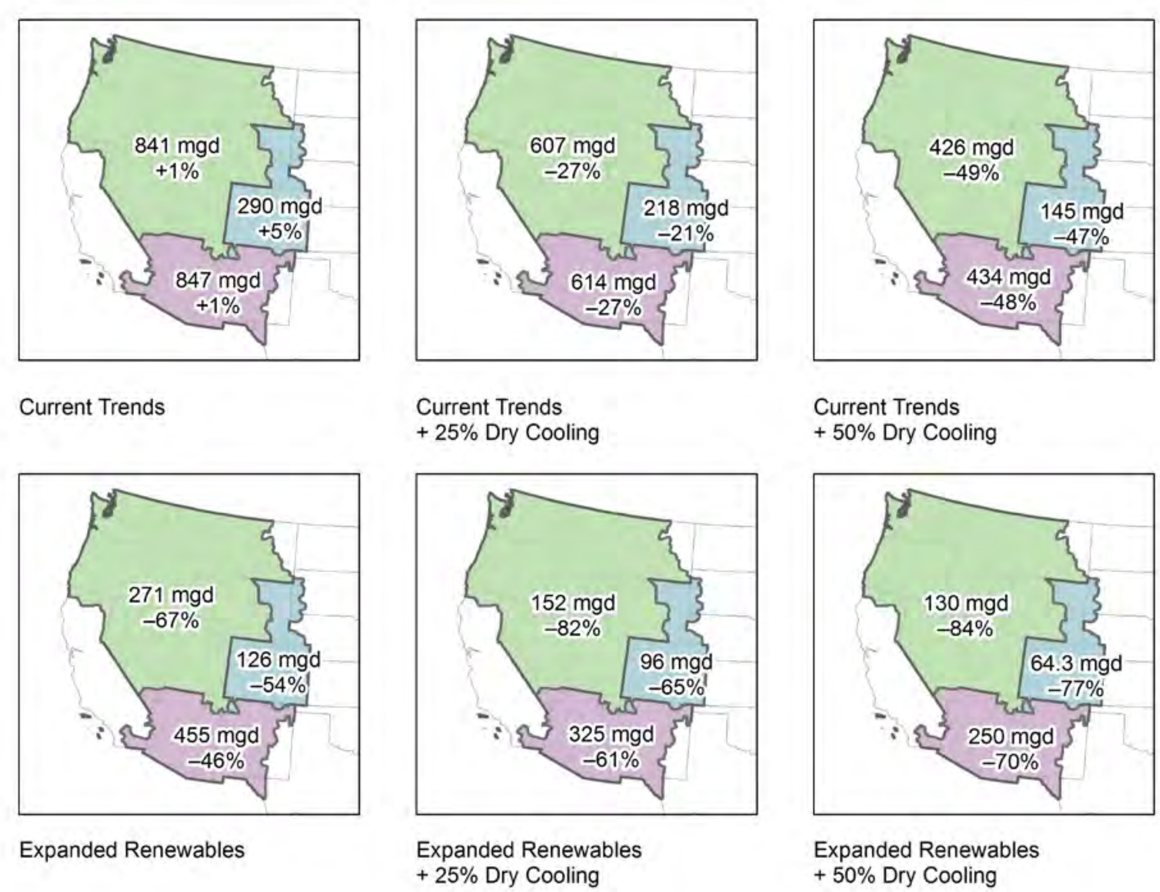

Figure 24. Water withdrawals, in million gallons per day (mgd), for electricity generation in the Intermountain West in 2035

Note: The percentage refers to the change relative to 2010 levels.

Although not evaluated here, alternative water sources can reduce freshwater requirements for electricity generation further. Reclaimed municipal wastewater, for example, is a reliable water source that is available in relative abundance across the United States. The Palo Verde Nuclear Generating Station, the largest nuclear power plant in the United States, currently uses treated wastewater from the City of Phoenix in its cooling towers. In 2007, however, only 57 power plants were using treated municipal wastewater, and of these, only seven were located within the Intermountain West (ANL 2007). Although reclaimed municipal wastewater may require additional treatment to avoid scaling or fouling within the cooling tower and may not be feasible in all locations, its use could be expanded in some cases and help reduce pressure on freshwater systems. Other alternative water sources include produced water from oil and gas wells, mine pool water, and industrial process water.

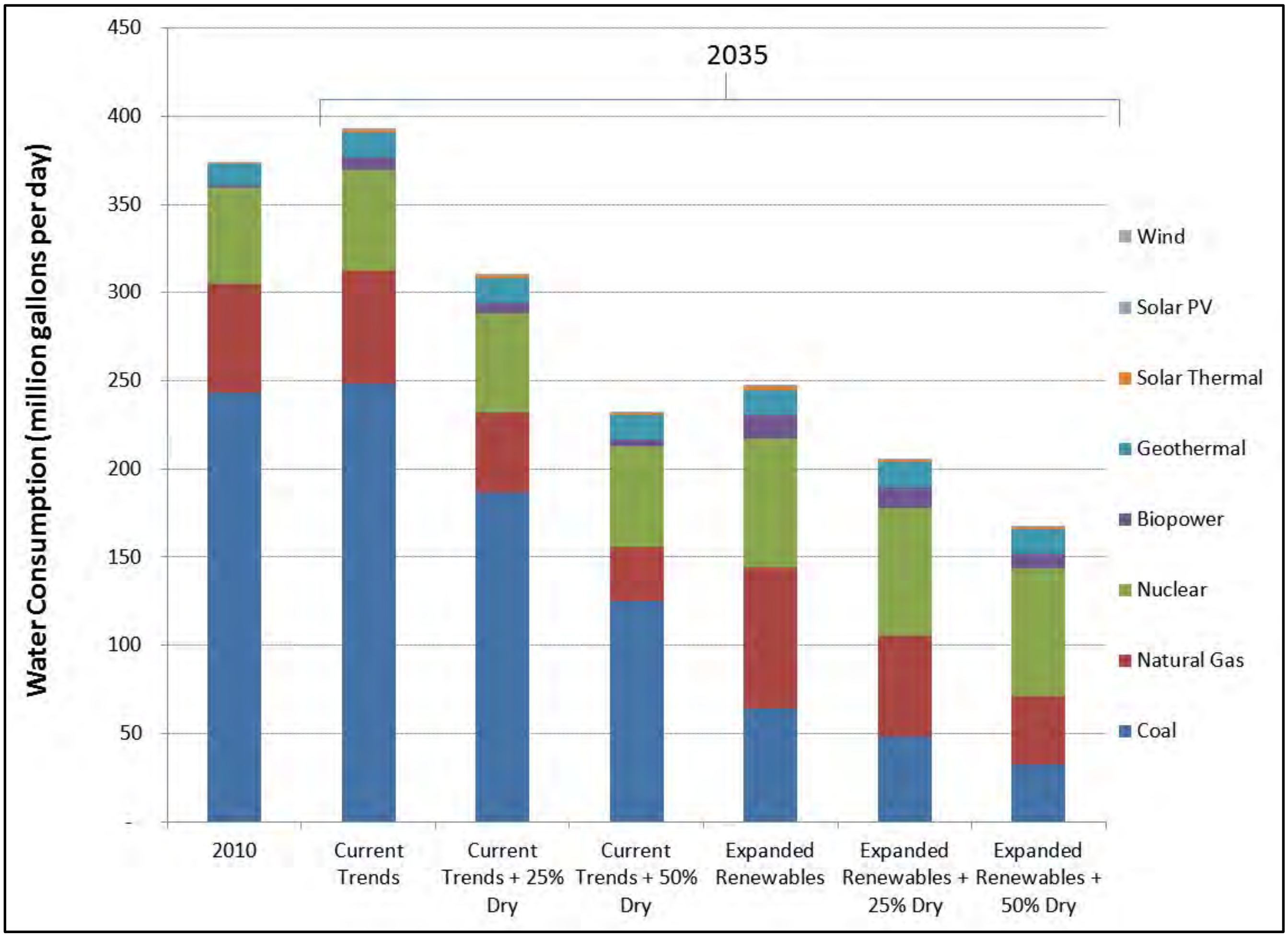

Figure 25. Water consumption, in million gallons per day, for electricity generation in 2010 and in 2035 under six scenarios

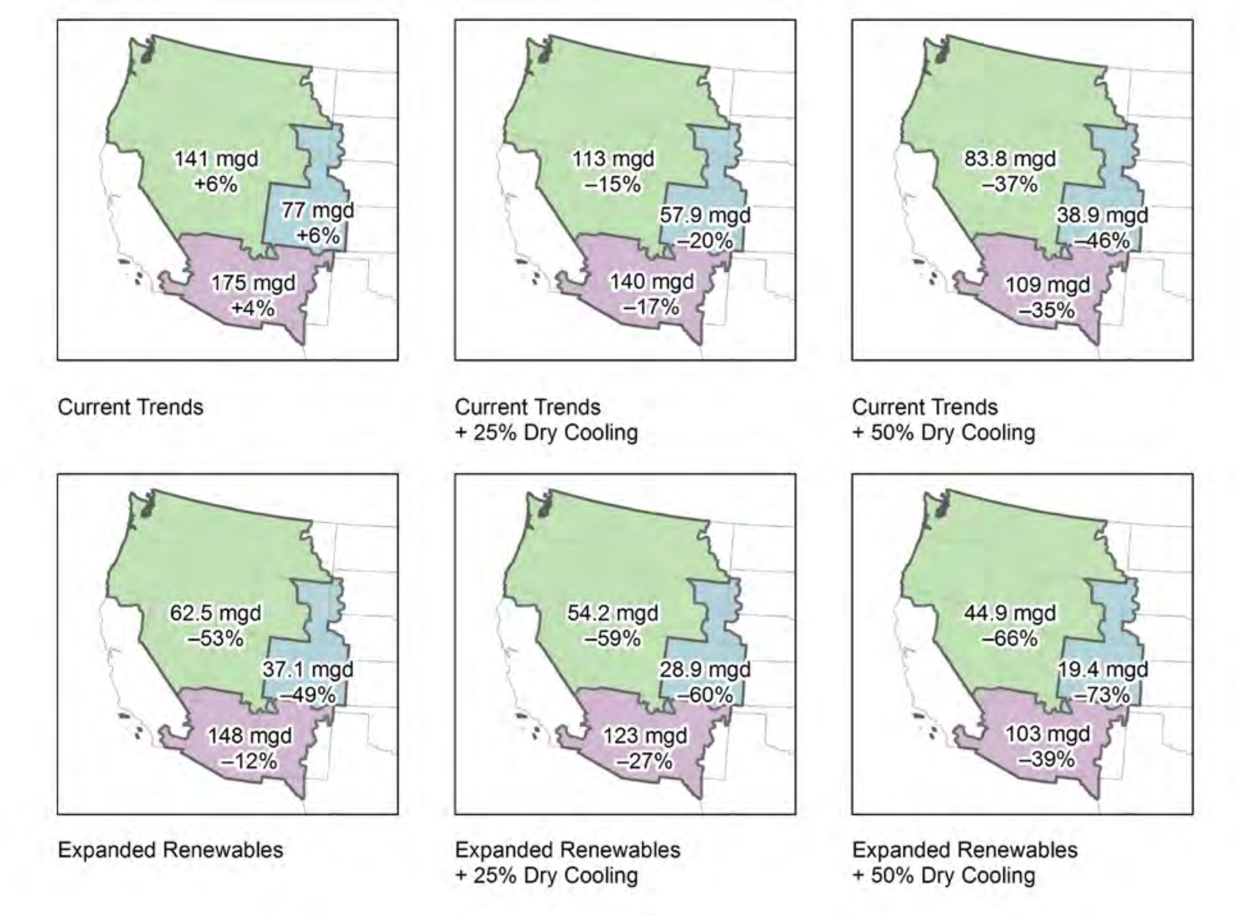

Figure 26. Water consumption, in million gallons per day (mgd), in the Intermountain West in 2035
Note: The percentage refers to the change from 2010 levels.

Section 4: Direction for Further Research

Water Requirements for Other Elements of the Fuel Cycle

As described previously, a comprehensive evaluation of the water requirements for the production of electricity would include water withdrawn and consumed in every phase of the fuel cycle, including to extract, process, and refine fuels; construct, operate, and maintain generation facilities; generate electricity; and dispose of wastes. Most studies, including this one, have focused on the operation of the power plant, specifically for cooling the power plant and replacing boiler water. The water requirements for fuel extraction, however, may pose a major threat for water resources in the Intermountain West in the future due to new demands for fuels and the development of water-intensive extraction methods (Figures 27 and 28). For example, under the EIA Reference case – which forms the basis of the Current Trends scenario in this study – annual coal production in the Intermountain West is projected to increase by nearly 50% by 2035. Natural gas production in the region is projected to increase by about 15% during this same period, with much of this growth from unconventional sources that use water-intensive hydraulic fracturing to enhance recovery.

Similarly, modest growth is projected for uranium mining, but the use of in-situ leaching might dramatically increase the water requirements for extracting this resource. In-situ leaching is a mining process that requires drilling boreholes, often fracturing the earth below, pumping an acid or alkali solution into the uranium ore deposit, and recovering it through nearby boreholes. The "leached" uranium solution is then transported to a processing plant, where it is subjected to a series of chemical reactions. In-situ leaching consumes 1.1 gallons of water per kWh (Mudd and Diesendorf 2008), significantly more than other uranium mining techniques and even some forms of power generation. There are seven in-situ leaching and processing plants in operation in the U.S., the largest of which is located in Wyoming (EIA 2011b). An additional 10.3 million pounds per year in in-situ leaching capacity is either under development or idling (EIA 2011b), which would nearly doubling the current capacity. Additional analysis is needed to determine whether fuel extraction will pose a significant risk on the availability of water resources in the Intermountain West in the future.

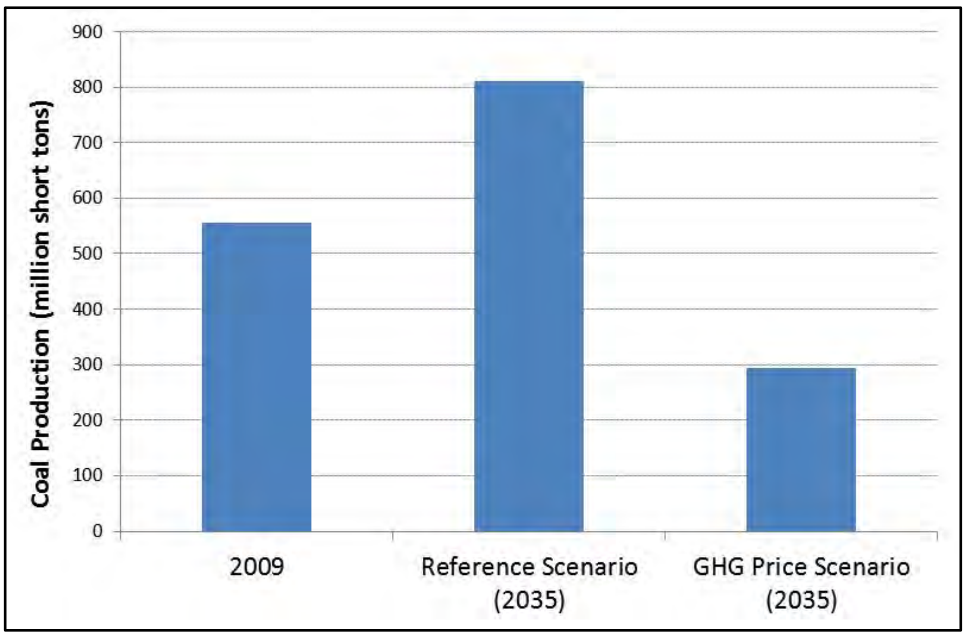

Figure 27. Current and future coal production (million short tons) estimates for the Intermountain West under the Reference and Greenhouse Gas Price scenarios
Source: EIA 2011a.
Note: Estimates include production in the following coal supply regions: Western Montana, Wyoming's Powder River Basin, Western Wyoming, Rocky Mountain, Arizona/New Mexico, and Washington/Alaska

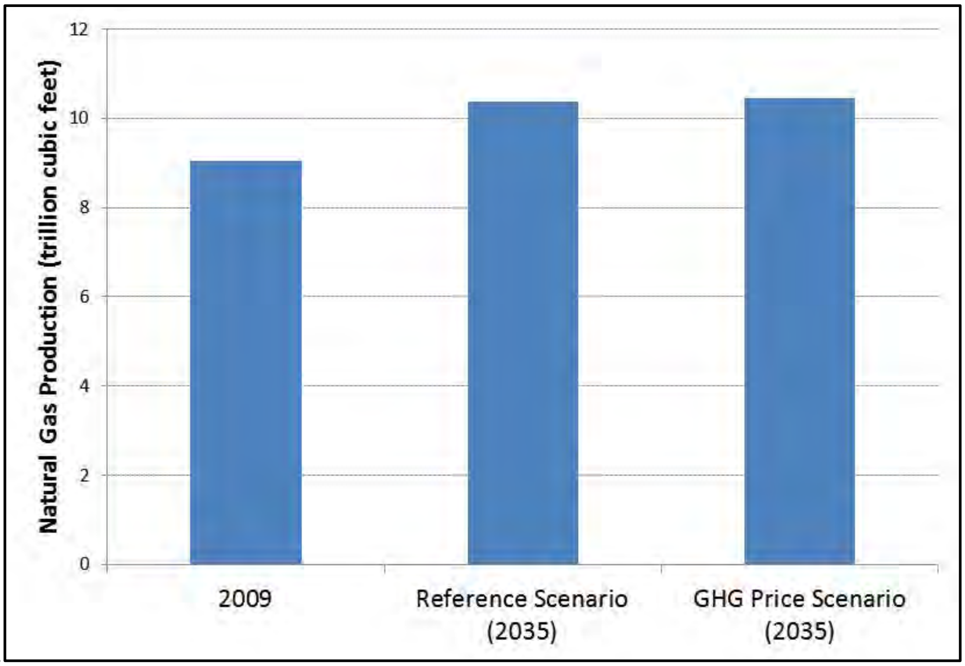

Figure 28. Current and future natural gas production (trillion cubic feet) estimates for the Intermountain West under the Reference and Greenhouse Gas Price scenarios

Source: EIA 2011a.

Note: Estimates include production in the following oil and gas supply regions: Southwest, Rocky Mountain, and West Coast.

The Implications of Climate Change on the Water Requirements for the Production of Electricity

Climate change will have major implications for electricity production and use across the Intermountain West, which will, in turn, affect water resources. Warmer temperatures reduce the efficiency of thermal power plants and of transmission and distribution lines (Sathaye 2011). The efficiency of dry cooled power plants will be reduced to a greater degree than wet-cooled power plants. To compensate for these losses, power plants will have to increase their output and the total water withdrawn and consumed.

In addition, warmer temperatures, combined with changes in precipitation patterns, will have major implications for hydropower generation. Warmer temperatures, for example, will increase evaporation from reservoirs, thereby reducing the total volume of water that flows through turbines. Likewise, reductions in the total volume of precipitation will reduce power generation. In addition, greater climate variability reduces the reliability of hydropower generation. To compensate for overall reductions in hydropower generation, energy managers may need to rely more heavily on other power sources, with undetermined impacts on water resources.

Climate change will also affect the demand for electricity. Warmer temperatures increase electricity demand for cooling but reduce demands for heating. Wilbanks et al. (2007) note: “These changes will vary by region and by season, but they will affect household and business energy costs and their demands on energy supply institutions.” A recent study in California found that warmer temperatures may increase total electricity demand in the state by up to 18% by the end of the century assuming a constant population (Aroonruengsawat and Auffhammer 2009).

Furthermore, our response to climate change will have a direct impact on water resources. Carbon capture and storage (CCS) has been proposed as one way to reduce the greenhouse gas emissions from fossil-based thermoelectric power plants, especially coal (see Box 3 on CCS). CCS, however, increases water requirements for energy extraction and electricity generation. Capturing and compressing CO_2 directly increases cooling water requirements. CCS also reduces the efficiency of the power plant, reducing its electricity output. To offset these losses, additional fuel extraction and electricity generation is required, effectively increasing water requirements.

In summary, climate change will alter electricity production and use, ultimately affecting water resources in the Intermountain West. More power will need to be generated, and more water withdrawn and consumed, to offset reductions in the efficiency of power plants and of transmission and distribution lines. Likewise, reductions in hydropower generation and increases in electricity demand associated with warmer temperatures will increase demand for new power generation and as a result, likely increase water withdrawals and consumption. Finally, climate mitigation policies, such as implementation of carbon capture and storage, may create additional demands on water resources. These impacts are not typically integrated in current electricity analyses; additional analysis is needed to better understand these factors.

Box 3. Carbon capture and storage

Growing concerns about climate change are forcing policy makers to explore ways to reduce atmospheric greenhouse gas emissions. Carbon capture and storage (CCS) has been proposed as one way to reduce the greenhouse gas emissions from thermoelectric power plants fueled by fossil fuels (coal in particular) and other point sources. CCS consists of three processes: capturing CO_2 from a large point source, such as a power plant; transporting it to a suitable storage location; and long-term isolation from the atmosphere. CCS reduces the overall efficiency of the plant but can reduce CO_2 emissions by 80% to 90%, compared to a plant without CCS (IPCC 2005).

CCS increases water requirements for both electricity generation and energy extraction. Capturing and compressing CO_2 directly increases cooling water requirements. CCS also reduces the efficiency of the power plant, thereby reducing its electricity output. To offset these losses, additional electricity generation is required. A 2010 assessment by NETL found that the CCS process alone, without taking into account the reduced generation resulting from the retrofits, would increase national water consumption by 1.5 billion gallons per day by 2035. Offsetting the reductions in generation would require an additional 0.9 to 3.5 billion gallons per day by 2035, depending on the technology employed to generate that electricity (NETL 2010a). Additional water would be required for energy extraction, processing, and transportation to offset these efficiency losses.

Research suggests that there is significant CO_2 storage potential around the world, although application of CCS is still in its infancy. Some elements of CCS have been used for small-scale industrial applications, such as industrial CO_2 production. Other elements of the process, however, still require a significant amount of R&D. As of late 2010, a total of 246 CCS projects have been initiated around the world; the majority of these projects are in the planning and development phase and only eight of these projects are actively capturing and storing CO_2 (NETL 2010b). Thus far, there have been no applications of CCS on a large (<500 MW) power plant (IPCC 2005). Furthermore, the DOE estimates that carbon capture currently costs around $150 per ton of carbon, which is not cost-effective given other approaches for reducing greenhouse gas emissions (NETL n.d.). Additionally, there remain a range of technical, legal, and regulatory challenges as well as concerns about environmental impacts.

Electricity Generation and Water Quality

The vast majority of studies on water and electricity have focused on the availability of water as a constraint for electricity generation. Yet the production of electricity, from fuel extraction to generation, has major water quality impacts that are too often ignored. For example, in some areas, acid mine drainage from coal mines flows directly into nearby rivers and streams or via groundwater pathways. Nuclear fuel extraction has also been implicated in surface and groundwater contamination, resulting in numerous EPA-sponsored Superfund sites including in the Navajo Nation, where over 500 abandoned uranium mines await remediation (EPA 2010).

Waste from electricity generation can also contaminate large volumes of water. Coal ash is a by-product of coal combustion and according to the EPA is "one of the largest waste streams generated in the United States" (EPA n.d.). Coal ash is typically disposed of in a landfill, recycled, or mixed with water and stored in an onsite impoundment reservoir. Materials in landfills or reservoir impoundments can leach into groundwater, or the impoundment may fail altogether. In 2000, for example, a coal ash impoundment in Kentucky collapsed and released an estimated 250 million gallons of coal sludge into surrounding waterways, disrupting local water supplies for days and impacting aquatic life in more than 100 miles of streambeds and associated floodplains (EPA 2001). More recently, in 2008, a coal ash impoundment at the Tennessee Valley Authority Kingston Fossil Plant collapsed, releasing an estimated 5.4 million cubic yards of fly ash onto the area adjacent to the plant and into the main channel of the Emory River (EPA 2010). Yet, water quality impacts are poorly understood and rarely acknowledged; additional data collection and analysis are needed in this area.

Conclusions

Water scarcity affects energy production.

Conflicts between energy production and water are on the rise as the overall pressure on scarce water resources grows. Water availability is beginning to affect energy production, even in areas not traditionally associated with water-supply constraints. For example:

- In September 2010, water levels in Lake Mead dropped to 1,084 feet, levels not seen since 1956, prompting the Bureau of Reclamation to reduce Hoover Dam's generating capacity by 23%. As water levels continued to drop and concerns about climate change intensified, dam operators were concerned that reductions in the electricity generating capacity would destabilize energy markets in the southwestern United States (Walton 2010).

- In August 2007, river flows and reservoir levels in the southeastern United States dropped due to drought, and in some cases, water levels were so low that power production was halted or curtailed, including at the Browns Ferry nuclear plant and at coal plants in the Tennessee Valley Authority system (Kimmell and Vail 2009).

- A seven-year drought reduced power production from the North Platte Project – which includes a series of dams and hydropower plants along the North Platte River from Nebraska to Wyoming – by about 50%, according to the executive director of the

Wyoming Municipal Power Agency. The drought also reduced production in other thermo- and hydroelectric plants along the river (LaMaack 2006).

- The proposed Ely Energy Center, a 1,500-megawatt coal-fired power plant, would have consumed over 7.1 million gallons of water each day. Local Nevada residents and environmental groups opposed the proposal due, in part, to concerns about water consumption (WRA n.d.). NV Energy abandoned the plan in 2009, citing economic and environmental uncertainties (NV Energy 2009).

- The Tennessee Valley Authority reported that it curtailed operations at some of its operating nuclear plants when temperature limits in the receiving waters below cooling water discharge pipes were exceeded due to drought (Weiss 2008, Kimmell and Vail 2009).

There is growing concern that these resource conflicts may intensify as a result of trends in energy use, water demand, and water availability. Population growth is concentrated in water scarce areas, increasing pressure on limited resources. This growth is also increasing demand for electricity. Furthermore, climate change is already affecting the supply of and demands for water throughout the region, and climate models find that the impacts and economic consequences of climate change will accelerate, particularly if efforts to reduce greenhouse gas emissions continue to be delayed.

Sustainable water and energy use requires integrated study and management.

Water and energy are deeply interwoven into our economy, environment, and society. Yet, for much of the 20th century, water and energy have largely been analyzed and managed separately, with different tools, institutions, definitions, and objectives. We now know, however, that there are very important and fundamental links between water and energy, and that long-term sustainable use of both resources requires comprehensive and integrated study and management. In addressing the water implications of energy choices, this report offers some new insights into the water risks of different electricity futures.

The focus of this analysis is the Intermountain West, which includes the area bounded by the Rocky Mountains to the East and the Sierra Nevada and Cascade Mountains to the West. States entirely or partially within this region include Washington, Oregon, Idaho, Montana, Wyoming, Nevada, Utah, Colorado, Arizona, New Mexico, and California. In this analysis, we evaluate water withdrawals and consumption for current (2010) electricity generation and for six future electricity-generation scenarios:

1. **Current Trends Scenario**: U.S. Energy Information Administration (EIA) “Reference” electricity generation scenario for 2035 with the current mix of cooling technologies;

2. **Current Trends + 25% Dry Cooling Scenario**: EIA “Reference” electricity generation scenario for 2035 with 25% dry cooling and 75% recirculating cooling;

3. **Current Trends + 50% Dry Cooling Scenario**: EIA “Reference” electricity generation scenario for 2035 with 50% dry cooling and 50% recirculating cooling;

4. **Expanded Renewables Scenario**[8]: EIA "Greenhouse Gas Price Economywide" electricity generation scenario for 2035 with current mix of cooling technologies;

5. **Expanded Renewables + 25% Dry Scenario**: EIA "Greenhouse Gas Price Economywide" electricity generation scenario for 2035 with 25% dry cooling and 75% recirculating cooling; and

6. **Expanded Renewables + 50% Dry Scenario**: EIA "Greenhouse Gas Price Economywide" electricity generation scenario for 2035 with 50% dry cooling and 50% recirculating cooling.

Under a business-as-usual approach, water resource challenges are likely to intensify throughout the Intermountain West.

Our results indicate that under a business-as-usual approach, as modeled in the Current Trends scenario, water withdrawals and consumption are projected to increase across the Intermountain West (Figure 29). Total water withdrawals increase to 1,980 million gallons per day, or 2% above 2010 levels. Likewise, water consumption increases to 393 million gallons per day, 5% above 2010 levels. The largest increases in both withdrawals and consumption occur in the Rocky Mountain area, a region with limited available water sources.

[8] The Expanded Renewables scenarios include energy-efficiency improvements and greater reliance on renewable energy systems.

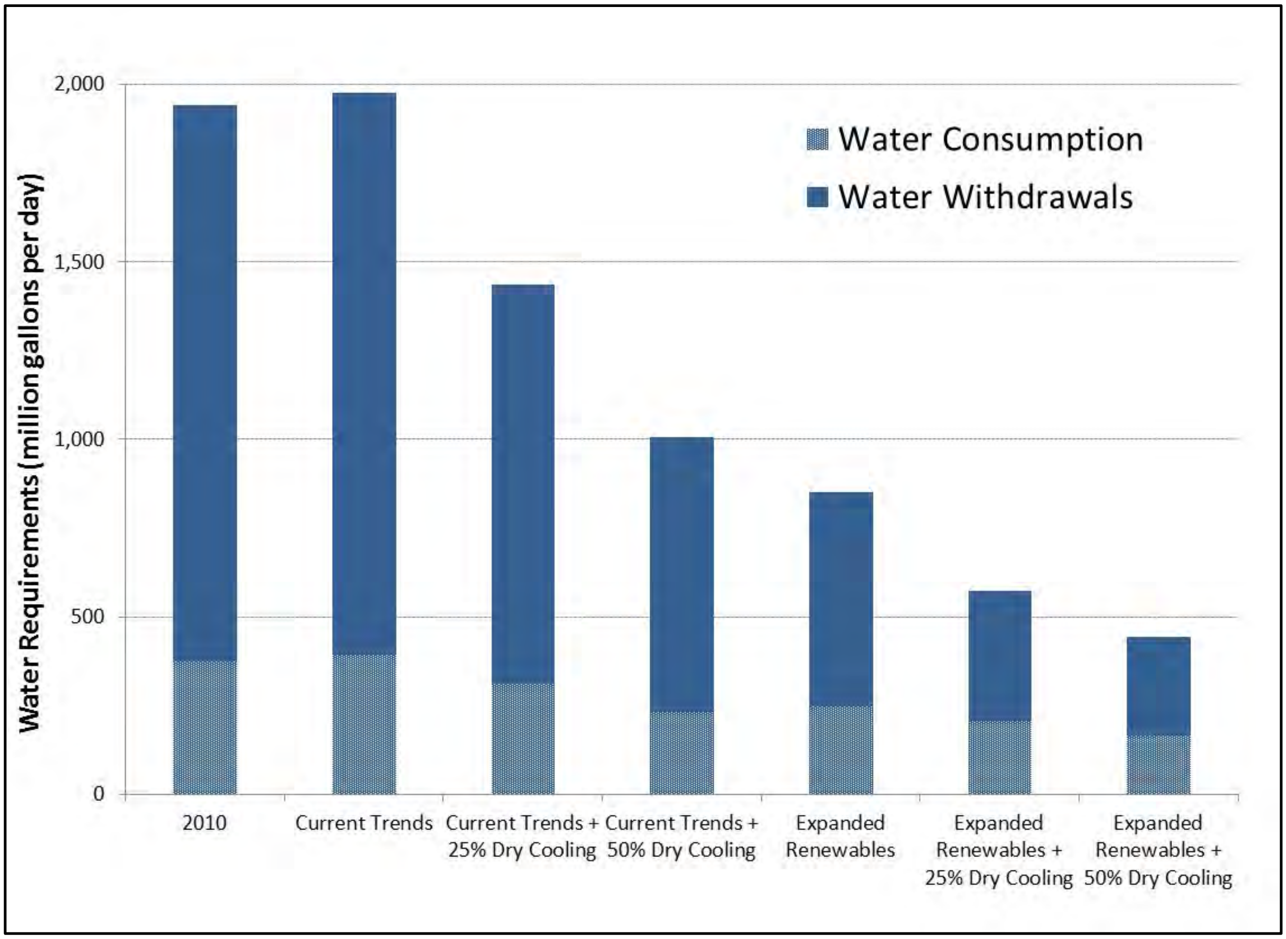

Figure 29. Water requirements for electricity generation in 2010 and in 2035 in six alternative scenarios.
Note: The full bar shows total water withdrawals for each scenario. Water consumption is shown as a proportion of the total withdrawals.

Electricity can be generated in the Intermountain West using less water, especially with the adoption of energy-efficiency improvements and dry cooling systems and greater reliance on renewables.

Expanding the use of dry cooling – either as the only cooling system at a given power plant or combined with a wet cooling tower as a hybrid system – produces large reductions in water withdrawals and consumption. Under the Current Trends + 25% Dry Cooling scenario, water withdrawals decline to 1,440 million gallons per day, 26% below 2010 levels. Likewise, water consumption declines to 310 million gallons per day, 17% below 2010 levels. By expanding the deployment of dry cooling to 50% of generation, additional water savings are possible.

Even greater savings can be achieved by expanding energy-efficiency efforts and relying more heavily on renewable energy systems. Under the Expanded Renewables scenario, water withdrawals decline to 853 million gallons per day, and water consumption declines to 247 million gallons per day. This results in a reduction a 56% reduction in water withdrawals and a 34% reduction in water consumption, compared to 2010 levels. Dry cooling systems can provide additional water savings. Under the Expanded Renewables and 25% Dry Cooling scenario, water withdrawals and consumption decline to 573 million gallons per day and 206 million gallons per day. This represents a 71% and 45% reduction in water withdrawals and consumption, respectively, compared to 2010 levels.

Extracting fuels for energy production has a water cost that must be evaluated.

This analysis also finds that while we can dramatically reduce the water requirements for electricity generation, there are other energy-related threats to regional water availability and quality that must be evaluated. In particular, most studies, including this one, have focused on the water requirements for electricity generation itself. In order to generate this electricity, however, more primary fuels, such as coal and natural gas, must be extracted and processed, processes which use and pollute water. Furthermore, some new energy extraction processes, such as hydraulic fracturing, are water intensive. More research and analysis are needed on the water requirements to extract and process the primary fuels needed to generate electricity.

Climate change will have major implications for water resources and electricity in the Intermountain West.

The impacts of climate change on water resources are already evident in the Intermountain West, including less precipitation and runoff, an earlier snowmelt, and more frequent and intense droughts. Climate models indicate that these impacts will accelerate, particularly if efforts to reduce greenhouse gas emissions continue to be delayed. Climate change will also have major implications for electricity production and use across the Intermountain West, which will, in turn, affect water resources. Warmer temperatures reduce the efficiency of thermal power plants and of transmission and distribution lines. More power will need to be generated, and more water withdrawn and consumed, to offset these efficiency losses. Likewise, reductions in hydropower generation and increases in electricity demand associated with warmer temperatures will increase demand for additional power generation and as a result, likely increase water withdrawals and consumption. Technologies that have been proposed to mitigate climate change, such as carbon capture and storage, might create additional demands on water resources. These impacts are not typically integrated in current electricity analyses; additional analysis is needed to better understand how climate change will affect electricity generation and ultimately water resources.

The production of electricity affects water quality and human and environmental health.

Finally, the production of electricity has a significant effect on water quality and ultimately human and environment health. The discharge of waste heat from cooling systems, for example, raises the temperature of rivers and lakes, which affects aquatic ecosystems. Wastewaters from fossil fuel or uranium mining operations, hydraulic fracturing, boilers, and cooling systems may be contaminated with heavy metals, radioactive materials, acids, organic materials, suspended solids, or other chemicals. For example, A *New York Times* analysis of Environmental Protection Agency data finds that power plants are the nation's biggest producer of toxic waste, and with efforts to reduce air pollution, many of these pollutants end up in our waterways (Duhigg 2009). In a single incident in Kentucky, a coal sludge impoundment collapsed and released an estimated 250 million gallons of coal sludge into surrounding waterways, disrupting local water supplies for days and devastating aquatic life along more than 100 miles of streambeds and associated floodplains (EPA 2001). Too often, water quality impacts are poorly understood and largely ignored.

Recommendations

Improve data, information, and education on impact of energy sector on water resources.

Water and energy analysts are often frustrated by the lack of available data on the water use and consumption of energy systems. In a recent report, the Government Accountability Office (GAO) outlines some of the major shortcomings of federal data-collection efforts on water availability and use as they relate to planning and siting energy facilities (2009). The USGS, for example, collects data on water withdrawals by power plants but not water consumption.[9] Streamflow gauges, which provide information on water availability, are disappearing. The EIA does not collect data on the use of advanced cooling technologies. No agency collects data on the use of alternative water sources, such as recycled water, for power production. Few data are available on the water-quality impacts of energy production, from energy extraction to generation. Many of these shortcomings are a result of budget cuts. State and federal agencies must enhance data collection and reporting capacities.

Accelerate efficiency improvements.

Improvements in water and energy efficiency can help meet the needs of a growing population, reduce or eliminate the need to develop capital-intensive infrastructure, and provide environmental benefits. Additionally, conservation and efficiency promote both water and energy security by reducing vulnerability to limits on the availability of these resources.

Promote renewable energy systems.

Shifting from conventional fossil fuels to less water-intensive renewable energy sources would reduce the water-intensity of the electricity sector, among other environmental benefits. This, in turn, would help reduce pressure on limited water resources and reduce the electricity sector's vulnerability to water-supply constraints.

Establish cooling-technology requirements.

Prior to 1970, most thermoelectric plants were built with once-through cooling systems. New requirements set by the Environmental Protection Agency under Section 316(b) of the Clean Water Act have made permitting requirements for these cooling systems more stringent. Additionally, in regions with limited water resources, plant operators have, out of necessity, moved away from water-intensive cooling technologies. Federal and state governments should continue to tighten water-cooling technology requirements through federal and state permitting processes. As many of the power plants in the Intermountain West are already in compliance

[9] Prior to 2000, the USGS collected and reported water withdrawals and consumption. However, only data on withdrawals was reported in 2000 and 2005. For the 2010 analysis, the USGS will include both withdrawals and consumption.

with 316(b) modifications, they must be motivated to further reduce their water impacts by moving to dry and hybrid cooling and other regionally appropriate technologies.

Promote switching to alternative water sources.

Alternative water sources can reduce freshwater requirements for electricity generation. Recycled municipal wastewater, for example, is a reliable water source that is available in relative abundance across the United States. In 2007, however, only 57 power plants, most of which were located in California, Florida, and Texas, were using treated municipal wastewater (ANL 2007), suggesting that its use could be dramatically expanded and help reduce pressure on freshwater systems. Other alternative water sources include produced water from oil and gas wells, mine pool water, and industrial process water.

Expand research and development efforts.

A number of strategies are available to reduce the tension between water and energy management. Key areas for research and development include technologies and management practices to promote the use of alternative water sources, including produced water, brackish groundwater, and municipal wastewater; application of dry and hybrid-cooling technologies for power plants; and improvements in power plant thermal efficiency.

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