# Water-Smart Power

## STRENGTHENING THE U.S. ELECTRICITY SYSTEM IN A WARMING WORLD

*A Report of the Energy and Water in a Warming World Initiative*




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# About EW3

The Energy and Water in a Warming World initiative (EW3) is a collaborative effort between the Union of Concerned Scientists and a team of independent experts to build and synthesize policy-relevant research on the water demands of energy production in the context of climate variability and change. The initiative includes core research collaborations intended to raise the national profile of the water demands of energy, along with policy-relevant energy development scenarios and regional perspectives.

This report is based primarily on the research of the EW3 energy-water futures collaborators listed below. The research appears in a special issue of *Environmental Research Letters:* Focus on Electricity, Water and Climate Connections (ERL 2013). This report is also available online at *www.ucsusa.org/watersmartpower*.

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# Contents

# Figures and Text Boxes

## Figures



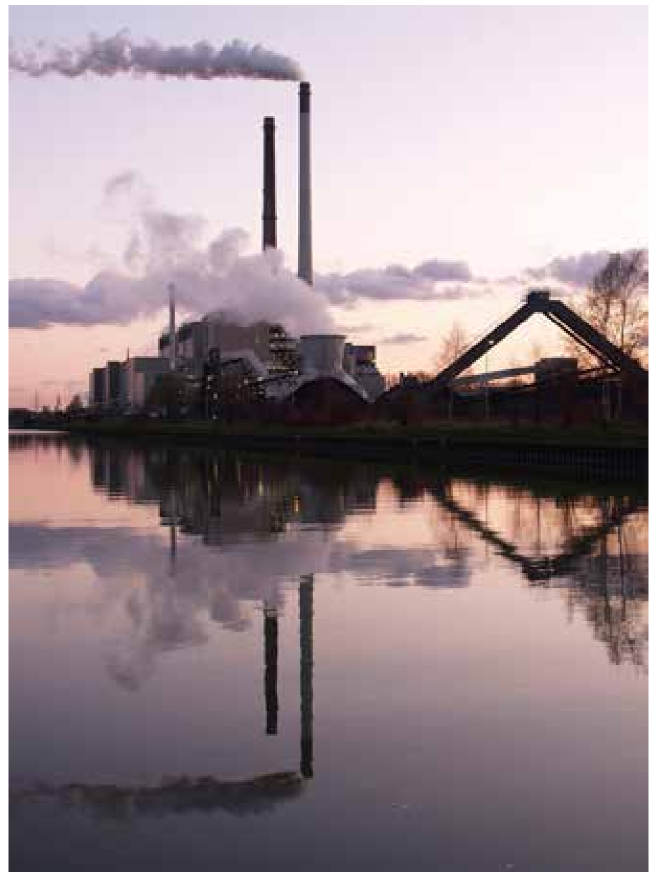
## Text Boxes

# Executive Summary

The heat waves and drought that hit the United States in 2011 and 2012 shined a harsh light on the vulnerability of the U.S. electricity sector to extreme weather. During the historic 2011 drought in Texas, power plant operators trucked in water from miles away to keep the plants running, and disputes deepened between cities and utilities seeking to construct new water-intensive coal plants. In 2012, heat and drought forced power plants, from the Gallatin coal plant in Tennessee to the Vermont Yankee nuclear plant on the Connecticut River, to reduce their output or shut down altogether. That summer, amid low water levels and soaring water temperatures, operators of other plants—at least seven coal and nuclear plants in the Midwest alone—received permission to discharge even hotter cooling water, to enable the plants to keep generating. These consecutive summers alone revealed water-related electricity risks across the country.

The power sector has historically placed large demands on both our air and water. In 2011, electricity generation accounted for one-third of U.S. heat-trapping emissions, the drivers of climate change. Power plants also accounted for more than 40 percent of U.S. freshwater withdrawals in 2005, and are one of the largest "consumers" of freshwater—losing water through evaporation during the cooling process—outside the agricultural sector.

The electricity system our nation built over the second half of the twentieth century helped fuel the growth of the U.S. economy and improve the quality of life of many Americans. Yet we built that system before fully appreciating the reality and risks of climate change, and before converging pressures created the strain on local water resources we see today in many places. This system clearly cannot meet our needs in a future of growing demand for electricity, worsening strains on water resources, and an urgent need to mitigate climate change.



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We can, however, use fuel and technology options available now to design an electricity future that begins to shed some of these risks. We can also expand our options by making strategic investments in energy and cooling technologies. The key is to understand what a low-carbon, "water-smart" electricity future looks like—which electric sector decisions best prepare us to avoid and minimize energy-water collisions, and to cope with those we cannot avoid—and to make decisions that will set and keep us on that path.

This report is the second from the Energy and Water in a Warming World Initiative (EW3), organized by the Union of Concerned Scientists to focus on the water implications of U.S. electricity choices. The first, *Freshwater Use by U.S. Power Plants,* documented the energy-water collisions already occurring because of the dependence of U.S. power plants on water. In that research, we found that past choices on fuel and cooling technologies in the power sector are contributing to water stress in many areas of the country.

Like the first report, this one stems from a collaboration among experts from universities, government, and the nonprofit sector. *Water-Smart Power* reflects comprehensive new research on the water implications of electricity choices in the United States under a range of pathways, at national, regional, and local levels. The report aims to provide critical information to inform decisions on U.S. power plants and the electricity supply, and motivate choices that safeguard water resources, reduce carbon emissions, and provide reliable power at a reasonable price—even in the context of a changing climate and pressure on water resources.

## The Challenges We Face

Our examination of today's electricity-water landscape reveals prominent challenges:

- **Energy-water collisions are happening now.** Because of its outsized water dependence, the U.S. electricity sector is running into and exacerbating growing water constraints in many parts of the country. The reliance of many power plants on lakes, rivers, and groundwater for cooling water can exert heavy pressure on those sources *and* leave the plants vulnerable to energy-water collisions, particularly during drought or hot weather. When plants cannot get enough cooling water, for example, they must cut back or completely shut down their generators, as happened repeatedly in 2012 at plants around the country.
- **As the contest for water heats up, the power sector is no guaranteed winner.** When the water supply has been tight, power plant operators have often secured the water they need. In the summer of 2012, for example, amid soaring temperatures in the Midwest and multiple large fish kills, a handful of power plant operators received permission to discharge exceptionally hot water rather than reduce power output. However, some users are

pushing back against the power sector's dominant stake. In Utah, for example, a proposal to build a 3,000-megawatt nuclear power plant fueled grave concerns about the impact of the plant's water use. And in Texas, regulators denied developers of a proposed 1,320-megawatt coal plant a permit to withdraw 8.3 billion gallons (25,000 acre-feet) of water annually from the state's Lower Colorado River.

- **Climate change complicates matters.** Energy-water collisions are poised to worsen in a warming world as the power sector helps drive climate change, which in turn affects water availability and quality. Climate change is already constraining or altering the water supply in many regions by changing the hydrology. In the Southwest, for example, where the population is growing rapidly and water supply is typically tight, much of the surface water on which many water users depend is declining. Scientists expect rising average temperatures, more extreme heat, and more intense droughts in many regions, along with reductions in water availability.

These conditions—heightened competition for water and more hydrologic variability—are not what our power sector was built to withstand. However, to be resilient, it must adjust to them.

## Change Is Under Way

Building an electricity system that can meet the challenges of the twenty-first century is a considerable task. Not only is the needed technology commercially available now, but a transition is also under way that is creating opportunities for real system-wide change:

- **The U.S. power sector is undergoing rapid transformation.** The biggest shift in capacity and fuel in half a century is under way, as electricity from coal plants shrinks and power from natural gas and renewables grows. Several factors are spurring this transition to a new mix of technologies and fuels. They include the advanced age of many power plants, expanding domestic gas supplies and low natural gas prices, state renewable energy and efficiency policies, new federal air-quality regulations, and the relative costs and risks of coal-fired and nuclear energy.



- **This presents an opportunity we cannot afford to miss.** Decisions about which power plants to retrofit or retire and which kind to build have both near-term and long-term implications, given the long lifetimes of power plants, their carbon emissions, and their water needs. Even a single average new coal plant could emit 150 million tons of carbon dioxide over 40 years—twice as much as a natural gas plant, and more than 20 million cars emit each year. Power plants that need cooling water will be at risk over their long lifetimes from declining water availability and rising water temperatures stemming from climate change, extreme weather events, and competition from other users. And power plants, in turn, will exacerbate the water risks of other users.

## Decisions in the Power Sector Matter

Choices, however, are important only if they lead to different outcomes. To analyze the impact of various options for our electricity future on water withdrawals and consumption, carbon emissions, and power prices, under this new research we focused on several key scenarios. These included "business as usual" and three scenarios based on a strict carbon budget—to address the power sector's contributions to global warming. Two of those three scenarios assumed the use of specific technologies to make those significant cuts in carbon emissions.

To explore the outcomes of these scenarios we used two models: the Regional Energy Deployment System (ReEDS) and the Water Evaluation and Planning (WEAP) system. With these two models and our set of scenarios, we analyzed the implications of water use in the power sector under different electricity pathways for the entire nation, for various regions, and for individual river basins in the southwestern and southeastern United States.

Our distinctive approach and new research—along with previous work—shows that our electricity choices will have major consequences over the coming decades, especially in water-stressed regions. Through this research, we have learned that:

- **Business as usual in the power sector would fail to reduce carbon emissions, and would not tap opportunities to safeguard water.** Because such a pathway for meeting future electricity needs would not cut carbon emissions, it would do nothing to address the impact of climate change on water. Changes in the power plant fleet would mean that water withdrawals by power plants would drop, yet plants' water consumption would not decline for decades, and then only slowly. The harmful effects of power plants on water temperatures in lakes and rivers might continue unabated, or even worsen. Greater extraction of fossil fuels for power plants would also affect water use and quality.
- **Low-carbon pathways can be water-smart.** A pathway focused on renewable energy and energy efficiency, we found, could deeply cut both carbon emissions and water effects from the power sector. Water withdrawals would drop 97 percent by 2050—much more than under business as usual. They would also drop faster, with 2030 withdrawals only half those under business as usual. And water consumption would decline 85 percent by 2050. This pathway could also curb local increases in water temperature from a warming climate. Meanwhile lower carbon emissions would help slow the pace and reduce the severity of climate change, including its long-term effects on water quantity and quality.
- **However, low-carbon power is not necessarily water-smart.** The menu of technologies qualifying as low-carbon is long, and includes some with substantial water needs. Electricity mixes that emphasize carbon capture and storage for coal plants, nuclear energy, or even water-cooled renewables such as some geothermal, biomass, or concentrating solar could worsen rather than lessen the sector's effects on water.
- **Renewables and energy efficiency can be a winning combination.** This scenario would be most effective in reducing carbon emissions, pressure on water resources, and electricity bills. Energy efficiency efforts could more than meet growth in demand for electricity, and renewable energy could supply 80 percent of the remaining demand. Although other low-carbon paths could rival this one in cutting water withdrawals and consumption, it would edge ahead in reducing groundwater use in the Southwest, improving river flows in the Southeast, and moderating high river temperatures. This scenario could also provide the lowest costs to consumers, with consumer electricity bills almost one-third lower than under business as usual.

## Toward a Water-Smart Energy Future

Water-smart energy decision making depends on understanding and effectively navigating the electricity-water-climate nexus, and applying best practices in decision making:

- **We can make decisions now to reduce water and climate risk.** Fuel and technology options already available mean we can design an electricity system with far lower water and climate risks. These include prioritizing low-carbon, water-smart options such as renewable energy and energy efficiency, upgrading power plant cooling systems with those that ease water stress, and matching cooling needs with the most appropriate water sources.
- **Electricity decisions should meet water-smart criteria.** These criteria can point decision makers to options that reduce carbon emissions *and* exposure to water-related risks, make sense locally, and are cost-effective.

- **Actors in many sectors have essential roles to play.** No single platform exists for sound, long-term decisions at the nexus of electricity and water, but those made in isolation will serve neither sector. Instead, actors across sectors and scales need to engage. For example: plant owners can prioritize low-carbon options that are water-appropriate for the local environment. Legislators can empower energy regulators to take carbon and water into account. Consumer groups can ensure that utilities do not simply pass on to ratepayers the costs of risky, water-intensive plants. Investors in utilities can demand information on water-related risks and seek low-carbon, water-smart options. Researchers can analyze future climate and water conditions and extremes, allowing planners to consider low-probability but high-impact events. And scientists and engineers can improve the efficiency and reduce the cost of low-water energy options.

Understanding and addressing the water impact of our electricity choices is urgent business. Because most power sector decisions are long-lived, what we do in the near term commits us to risks or resiliencies for decades. We can untangle the production of electricity from the water supply, and we can build an electricity system that produces no carbon emissions. But we cannot wait, nor do either in isolation, without compromising both. For our climate—and for a secure supply of water and power—we must get this right.

CHAPTER 1

# Electricity, Water, and Carbon: Introduction

Power plants that generate steam to make electricity—all coal and nuclear plants, many natural gas plants, and some renewable energy facilities—typically use water to cool and re-condense that steam for reuse, and often in large quantities (DOE 2006). Such *thermoelectric* power plants are responsible for the largest share of freshwater withdrawals in the United States: more than 40 percent in 2005 (Kenny et al. 2009). They are also one of the largest non-agricultural *consumers* of such water, through the evaporation that serves to remove the excess heat during the cooling process (Solley, Pierce, and Perlman 1998).[1]

Power plants that require cooling use different technologies, each with advantages and disadvantages. Some use once-through cooling systems, which withdraw enormous amounts of water from lakes, rivers, or streams, use it once, and return it to the source. Once-through systems are the least capital-intensive, and lose less water to evaporation, but discharge much-hotter water. The water withdrawals and the discharge of hotter water can disrupt local ecosystems (Stewart et al. 2013; EPA 2011a; GAO 2009; Langford 2001).[2]

Photo courtesy Dominion, www.dom.com

***Power plants and cooling water.*** **Power plants that use water take different approaches to meeting their cooling needs. Some withdraw large amounts of water but put most of it back—though hotter. Others withdraw much less but consume (evaporate) most or all of it. Either type of cooling can pose risks for the plants that use it and the water sources on which they depend.**

Newer power plants tend to use recirculating cooling systems, which withdraw much less water. Those systems consume much of it through evaporation during cooling, however, and also require more initial investment than once-through cooling systems and are less energy-efficient (GAO 2009).

Either type of cooling poses risks for the power plants that use them. Developers must site the plants near major sources of water. And the plants are exposed to risks when water is too scarce or too hot to allow the generators to operate safely or efficiently (Spanger-Siegfried 2012).[3]

Droughts and heat waves already affect power generation in the United States, particularly in summer, when demand for electricity is highest. Our changing climate means that such events are becoming more frequent in many parts of the country. Energy facilities that need cooling water will face risks during their long lifetimes from any drops in water availability from climate change or competition for water sources. The facilities will also be at risk from increases in cooling water temperatures. And they will exacerbate the water-supply risks of other users (Averyt et al. 2011).

The power sector, meanwhile, is undergoing an unprecedented level of change, too. A newfound abundance of natural gas in the United States and historically low prices—combined with increases in renewable

1 While agriculture accounts for 84 percent of water consumption, the power sector consumes 20 percent of the remainder (3.3 percent overall), second only to household (domestic) use. Data are from 1995, the year of the most recent survey of water consumption by the U.S. Geological Survey.

2 Power plant withdrawals kill fish through impingement (trapping against a screen), and fish larvae through entrainment (pulling through the cooling process). The dozens of power stations that withdraw Great Lakes water for cooling, for example, kill an estimated 100 million fish and more than a billion larval fish annually (Kelso and Milburn 1979; also see EPA 2001).

3 While this report focuses on water scarcity and high water temperatures, many power plants are at risk of flooding, given that they are often located near major bodies of water. Freezes can also interfere with power plants' intake of cooling water. See, for example, Webber 2012.


***Compounding factors.*** **Many power plants are both large carbon emitters and heavy water users. That means they put pressure on local water resources directly while contributing to climate change and its effects on water.**

energy and energy efficiency and new federal air-quality regulations—have challenged coal's dominance in the electricity sector. Tens of thousands of megawatts of U.S. coal power capacity are slated for retirement in the next several years, and many other coal plants are economically vulnerable, given pressure to upgrade pollution controls and competition from other power sources (Cleetus et al. 2012).

What's more, decisions about which power plants to retrofit or retire and which new ones to build will themselves have enormous bearing on both near-term and long-term climate change—including its impact on water resources. The power sector is the largest single contributor to U.S. carbon emissions—33 percent, largely because of coal plants (EPA 2013a).[4] And because they will last decades, new power plants have long-term implications for carbon emissions and water use.

In the face of overwhelming evidence of human-induced climate change, the challenge is not whether to address it but how best to both limit further climate change and adapt to what is already coming. While meeting those challenges will require changes all across the economy, the power sector's massive carbon emissions, and the many lower-carbon options for producing electricity, mean that our electricity choices will play a major role in our ability to mitigate climate change.

## Evaluating Our Options

This report is the second from the Energy and Water in a Warming World initiative (EW3), organized by the Union of Concerned Scientists to analyze the implications of U.S. electricity choices for our water supply and water use.[5] Produced by a team of experts from universities, government, and nonprofit organizations, this report reflects comprehensive new research on the impact on water of a range of electricity choices at national, regional, and local levels.

The report aims to inform our choices so we safeguard our water resources while obtaining reliable electricity at a reasonable price, strengthening the economy, and reducing the carbon profile of our electricity supply. Toward that end, we explore options for cutting carbon emissions from power plants significantly and reducing water withdrawals and consumption and related risks—including in the nation's driest and fastest-growing regions.

Chapter 2 describes current energy-water collisions, and climate change dimensions that are likely to exacerbate those over the next few decades. Chapter 3 describes changes in fuel costs, environmental regulations, and technologies that have produced a pivot point in the U.S. electricity sector. That chapter also explains the distinctive approach developed by our research team to produce new findings on water and other implications of various electricity pathways.

Chapter 4 compares the carbon emissions, water use and impact, risks, and costs of a range of scenarios for the electricity sector, including business-as-usual and low-carbon cases, drawing on both our own research and that of others. Chapter 5 suggests strategies for incorporating water more fully into decision making on which new power plants to build or existing plants to retire, to reduce the sector's water-related impact and strengthen its resilience in the face of a changing climate.

4 In this report, "carbon emissions" refers to carbon dioxide equivalent, taking into account the potency of various heat-trapping gases such as methane and nitrous oxide and converting their total global warming impact to an equivalent mass of carbon dioxide, the most prevalent heat-trapping gas.

5 The first EW3 report was Averyt et al. 2011.

CHAPTER 2

# Energy-Water Collisions

### *KEY FINDINGS*

- **Energy-water collisions are happening now.** Because of its outsized water dependence, the U.S. electricity sector is running into and exacerbating growing water constraints in many parts of the country. The reliance of many power plants on lakes, rivers, and groundwater for cooling water can exert heavy pressure on those sources *and* leave the plants vulnerable to energy-water collisions, particularly during drought or hot weather. When plants cannot get enough cooling water, for example, they must cut back or completely shut down their generators, as happened repeatedly in 2012 at plants around the country.
- **As the contest for water heats up, the power sector is no guaranteed winner.** When the water supply has been tight, power plant operators have often secured the water they need. In the summer of 2012, for example, amid soaring temperatures in the Midwest and multiple large fish kills, a handful of power plant operators received permission to discharge exceptionally hot water rather than reduce power output. However, some users are pushing back against the power sector's dominant stake. In Utah, for example, a proposal to build a 3,000-megawatt nuclear power plant fueled grave concerns about the impact of the plant's water use. And in Texas, regulators denied developers of a proposed 1,320-megawatt coal plant a permit to withdraw 8.3 billion gallons (25,000 acre-feet) of water annually from the state's Lower Colorado River.
- **Climate change complicates matters.** Energy-water collisions are poised to worsen in a warming world as the power sector helps drive climate change, which in turn affects water availability and quality. Climate change is already constraining or altering the water supply in many regions by changing the hydrology. In the Southwest, for example, where the population is growing rapidly and water supply is typically tight, much of the surface water on which many water users depend is declining. Scientists expect rising average temperatures, more extreme heat, and more intense droughts in many regions, along with reductions in water availability.

## The Power Sector and Water Risks

Power plants are affected by water quantity, water quality—particularly temperature—or both. Intake water that is too hot can reduce the efficiency of a power plant, or even make it unsafe to operate (UCS 2007). And hot water exiting a plant can place it out of compliance with temperature limits set to prevent harm to ecosystems, leading to fish kills and other effects (Madden, Lewis, and Davis 2013).

When plants cannot get enough cooling water, operators must reduce power production or completely shut down the generators, as happened repeatedly in 2012 at plants around the country. For example, operators of the Powerton coal plant in central Illinois had to temporarily shut down a generator during peak summer heat, when water in the cooling pond became too warm for effective cooling (Bruch 2012; Schulte 2012).

Operators of the 620-megawatt Vermont Yankee nuclear plant cut power production by up to 17 percent in July that year, because of high water temperatures and low flows in the Connecticut River (Harvey 2012; Nuclear Regulatory Commission 2012a). In Connecticut, operators shut down one of two reactors of the Millstone nuclear plant in mid-July because water in Long Island Sound was too warm to cool the plant (Wald 2012). And operators of the Gallatin and Cumberland coal plants in Tennessee had to limit power output because of high river temperatures (TVA 2012).

The 2012 drought was severe, but the power plant problems it provoked were hardly unique. In 2011, for example, during the historic drought in Texas, plants had to cut back their operations and truck water in to address the lack of cooling water (Averyt et al. 2011).

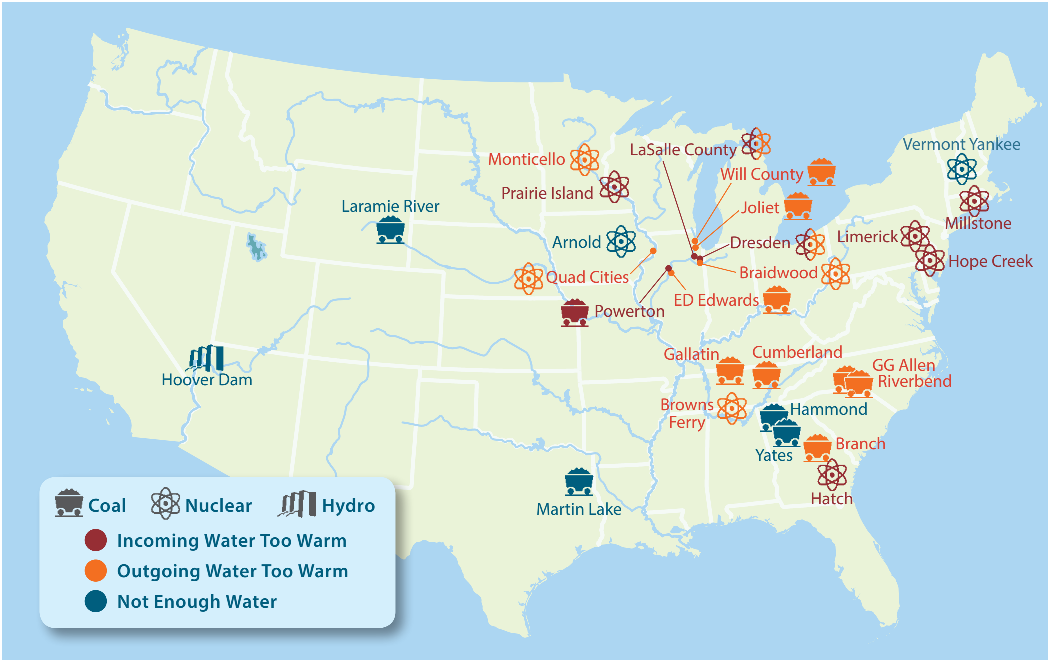


**FIGURE 1. Energy-Water Collisions**

**Power plant dependence on water can create a range of problems, including for the plants themselves. Plants have recently run into three kinds of challenges: incoming cooling water that is too warm for efficient and safe operation, cooling water that is too hot for safe release into nearby rivers or lakes, and inadequate water supplies. In response, operators must reduce plant output or discharge hot water anyway, at times when demand for electricity is high and rivers and lakes are already warm.**

Source: Spanger-Siegfried 2012.

Note: Selected events, 2006–2012.

Over roughly the past decade, a range of water-related issues have cropped up around the country, affecting a variety of power plants (Figure 1).

## Winners and Losers in Water Collisions

When water supply is tight and users are in competition, power plants often win. During the 2011 drought, for example, the Texas Commission on Environmental Quality elected not to suspend power plant water rights because of safety concerns (Ickert 2013).

However, the impact on the losing side can be considerable. In 2012, for example, at least seven coal and nuclear plants in Illinois—including the Will County and Joliet coal plants and the Braidwood and Dresden nuclear facilities—received state waivers to discharge water hotter than their permits allow. Regulators approved the "thermal variances" even though hot water in rivers and streams was already causing extensive fish kills across the Midwest (Spanger-Siegfried 2012).

Given heightened conflict over water resources, some states and communities have pushed back

© Flickr/Nuclear Regulatory Commission

***Turning up the heat in local waters.*** **When power plants discharge hot cooling water back into lakes and rivers, they can raise water temperatures, disrupting local ecosystems. During the extensive drought and heat of summer 2012, the Braidwood nuclear plant in Illinois was one of at least seven coal and nuclear plants to receive state permission to release hotter water than normal, so they could keep producing power. With worse summer heat projected for the Midwest and much of the nation in coming decades, water-dependent plants could require more such "thermal variances"—stressing lakes, rivers, wildlife, and the millions of people who count on them.**


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***Stakeholders step in.*** **Texas's historic 2011 drought mobilized a range of water users to oppose White Stallion, a proposed coal plant that sought to use millions of gallons of water per day. After the Lower Colorado River Authority rejected the water request in 2011, the developers proposed dry cooling, which would have cut water use yet increased the plant's heat-trapping emissions. The developers have since suspended the project (Gronewold 2013; Henry 2013).**

against or rejected proposals to build power plants that would require too much water. A proposal to build a 3,000-megawatt nuclear power plant on Utah's Green River, for example, ignited fierce opposition centered on its proposed water use (Hasemyer 2012; NoGRN 2012; HEAL Utah 2011). Texas regulators denied a request by developers of the proposed $2.5 billion, 1,320-megawatt coal-fired White Stallion Energy Center to withdraw 8.3 billion gallons (25,000 acre-feet) of water annually from the state's Lower Colorado River (SCOT 2011). And Arizona's public utility commission ruled that a proposed 340-megawatt concentrating solar power plant in Mohave County must use dry cooling or treated wastewater rather than 780 million gallons (2,400 acre-feet) of groundwater annually from the Hualapai Valley Aquifer (ACC 2010). We can expect to see more such collisions.

The contest over water extends to the production of fuels for power plants as well (see Box 2, p. 23). In Colorado and elsewhere, the purchase by the hydraulic fracturing (hydrofracking) industry of water rights for gas and oil extraction has prompted concern about the impact on farmers (Burke 2013; Finley 2012; Healy 2012). Almost half of all hydrofracking is occurring in regions with high or extremely high water stress, including Texas and Colorado (Ceres 2013a). And even in water-rich Pennsylvania, the Susquehanna River Basin Commission temporarily suspended water withdrawals for hydrofracking of natural gas in summer 2012 because of low stream levels (SRBC 2012).

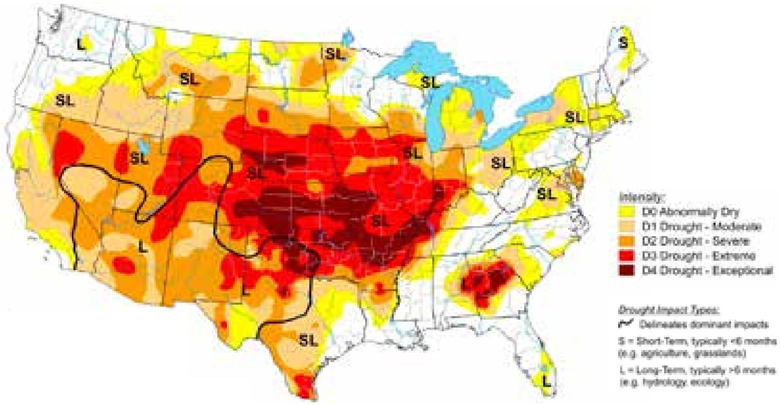
## Climate Complications Today and Tomorrow

An assortment of meteorological conditions led to 2012's punishing heat, drought, and storms. But many of the incidents bear connections to longer-term climate change trends. Climate change projections point to increases in average temperatures as well as extreme heat in most regions, an intensification of droughts, especially in the Southwest and Great Plains, and reductions in water availability in the Southwest and Southeast (Dai 2013; Kunkel et al. 2013a; Hoerling et al. 2012a).[6] Meanwhile some regions such as the Northeast and Midwest are expected to see more precipitation, delivered through extreme rainfall events that occur more often (Bales et al. 2013; Kunkel et al. 2013b).

Regional trends toward higher temperatures, more intense precipitation, longer and more persistent drought, and other extremes offer strong evidence that the climate is already changing, both globally and in the United States (IPCC 2012; Karl et al. 2009). The first decade of the twenty-first century was the hottest on record globally. The 10 hottest years on record worldwide have all occurred in the last 15 years (NCDC 2013; NOAA 2012). Average temperatures have risen 0.3°F to 0.45°F (0.17°C to 0.25°C) each decade since the late 1970s (EPA 2013b).

Nationally, the 2012 drought was the worst in half a century, with more than 60 percent of the continental United States suffering from moderate to exceptional drought (Freedman 2012) (see Figure 2). In the summer of 2011, Texas suffered from the driest 10 months since recordkeeping began in 1895 (LCRA 2011). And research shows that human activities have already increased the probability of extreme heat events like that of 2011, and exacerbated drought intensity (Hoerling et al. 2012b; Weiss, Overpeck, and Cole 2012).

6 The changes outlined in this section are projected to be similar over the next several decades under both higher and lower greenhouse gas emissions scenarios; greater differences between scenarios become apparent in the second half of the century (Kunkel et al. 2013a).




Source: Drought Monitor map from August 21, 2012. The U.S. Drought Monitor is produced in partnership between the National Drought Mitigation Center at the University of Nebraska–Lincoln, the United States Department of Agriculture, and the National Oceanic and Atmospheric Administration. Map courtesy of NDMC-UNL.

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**FIGURE 2. Dry Times, Present and Future**

**Severe to exceptional drought stressed vast areas of the nation in summer 2012, affecting water-dependent sectors from agriculture to electricity. With more drought anticipated for many regions in the decades ahead, heavy water dependence could become a significant liability in any sector.**

Stream flows in major Southwest rivers were 5 percent to nearly 40 percent lower from 2001 to 2010 than average twentieth-century flows (Hoerling et al. 2012c; Rousseau 2012). Indeed, tree ring data suggest that the western United States had the driest conditions in 800 years over the last decade (Schwalm et al. 2012). Meanwhile the region's population is growing rapidly.

In the Southwest, the vast majority of water withdrawn is used to irrigate arid agricultural lands (Kenny et al. 2009). The region's water supply depends heavily on snowpack, which melts in spring, supplying water to streams and reservoirs. Yet snowpack and stream flow are declining (Hoerling et al. 2012c; Overpeck and Udall 2010). Snowpack has been melting ever earlier over the past 50 years, so most of each year's stream flow is arriving earlier—a shift attributed partly to climate change (Garfin 2012; Hidalgo et al. 2009; Pierce et al. 2008; Stewart, Cayan, and Dettinger 2005).[7]


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***Water pressure in the Southeast.*** **In the Southeast, a region prone to short (one- to three-year) droughts, rapid growth in population and water demand has increased the region's vulnerability to drought conditions. Relative to their western counterparts, Southeast reservoirs are small, often holding reserves for just a year. In this context, decisions over water can have major consequences, including for cities like Atlanta, which depends on water from Georgia's Lake Lanier, shown here during the 2007–2008 drought. Concerns about drought made control over the water in Lake Lanier a factor in federal lawsuits between multiple Southeast states.**

In the Southeast, average annual temperatures have been rising steadily in recent decades, with 2001 to 2010 the warmest on record.[8] Summers in the region have shifted toward the hydrological extremes: either very dry or very wet compared with the middle of the twentieth century (Kunkel et al. 2013a; Wang et al. 2010). In a region where thermoelectric power plants account for more than two-thirds of water withdrawals, states are in continual conflict over water use, creating demand-driven drought conditions in some areas (Georgakakos, Zhang, and Yao 2010; Kenny et al. 2009). And unlike in the Southwest, Southeast reservoirs typically have the capacity to store just a single year's water use, making the water supply vulnerable to both short-term and long-term changes (Ingram, Dow, and Carter 2012).

7 Scientists have attributed up to 60 percent of the change in arrival time to rising concentrations of heat-trapping gases in the atmosphere (Garfin 2012).

8 Recent warming in the Southeast (2°F [1.1°C] since 1970) follows a cool period in the 1960s and 1970s, and substantial variability in the first half of the twenty-first century (Kunkel et al. 2013a).

Compared with recent averages, temperatures are projected to rise another 2.5° F to 5.5° F (1.4° C to 3.1° C) in most regions of the United States by mid-century (Kunkel et al. 2013a). In that time frame, parts of the Southeast, Southwest, and South Central U.S. can expect an additional 25 days above 95° F each year, on average (Kunkel et al. 2013a). As warming shifts historic patterns of precipitation, hydrology will become more variable and prone to extremes. Extreme heat events and droughts are expected to become more intense in many regions, especially the Southwest and Great Plains (Cayan et al. 2013; Dai 2013; Kunkel et al. 2013a; Hoerling et al. 2012a; Hoerling et al. 2012c).

Rising temperatures and changes in precipitation mean that less water would be available in the Southwest and Southeast over the longer term (Kunkel et al. 2013a; Caldwell et al. 2012). In the Southeast, scientists expect the net water supply to decline by 2060 while population and demand rise, worsening water stress and affecting wildlife in some of the nation's most sensitive and biologically diverse rivers (Kunkel et al. 2013a; Caldwell et al. 2012; U.S. Census Bureau 2010).[9]

For many major Southwest cities, water supply challenges are highly likely in the decades ahead even *without* climate change (Figure 3).[10] Yet a changing climate is expected to intensify Southwest drought and lower both surface and groundwater levels significantly (Kunkel et al. 2013a; Overpeck and Udall 2010). Climate scientists also project further drops in late winter and spring snowpack and subsequent reductions in runoff and soil moisture, which are vital to regional reservoirs (Cayan et al. 2010; Cayan et al. 2008; Christensen and Lettenmaier 2007).

Given continued high carbon emissions, California's "snow water equivalent"—the depth of water if snowpack were melted—is projected to drop nearly 60 percent by 2099. And scientists expect Arizona's snow water equivalent to decline by nearly 90 percent, and Colorado's—which supplies water to much of the region—by more than 25 percent.[11] Along with rising population, those changes would deeply compromise the ability of the water supply—already scarce and overallocated—to meet the needs of power plants as well as Southwest cities, agriculture, and ecosystems.

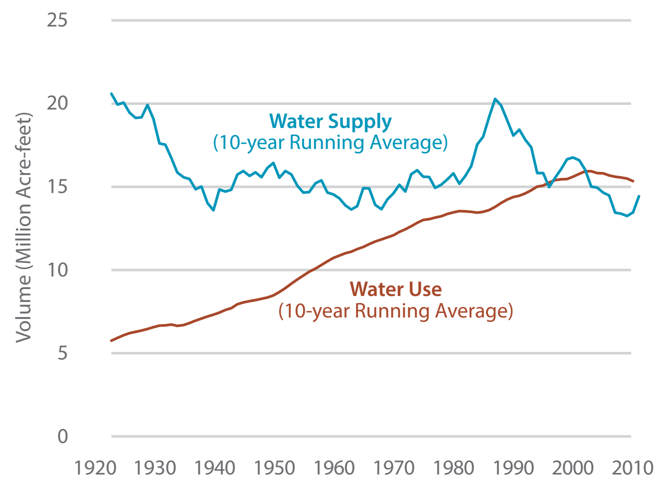



**FIGURE 3. Water Supply versus Water Demand in the Colorado River Basin**

**Over the last century, the natural flow of the Colorado River has averaged roughly 16 million acre-feet (5 trillion gallons) per year. However, water use in the basin has risen over time, while water supply has been dropping because of drought. Rising demand for water has been met through drawdowns of water stored in reservoirs such as Lake Mead and Lake Powell.**[12] Source: USBR 2012.

9 These declines are expected to be strongest in the subregion spanning Georgia, Alabama, Tennessee, Mississippi, Louisiana, and Texas. Parts of the East Coast may see some increases in precipitation (Kunkel et al. 2013a; Caldwell et al. 2012). During periods of extreme heat and drought, high river temperatures can combine with thermal discharges to reduce dissolved oxygen and the capacity of streams to absorb waste (Kunkel et al. 2013a).

10 The probability of conflicts reflects several factors, including population growth and the water requirements of endangered species. Multiple locations throughout the Southwest are considered "substantially likely" or "highly likely" to see water conflicts by 2025, even without the effects of climate change (USGCRP 2009; USBR 2005).

11 California, Nevada, Utah, Colorado, Arizona, and New Mexico are projected to see marked reductions in snow water equivalent. Declining precipitation is the cause in some cases, and a shift toward more rain and less snow in others (Cayan et al. 2013).

12 Total use of water throughout the basin includes agricultural, municipal, industrial, and other consumptive uses (including flows to Mexico), plus use by vegetation and losses through evaporation at mainstream reservoirs. Natural flow is used to estimate water supply in the basin. In the current natural flow record, historical inflows based on U.S. Geological Survey gauged records are used to estimate the natural flow for the Paria, Little Colorado, Virgin, and Bill Williams rivers, without adjusting for upstream water use. However, the Gila River is not included in the natural flow record. Therefore, the use reported here excludes consumptive uses on these tributaries.

CHAPTER 3

# Pivot Point for U.S. Power

### *KEY FINDINGS*

- **The U.S. power sector is undergoing rapid transformation.** The biggest shift in capacity and fuel in half a century is under way, as electricity from coal plants shrinks and power from natural gas and renewables grows. Several factors are spurring this transition to a new mix of technologies and fuels. They include the advanced age of many power plants, expanding domestic gas supplies and low natural gas prices, state renewable energy and efficiency policies, new federal air-quality regulations, and the relative costs and risks of coal-fired and nuclear energy.
- **This presents an opportunity we cannot afford to miss.** Decisions about which power plants to retrofit or retire and which kind to build have both near-term and long-term implications, given the long lifetimes of power plants, their carbon emissions, and their water needs. Even a single average new coal plant could emit 150 million tons of carbon dioxide over 40 years—twice as much as a natural gas plant, and more than 20 million cars emit each year. Power plants that need cooling water will be at risk over their long lifetimes from declining water availability and rising water temperatures stemming from climate change, extreme weather events, and competition from other users. And power plants, in turn, will exacerbate the water risks of other users.

## Change Is Under Way

In 2007, the U.S. electricity sector still pointed strongly toward more coal-fired power. The industry was proposing to construct 159 new coal-fired plants, or 96,000 megawatts of new capacity—a 29 percent increase over existing coal capacity (Shuster 2007). The Energy Information Administration (EIA) projected that electricity's fuel mix would persist largely unchanged through 2035 (EIA 2007).

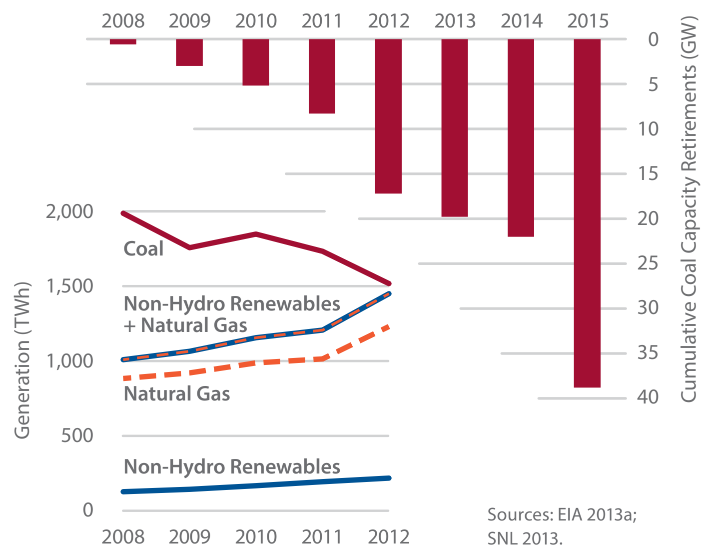



**FIGURE 4. Electricity Sector in Transition: The U.S. Electricity Mix and Retiring Coal Plants**

**Growing amounts of power from natural gas and non-hydro renewables—along with declining amounts of power from coal plants—have challenged coal's dominance in the U.S. electricity mix (left axis). In 2008, coal supplied almost half of U.S. electricity. By 2012, that share had dropped to 37 percent, while natural gas and renewable energy together supplied more than 35 percent. Tens of thousands of megawatts of coal generators are slated for retirement, unable to compete economically (right axis). (TWh = terawatt-hours, or million megawatt-hours; GW = gigawatts, or thousands of megawatts)**

But the picture quickly began to change dramatically. Coal shrank from fueling nearly half of U.S. power production in 2008 to 37 percent in 2012 (Figure 4) (EIA 2013a). By early 2013, plant owners had announced plans to retire almost 50,000 megawatts of coal plants—14 percent of the U.S. coal fleet—and another 52,000 megawatts were economically vulnerable (UCS 2013).

Meanwhile, electricity fueled by natural gas rose from 21 percent to 30 percent of the U.S. mix from 2008 to 2012, while power from non-hydro renewables such as wind and solar grew from 3.1 percent to

## BOX 1. *Energy Technology Transitions*

**Natural gas.** A significant expansion of U.S. natural gas production is driving changes in the mix of fuels used to generate power. Industry's use of horizontal drilling and hydraulic fracturing (hydrofracking) to tap the gas in deep shale formations had begun to expand domestic supplies by 2010. By 2012, U.S. natural gas production had climbed 34 percent from 2005 levels (EIA 2013b). That increase—along with weaker demand and some warmer winters—brought natural gas prices to near-record lows (EIA 2013c).

**Renewable energy.** State and federal renewable electricity policies, and a recent decline in the cost of wind and solar power, have accelerated the growth of renewable energy. The U.S. wind energy industry had installed more than 40,000 turbines, capable of supplying 60,000 megawatts, by the end of 2012 (AWEA 2013). Wind power accounted for more than 35 percent of all new capacity installed from 2008 to 2012—more than nuclear and coal combined (AWEA 2013). Meanwhile the U.S. solar industry installed 76 percent more capacity in 2012 than it had in 2011, and total solar capacity expanded by a factor of five from 2009 to 2012 (SEIA 2013).

**Coal.** While natural gas costs plummeted, coal prices rose by 31 percent from 2007 to 2011 because of rising production and transportation costs (EIA 2012). Although prices have recently dropped, coal producers using mountaintop removal are facing more stringent regulations designed to protect local streams, water quality, and public health (EIA 2013d; Hitt 2013; U.S. ACE 2012; EPA 2011b). Meanwhile the average age[13] of the U.S. coal fleet is 42 years, and many older plants are inefficient (SNL Financial 2013). The federal government has also taken steps to cut air pollution and reduce the public health effects from coal-fired plants, and carbon dioxide emissions from new power plants, so operators are facing new costs (EPA 2012a; EPA 2012b).

**Nuclear.** While calls for more low-carbon electricity several years ago led to predictions of a nuclear renaissance, the sector has struggled. High costs have plagued nuclear energy for decades (McMahon 2012; Madsen, Neumann, and Rusch 2009). The 2011 Fukushima Daiichi disaster in Japan, leaks of radioactive steam that led to the shutdown of California's San Onofre plant, and other incidents also dampened enthusiasm for a nuclear renaissance (Lee 2013; Nuclear Regulatory Commission 2012b). Few nuclear projects are moving forward in 2013, and some plants are being retired, including San Onofre (EIA 2013e; SCE 2013).

13 That is, the capacity-weighted mean.

5.4 percent (EIA 2013a). These changes are being driven by the advanced age of many power plants; a significant expansion of U.S. natural gas production; low natural gas prices; state renewable energy, energy efficiency, and climate policies; new federal air-quality regulations; and the costs and risks of coal-fired and nuclear energy (see Box 1). Coal's dominance seems likely to continue to wane as operators retire more coal plants, given pressure to upgrade pollution controls and competition from other power sources (Cusick 2013).



***Energy-water-climate tradeoffs.*** **The links among electricity, water, and climate are complex. Recirculating cooling systems require much less water than circulating systems, and dry cooling requires no water. Yet both are less energy-efficient, so they release more carbon emissions for a given amount of electricity. Nuclear plants have no emissions but are water-intensive. Carbon capture and storage projects, as at the Barry plant near Mobile, AL, pictured here, can store some of the carbon emissions from coal plants deep underground. However, that technology also makes power production less efficient, and increases water consumption by 45 percent to 90 percent (Macknick et al. 2012a).**

## Building the Electricity System of the Twenty-first Century

These rapid changes give us the opportunity to put the United States on a pathway that lowers carbon emissions from the electricity sector while curbing energy-water collisions. Power plant owners, developers, regulators, and legislators are making critical choices now about our nation's electricity mix in coming decades. For improved resilience of long-lived power projects and the sector as a whole, these decision makers will need to consider the impact of climate change, greater hydrologic variability, higher peak electricity demand, and the need to swiftly and deeply cut carbon emissions.

To analyze the impact of various options for our electricity future on water withdrawals and consumption, carbon emissions, and electricity and natural gas prices, we focused on several key scenarios. The first—"business as usual"—assumed an electricity mix based on existing state and federal policies and the costs of various technologies.[14]

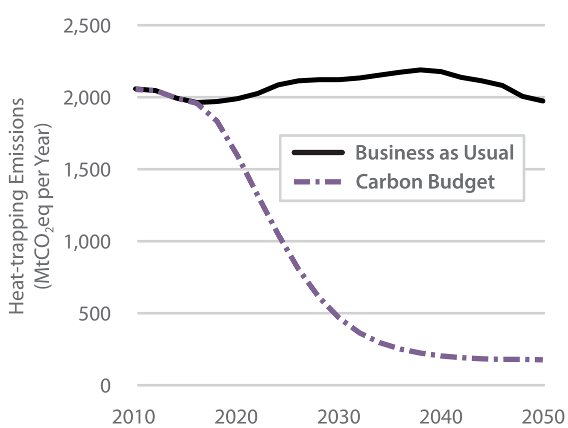



**FIGURE 5. A Carbon Budget for the U.S. Electricity Sector**

**Under a business-as-usual electricity pathway, U.S. power plant carbon emissions would stay near today's levels for decades. Under an economy-wide carbon budget to cut emissions 80 percent by 2050, the electricity sector could account for three-quarters of the needed cuts from 2010 to 2050, given available technology options (National Research Council 2010; Fawcett et al. 2009). ($MtCO_2eq$ = million tons of carbon dioxide equivalent)**

Source: Clemmer et al. 2013.


***How renewable energy stacks up, water-wise.*** **Some renewable energy technologies, such as wind turbines and solar photovoltaics, use essentially no water and produce no carbon. Others, such as geothermal, biomass, and concentrating solar power plants, use steam processes to generate electricity, and may use water to cool that steam. Such plants can more readily use dry cooling, though, or produce water that can be used for cooling (geothermal).**

We analyzed three other scenarios that reflect the power sector component of an economy-wide carbon budget to achieve 80 percent lower emissions in 2050 than in 1990, as a budget that has a reasonable chance of limiting global heat-trapping emissions to 450 parts per million (National Research Council 2010).[15] Three-quarters of cuts in such emissions would come from the electricity sector, according to studies by the Stanford Energy Modeling Forum and National Research Council, because it has more near-term opportunities (Figure 5) (Clemmer et al. 2013; Fawcett et al. 2009).

We focused two of our three carbon budget scenarios on particular energy technologies. One assumed aggressive deployment of renewable energy and energy efficiency technologies. Another assumed high levels of coal use with carbon capture and storage (CCS)—to reduce heat-trapping emissions from coal plants—and nuclear energy. (The third scenario included the carbon budget but did not specify particular technologies. We focused much of our analysis on the first two.)

14 We patterned this scenario after the reference case in the EIA's *Annual Energy Outlook* for 2011 (EIA 2011).

15 Four hundred and fifty parts per million is the level projected to provide a roughly 50 percent chance of keeping the global average temperature from rising more than 3.6° F (2° C) above pre-industrial levels (Luers et al. 2007).

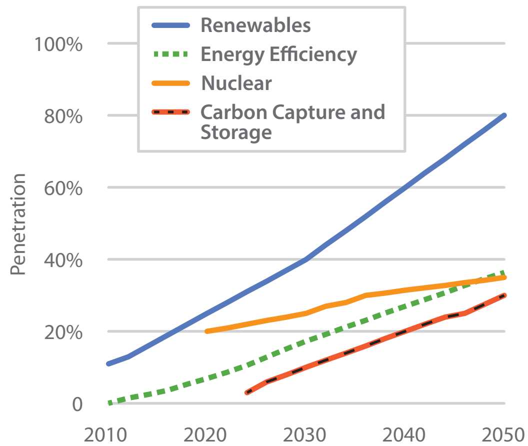



**FIGURE 6. Technology Targets for the Electricity Sector**

**Our modeling included aggressive targets for technologies that could provide the largest cuts in carbon emissions over the next 40 years, according to numerous studies. Under a scenario that emphasized renewable energy and efficiency, for example, we assumed that energy-efficient technologies and buildings would reduce U.S. electricity use by about 1 percent per year on average, and that electricity generation from renewable energy technologies would grow from about 10 percent in 2010 to 50 percent in 2035 and 80 percent by 2050.**

Source: Clemmer et al. 2013.

We chose these energy pathways to accentuate differences in water withdrawals and consumption. Under the business-as-usual case, the electricity sector remains heavily dependent on fossil fuels, which tend to use water for cooling. Under the renewables-and-efficiency scenario, while some renewable sources such as geothermal, biomass, and concentrating solar can be water-intensive, most of the electricity demand could be met with technologies that use little or no water. Under the CCS-and-nuclear scenario, electricity comes mostly from technologies that require large amounts of water.

Our carbon budget scenarios include technology mixes that are within the range of those of other analyses, although at or near the upper end for each technology (Figure 6) (Clemmer et al. 2013). We drew assumptions about the cost and performance of different technologies primarily from the EIA's *Annual Energy Outlook,* updated with data on recent projects (Clemmer et al. 2013). We also used the EIA's projections for growth in electricity demand by 2035, extrapolated to 2050.

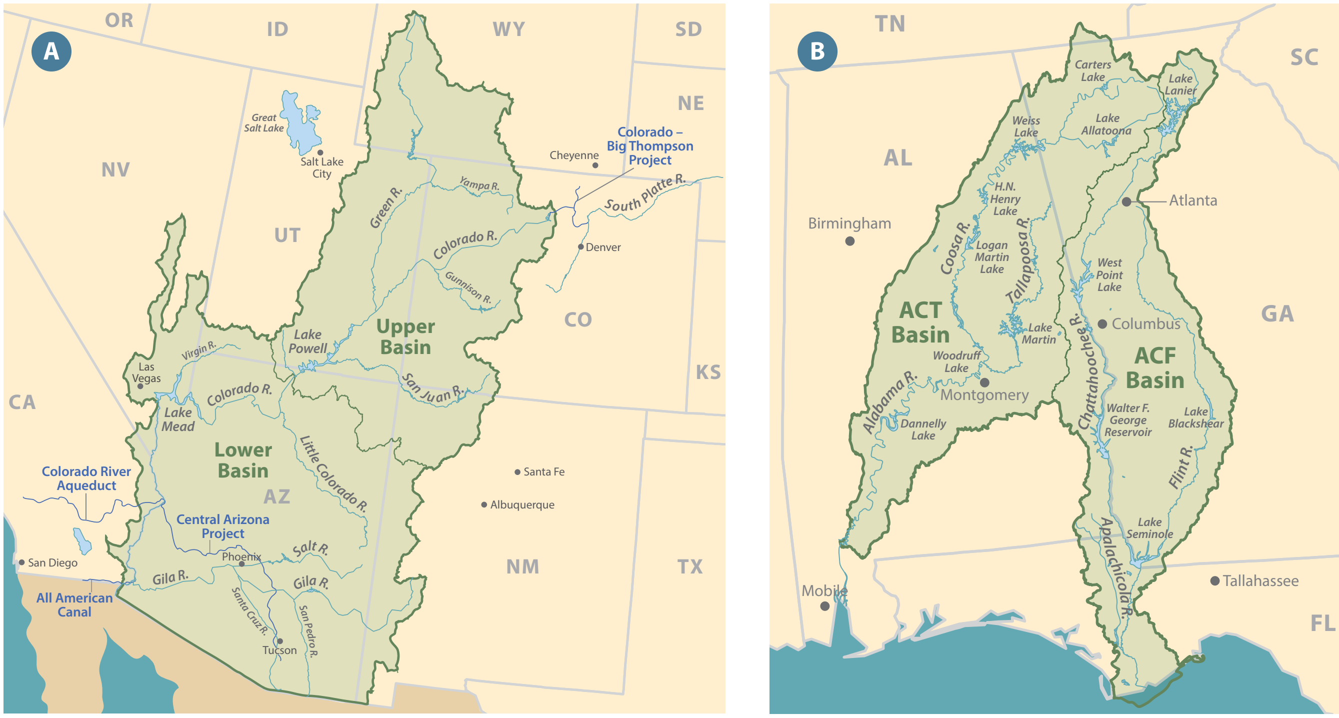
**For improved resilience of long-lived power projects, decision makers will need to consider the impact of climate change, greater hydrologic variability, higher peak electricity demand, and the need to swiftly and deeply cut carbon emissions.**

## Focusing on Two Vulnerable Regions

Beyond our national and general regional analyses, we also explored how various power plant choices interact with water supply and demand in particular water basins (river systems) in the Southeast and Southwest. Both regions have seen energy-water conflicts, though for different primary reasons—water scarcity in the Southwest, and high water temperatures in the Southeast.

As noted, the Southwest is facing rapid population growth and rising electricity demand while water resources are declining (Kunkel et al. 2013a). In that region, our modeling focused on the surface and groundwater systems in the Colorado River Basin and related areas, including the Upper and Lower Colorado rivers, the Rio Grande, and—given long-distance transport of water in the region—Northern and Southern California (Figure 7A).

The Southeast is also seeing rapid population growth, and is vulnerable to rising temperatures and declining water availability in coming decades (Ingram, Dow, and Carter 2012). In that region, we focused on the Alabama-Coosa-Tallapoosa (ACT) and the Apalachicola-Chattahoochee-Flint (ACF) basins in Georgia, Alabama, and the Florida Panhandle (Figure 7B). Those states have fought over water from the two basins, particularly in times of water stress (Yates et al. 2013a).




## FIGURE 7. Electricity-Water Challenges in Two Regions

**Electricity-water challenges differ by region. In the Southwest (A), including the Colorado River Basin, population and electricity demand are rising but water resources—already overallocated—are declining. In the Southeast (B), including the Alabama-Coosa-Tallapoosa (ACT) Basin and the Apalachicola-Chattahoochee-Flint (ACF) Basin, the coming decades may bring rapid population growth, rising temperatures, and declines in available water. Alabama, Georgia, and Florida have already seen contests over water, particularly during times of water stress.**

## Our Innovative Approach to Modeling

Our innovative approach to exploring the water implications of electricity choices entailed pairing two models—one on electricity and one on water—and feeding in our range of scenarios. The first model is the Regional Energy Deployment System (ReEDS) of the National Renewable Energy Laboratory. ReEDS allowed us to analyze power generation by fuel type for 134 regions around the country—a much finer degree of geographic resolution than other models.

The second model is the Water Evaluation and Planning (WEAP) system of the Stockholm Environment Institute, which allowed us to analyze water withdrawals and consumption in the power sector based on results from ReEDS. WEAP uses climate-driven simulations of water supply and detailed descriptions of water demand to capture both basin-wide and local tradeoffs amid changing water conditions.

In both the WEAP analyses and higher-level (national and regional) results, we based water use on published information for various combinations of power plant fuels and cooling technologies (Macknick et al. 2012a).[16]

For our two key regions, we fed results from ReEDS into new WEAP-based models of the target river basins (Sattler et al. 2013). We based precipitation on dry sequences of years from recent history (Flores-Lopez and Yates 2013; Yates et al. 2013b). We also assumed that air temperatures would rise by 3.6°F (2°C)

16 We used the median values for withdrawal and consumption for each combination (Macknick et al. 2012a). We incorporated only water use at power plants, chiefly for cooling. We did not include water withdrawals or consumption associated with hydroelectric facilities, which can be more challenging to calculate because of, for example, the multiple uses of reservoirs in addition to power generation (Averyt et al. 2011). The ReEDS model covers the 48 contiguous states, so calculations do not include Alaska and Hawaii.

between 2010 and 2050 (Flores-Lopez and Yates 2013; Yates et al. 2013b), consistent with projections used in the National Climate Assessment (Kunkel et al. 2013a).

Our approach also included several other notable aspects:

- We focused on the impact of water use for cooling power plants—only a subset of the water implications of electricity choices. Other aspects of these choices could also have important water-related effects, such as the use of hydraulic fracturing to extract natural gas.
- Climate change will likely increase peak power demand, as hotter days drive more use of air conditioning, for example. The EIA projections for electricity demand that we draw on do not take that into account.
- While decision makers shaping our electricity future should consider the availability of water for power, our modeling treated water dimensions solely as outputs, not inputs.
- We assumed that the water efficiencies of various technologies—that is, water use per unit of electricity—would not change over time. In reality, the efficiencies of established fossil fuel, nuclear, and renewable technologies, and newer technologies such as CCS, may improve.
- Our modeling does not take into account that other water users may change their behavior in response to changing water conditions, or that users of electricity may change their habits based on higher or lower prices.
- Our modeling provides monthly averages for water use and effects. However, changes over shorter periods of time could prove important in energy-water collisions. We also used average figures for power production at various points during each year, which may not capture potentially important periods of peak demand. In analyzing water temperatures, we applied any average/monthly result below a certain threshold (90° F, or 32° C) to the whole month, and any result above that threshold to the whole month.

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***Linking electricity modeling and water modeling.*** **Our innovative approach to analyzing electricity and water links national- and regional-scale modeling to modeling at scales that matter from a water perspective: river basins and sub-basins. The Colorado River, pictured here, is one of three basins we modeled.**

CHAPTER 4

# Findings: The Impact of Power Pathways on Water

### *KEY FINDINGS*

- **Business as usual in the power sector would fail to reduce carbon emissions, and would not tap opportunities to safeguard water.** Because such a pathway for meeting future electricity needs would not cut carbon emissions, it would do nothing to address the impact of climate change on water. Changes in the power plant fleet would mean that water withdrawals by power plants would drop, yet plants' water consumption would not decline for decades, and then only slowly. The harmful effects of power plants on water temperatures in lakes and rivers might continue unabated, or even worsen. Greater extraction of fossil fuels for power plants would also affect water use and quality.
- **Low-carbon pathways can be water-smart.** A pathway focused on renewable energy and energy efficiency, we found, could deeply cut both carbon emissions and water effects from the power sector. Water withdrawals would drop 97 percent by 2050—much more than under business as usual. They would also drop faster, with 2030 withdrawals only half those under business as usual. And water consumption would decline 85 percent by 2050. This pathway could also curb local increases in water temperature from a warming climate. Meanwhile lower carbon emissions would help slow the pace and reduce the severity of climate change, including its long-term effects on water quantity and quality.
- **However, low-carbon power is not necessarily water-smart.** The menu of technologies qualifying as low-carbon is long, and includes some with substantial water needs. Electricity mixes that emphasize carbon capture and storage for coal plants, nuclear energy, or even water-cooled renewables such as some geothermal, biomass, or concentrating solar could worsen rather than lessen the sector's effects on water.
- **Renewables and energy efficiency can be a winning combination.** This scenario would be most effective in reducing carbon emissions, pressure on water resources, and electricity bills. Energy efficiency efforts could more than meet growth in demand for electricity, and renewable energy could supply 80 percent of the remaining demand. Although other low-carbon paths could rival this one in cutting water withdrawals and consumption, it would edge ahead in reducing groundwater use in the Southwest, improving river flows in the Southeast, and moderating high river temperatures. This scenario could also provide the lowest costs to consumers, with consumer electricity bills almost one-third lower than under business as usual.

**The most serious critique of a business-as-usual pathway is that it would do little or nothing to reduce the power sector's carbon emissions.**

## Business as Usual: Good, Bad, and Ugly

Even under the business-as-usual pathway, we found the electricity mix would change drastically over the next several decades, consistent with the rapid transformation now under way. Power production from coal would shrink significantly, based on plant retirements that have already been announced and continued pressure from low natural gas prices, federal air-quality and other regulations, and clean energy policies.[17]

17 Except where otherwise noted, electricity results are drawn from Clemmer et al. 2013 and related research.

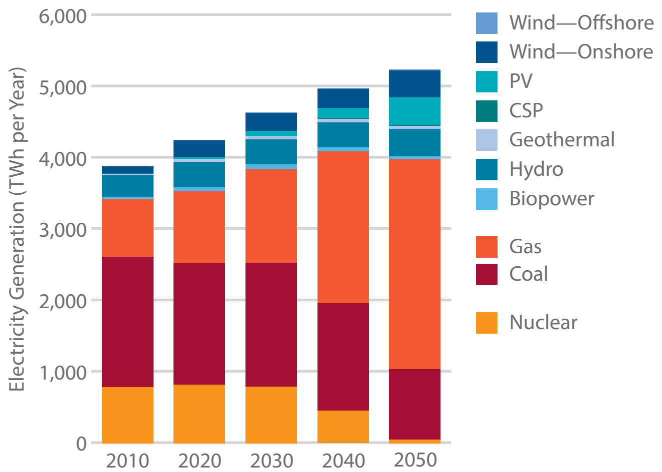



**FIGURE 8. U.S. Electricity Mix under Business as Usual, 2010–2050**

**The electricity mix would change markedly over the next several decades under a business-as-usual pathway, given the rapid transformation already under way. Coal power would drop significantly, based on coal plant retirements that have already been announced, pressure from low natural gas prices, and state and federal policies to protect public health and drive energy innovation. Nuclear power would disappear, as existing plants reach the end of their lives and new reactors would be unable to compete economically. Natural gas would dominate the electricity mix, supplying almost 60 percent of U.S. power by 2050. (PV = solar photovoltaics; CSP = concentrating solar power)** Source: Clemmer et al. 2013.

Nuclear-powered electricity would stay near today's levels for two decades, then steadily fall to nearly zero by 2050, as existing nuclear plants reach the end of their assumed 60-year lives and new nuclear reactors would be unable to compete economically. Natural gas would dominate the electricity mix, supplying almost 60 percent of the nation's power by 2050 (Figure 8).[18]

The most serious critique of a business-as-usual pathway is that it would do little or nothing to reduce the power sector's carbon emissions, because of continued use of fossil fuels and rising demand. Emissions would stay within 5 percent of today's levels through 2050, according to our modeling. The EIA similarly projects that electricity-related carbon emissions under a business-as-usual scenario would not drop, and would indeed rise 12 percent above 2012 levels by 2040 (EIA 2013f). Climate change would continue relatively unabated, with commensurate effects on water availability, air and water temperatures, and demand for water and electricity.

A business-as usual pathway would have some positive effects on water use by power plants but many negative effects. Virtually all plants cooled by once-through systems would be among the plants that our modeling predicted would be retired based on costs. New power facilities would be more efficient, and would use recirculating or dry cooling. In fact, freshwater withdrawals would drop more than 80 percent from today's levels by 2050, and water consumption more than 40 percent, under our business-as usual case.[19] Reductions on that scale would, at face value, strengthen the power sector's ability to cope with changes in water availability and temperature while easing pressure on water resources.

However, a business-as-usual trajectory would bring familiar problems—and new ones—at national, regional, and local levels.

**National.** Water withdrawals for power plants would drop under a business-as-usual scenario—but only slowly until around 2030.[20] Water consumption would stay basically unchanged for two decades before finally dropping. Neither trajectory would position the power plant fleet to perform well if a deep drought hit before 2030. Even by 2050, water consumption would fall by less than half, prolonging the power sector's exposure to water risks (Figure 9).

We prioritized retirement of plants with once-through cooling, so our modeling produced relatively steep reductions in water use. Other analyses project less encouraging water trends. A study from the National Energy Technology Laboratory, for example, found that freshwater consumption in the power sector would rise

18 We used EIA assumptions about natural gas supply and prices, extrapolated to 2050 (Clemmer et al. 2013).

19 Water results here and following consider the use of freshwater sources, defined in this report as all non-ocean sources.

20 Except where otherwise noted, large-scale water results are drawn from Macknick et al. 2013b and related research.

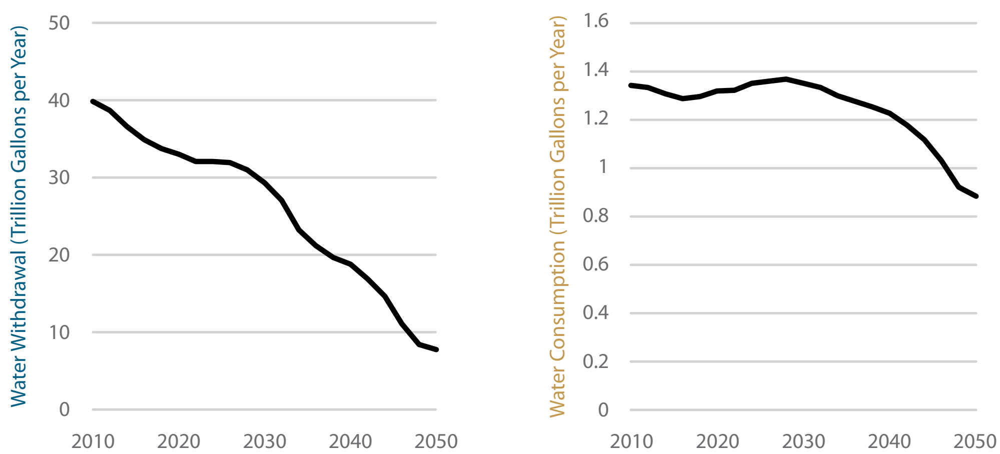



**FIGURE 9. Power Plant Water Use under Business as Usual, 2010–2050**

**Water use by power plants would fall substantially from today's levels by 2050 under business as usual, given changes in the electricity mix. Withdrawals (left) would drop more than 80 percent, and consumption (right) more than 40 percent. Yet withdrawals would decline only slowly until around 2030, and consumption would stay basically unchanged for decades. Against a backdrop of growing population and water constraints, these trajectories are arguably too little, too late. (1 trillion gallons = 3 million acre-feet)** Source: Macknick et al. 2012b.

Note: Projections shown here and in later figures incorporate median water-use values from Macknick et al. 2012a, and include freshwater (non-ocean water) only.

between 16 percent and 29 percent from 2005 to 2030 (NETL 2009a).

Another study projected that water consumption by power plants would increase between 36 percent and 43 percent from 1995 to 2035 (Tidwell et al. 2012). That growth would occur chiefly in water basins with rapidly growing demand outside the power sector. And 10 percent to 19 percent of all new thermoelectric power production would likely occur in "watersheds with limited surface and/or groundwater availability," the study reported.

**Regional.** Under the business-as-usual case, withdrawals in the Southeast, Midwest, and Northeast would largely track the national decline, as their larger numbers of once-through-cooled plants are retired. In the Southwest, Texas, and the Great Plains, withdrawals would drop much less than at the national level by 2050—in the Southwest by only one-third.

In the Southeast and elsewhere, water consumption by power plants would eventually drop—in the Southeast by a third. Consumption would drop only half as much in the Southwest, though, because of continued use of existing coal plants.

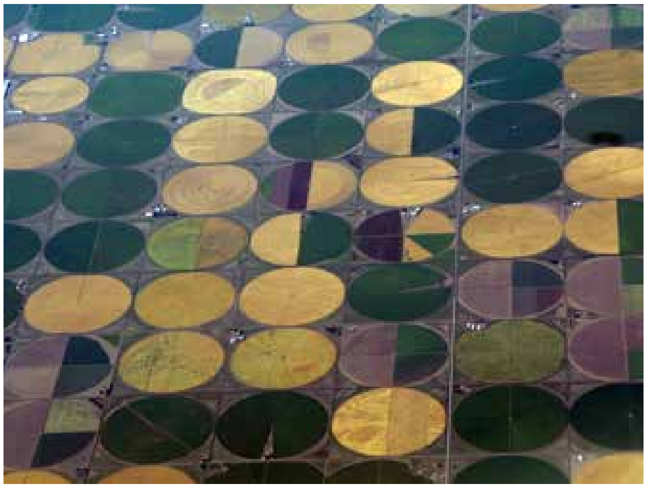
A study of power plant water use in the Great Lakes region found that a business-as-usual pathway would actually lead to a 10 percent increase in water withdrawals and consumption (Moore, Tidwell, and Pebbles 2013). And power plants already account for 76 percent of withdrawals and 13 percent of consumption in that region, according to that study.

**Local.** To gauge the local impact of power production, we looked at how often river temperatures might exceed a 90°F (32°C) threshold for thermal pollution in select locations.[21] On the Coosa River, power plants above Weiss Lake on the Alabama-Georgia border—such as the 950-megawatt Plant Hammond coal facility, which uses once-through cooling—affect the temperature of the river.[22] Under a business-as-usual scenario, river temperatures from 2040 to 2049 would exceed 90°F (32°C) 18 days per year, on average—three times the number from 2010 to 2019.[23]

21 At least 14 states prohibit water discharges above 90°F (32°C) to avoid harm to fish and other wildlife (Madden, Lewis, and Davis 2013; EPA 2011d; Beitinger et al. 1999).

22 Except where otherwise noted, Southeast water results are drawn from Yates et al. 2013a and related research.

23 We assumed no changes in operation of the power plants or management of the river because of higher temperatures. Such changes could include the use of portable cooling towers, which occurred at Plant Hammond in 2007 (Cheek and Evans 2008).



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***Winners and losers.*** **If power plants need more water and can secure it (by paying more, for example), or if they do not cut their use when supplies drop, the amount available for other uses such as agriculture will shrink. Take Colorado's South Platte basin. Under business as usual, 16 percent less water would be available for agriculture in summer in the 2040-to-2049 decade versus 2010 to 2019—with drought the dominant cause. An electricity mix that uses less water could reduce some of those losses. The renewables-and-efficiency scenario could provide billions more gallons (tens of thousands of acre-feet) of water each year to agriculture from 2040 to 2049.**

If power plant operators do not cut back production in the face of drops in the water supply, and they command priority access to the water, the amount available for other uses will drop. This effect is most evident in agriculture. Under business as usual in the South Platte Basin that includes the Denver metropolitan area, for example, 16 percent less water would be available for agriculture in summer from 2040 to 2049 than from 2010 to 2019, on average.[24]

Continued reliance on water-using power plants could also steepen declines in the amount of water stored in reservoirs and flowing in rivers. Under our business-as-usual case, the amount of water stored in Lake Mead in Nevada and Arizona, and Lake Powell in Utah and Arizona, for example, would be only 50 percent of the long-term historical average (1971–2007) by 2050, and the 2040–2049 average would be one-third below the historical average (Yates et al. 2013a; NRCS 2008).[25] Average annual stream flow in the

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***Mighty reservoirs face mighty strain.*** **Lake Mead, the nation's largest reservoir, on the Arizona-Nevada border, and Lake Powell, in Arizona and Utah, play crucial roles in the Southwest economy. Together they hold the equivalent of three years of flow from the Colorado River, and provide multiyear water storage for five states (National Research Council 2007). Yet drought and water demand take their toll even on those large reservoirs. In November 2010, Lake Mead was just 41 percent full, and contained 4.5 trillion fewer gallons (14 million acre-feet) than in 1999, when it had last been nearly full.**

24 Agricultural users often hold the most senior water rights in states with "prior appropriation" laws, which include most western states. Under such laws, if water is scarce, those with more junior rights, including many power plant operators, must lease or purchase water from users with senior rights. Farmers often do sell water to plant operators in such situations, because doing so is lucrative for them.

25 Except where otherwise noted, Southwest water results are drawn from Yates, Meldrum, and Averyt 2013 and related research.

Alabama-Coosa-Tallapoosa Basin from 2040 to 2049 would be 24 percent below the historical average (1950 to 2010), and in the Apalachicola-Chattahoochee-Flint Basin by 17 percent. Such changes in stream flow could make a marked difference, even where water is relatively abundant.

Power plants that use a lot of water will face growing difficulty under a changing climate, particularly during periods of drought and high temperatures, as limited water availability and less effective cooling will make them less efficient and operations more challenging. A 2012 study by American and European researchers found that as temperatures steadily rise, power generation at existing thermoelectric power plants will decline, especially in summer and in the Southeast (Van Vliet et al. 2012). Power capacity would

## BOX 2. *The Impact of Hydrofracking on Water*

Natural gas combined-cycle power plants are much more thermally efficient than coal or nuclear plants—meaning they need less water for cooling. Such plants also have much less of an impact on the quality of the local water supply than coal or nuclear plants using the same cooling technologies.

However, continued ramp-up of hydrofracking could greatly diminish the net water advantages of power plants that use natural gas. While power plant water use is much larger per unit of electricity potentially generated using natural gas from hydrofracking, water quantity—and quality—issues are still important to consider, particularly in the vicinity of hydrofracking operations (Meldrum et al. 2013; Cooley and Donnelly 2012).

For example, the U.S. Environmental Protection Agency (EPA) estimates that some 35,000 hydrofracking wells used 70 billion to 140 billion gallons of water in 2011 (EPA 2011c).

Depending on the type of well and its depth and location, a single well can require 3 million to 12 million gallons of water when it is first drilled and fracked—many times the amount used in conventional vertical drilling (COGA 2013; Breitling Oil and Gas 2012; NETL 2009b). And operators use similar amounts of water each time they give a well a "work-over" to maintain pressure and gas production. A typical shale gas well will undergo two work-overs during its life span (NETL 2012).

Withdrawing these amounts of water over a short period of time can strain local water supplies, especially in arid and drought-prone regions in the West such as Texas. Hydrofracking for natural gas in Texas alone could require some 50 billion gallons of water in 2020 (Nicot and Scanlon 2012). And unlike much of the water withdrawn for cooling power plants, most water used for hydrofracking is not recoverable because it stays in the wells (EPA 2011c).

Hydrofracking can also affect water quality, because of improper well drilling and insufficient protection of drinking water aquifers (EPA 2012c). An EPA study identified more than 1,000 chemicals used in fracking (EPA 2012c). Many are considered harmless, but others, such as benzene, lead, and methanol, are toxic. A 2011 study identified another 29 of these chemicals as carcinogens (U.S. House of Representatives 2011). And a Cornell University study found that, of 353 chemicals used in hydrofracking and examined in the study, 25 percent cause cancer or other mutations, and about half could severely damage neurological, cardiovascular, endocrine, and immune systems (Colborn, Kwiatkowski, and Schultz 2011).

Industry attempts to reuse more water recovered from wells, or to use saline water rather than fresh, may lessen some of the effects of hydrofracking on both water quantity and quality (Ceres 2013a; EPA 2013c; Henrids 2012).

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***High water temperatures and low flows affect power plants.*** **As temperatures rise and water supplies shrink, the capacity and output of thermoelectric plants drop, especially in summer. The capacity of U.S. power plants is expected to decline further in the decades ahead. Those plants could include facilities with once-through cooling like the New Madrid coal plant on the Mississippi River in southeastern Missouri, pictured here. By 2040, low water flows and higher water temperatures could reduce capacity at New Madrid by two-thirds in late summer.**

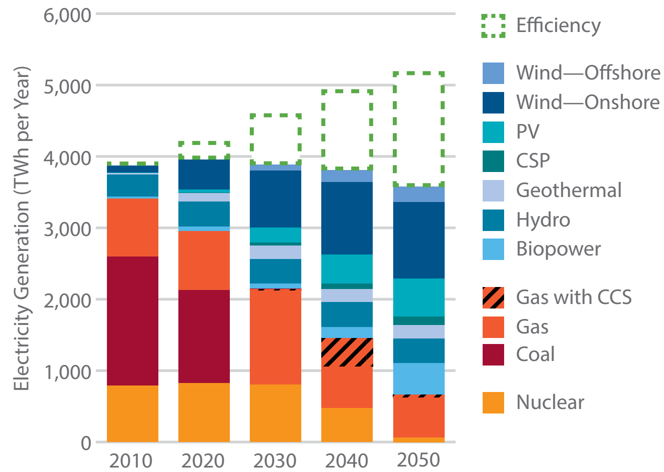



**FIGURE 10. U.S. Electricity Mix under the Renewables-and-Efficiency Scenario**

**One option for swift and deep cuts in carbon emissions from the power sector is significant reliance on energy efficiency and renewable energy. Under our renewables-and-efficiency scenario, the use of more efficient heating, cooling, lighting, and other technologies would more than offset projected growth in electricity demand by 2050, while deeply reducing carbon emissions. Renewable sources such as wind, solar, and geothermal could supply 80 percent of the remaining electricity demand.** Source: Clemmer et al. 2013.

drop by 4.4 percent to 16 percent in the years 2031 to 2060, and extreme reductions in capacity—greater than 90 percent—would be three times as likely in that period. By 2040, low water flows and higher water temperatures could reduce capacity at Missouri's New Madrid, a 1,200-megawatt coal plant with once-through cooling, by two-thirds in late summer.[26]

Power plants will also get into trouble if water levels in rivers, lakes, and reservoirs drop below the plants' water intake pipes. A study by researchers at Argonne National Laboratory found that 43 percent of 423 U.S. plants were at risk of lower power output during droughts because their intake pipes were 10 feet beneath the surface or less (Kimmel and Veil 2009). And that study did not consider the more frequent low flows, regional drought, and higher water temperatures that future climate change could bring.

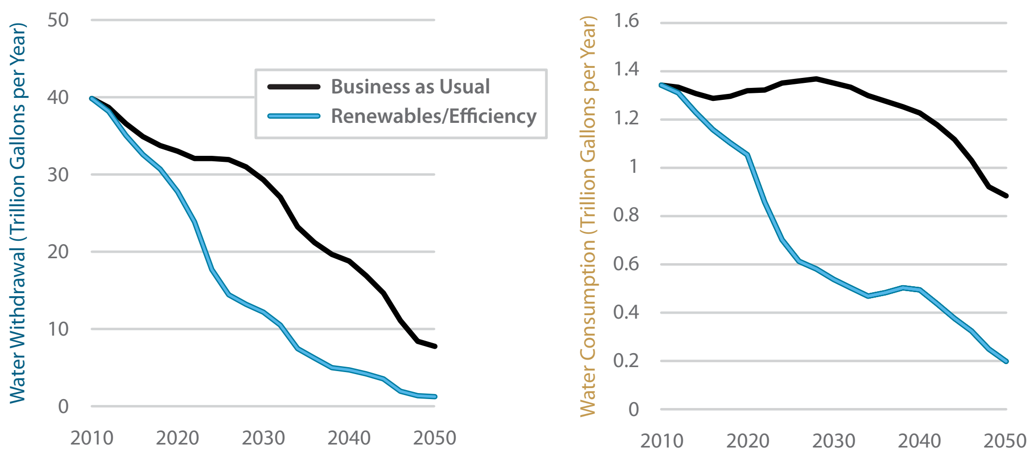
All these studies, including ours, examined the longer-term effects of drought and high temperatures. However, temperatures in a river or lake over a just a few days or even hours can affect both power plant operations and their impact.

Given that power plant choices can also affect water resources because of related fuel extraction, a dramatic increase in the use of natural gas, such as that projected under business as usual, could also worsen the impact of hydrofracking on water quantity and quality (see Box 2, p. 23).

## A Better Pathway: Curbing Carbon Emissions *and* Water Use

As noted, the power sector offers many of the nearest-term opportunities for cutting heat-trapping emissions, given the range of low- or no-carbon technologies available now. Indeed, the nation could deploy a range of electricity mixes to tackle the carbon problem. But how would those mixes affect water? And how water-smart would they be: how well would they prepare us to avoid and minimize energy-water collisions, and to cope with those we cannot avoid?

26 Based on one standard deviation below the mean.




Source: Macknick et al. 2012b.

**FIGURE 11. Power Plant Water Use under the Renewables-and-Efficiency Case, 2010–2050**

**Dramatic reductions in water use by the power sector are possible. Water use would drop much further under a renewables-and-efficiency scenario than under business as usual—and much more quickly. By 2030, under the former, both withdrawals (left) and consumption (right) would be less than half of today's levels. By 2050, under the renewables-and-efficiency scenario, withdrawals would be 97 percent below today's levels. Water consumption would drop by 85 percent, and be almost 80 percent below business as usual in 2050. Power plants would withdraw 9 trillion gallons (28 million acre-feet) less per year than under business as usual—as much as is now withdrawn for all uses in Pennsylvania, Maryland, New Jersey, and West Virginia combined (Kenny et al. 2009).**

One option for swift and deep reductions in power sector carbon emissions is significant use of renewable energy and energy efficiency. In our renewables-and-efficiency scenario, the use of more efficient technologies for providing heat, cooling, light, and other services in buildings and industry would more than offset growth in electricity demand now projected for 2050. And renewable energy would produce 80 percent of the power needed to fulfill the remaining demand.

Under that approach, carbon emissions in the power sector would drop 90 percent from today's levels, chiefly in the first 20 years, as part of economy-wide reductions of more than 80 percent by 2050 (Figure 10). What's more, that mix of technologies would bring strong water benefits.

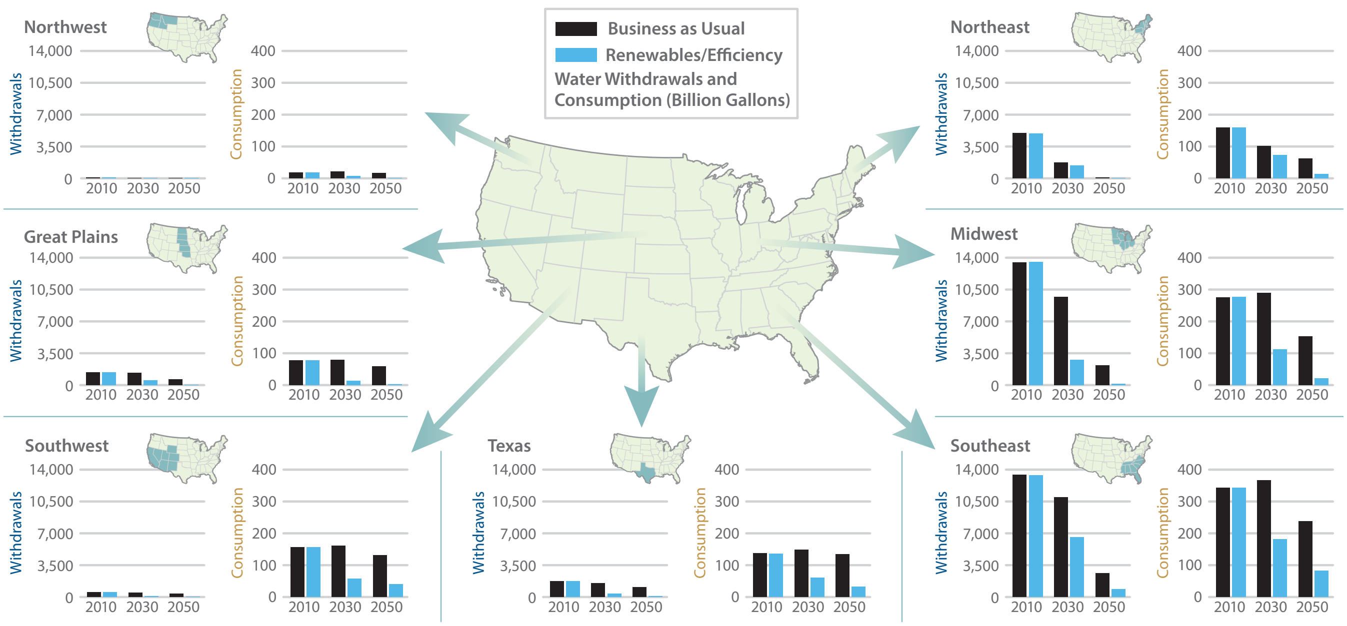
**National.** While water withdrawals in the power sector would drop under the business-as-usual case, they would decline even more—by 97 percent from today's levels—under the renewables-and-efficiency scenario in 2050 (Figure 11). Water consumption would drop by 85 percent from today's levels, and be 78 percent below consumption under the business-as-usual case in 2050. In a future where hydrologic variability is expected to increase, such a scenario would make the power sector much more resilient while also benefiting other water users.

Reductions in water withdrawals and consumption by power plants would also occur much sooner under the renewables-and-efficiency case. By 2030, both withdrawals and consumption would be less than half of both today's levels and those under the business-as-usual case.

**Regional.** Under the renewables-and-efficiency pathway, regional changes in water use by power plants would mirror the national changes. Water withdrawals would drop at least 50 percent from current levels in every region by 2030, and at least 90 percent by 2050. Water consumption would also drop by roughly half or more by 2030, and by three-quarters or more by 2050. And both water withdrawals and consumption would be lower in every region in both 2030 and 2050 compared with business as usual (Figure 12, p. 26).

**Local.** Differences in water use between the two scenarios also show up at local levels. While power plants are responsible for a small fraction of water consumption in the Colorado River Basin, energy choices can affect water availability markedly on a cumulative basis, as evident in projections of reservoir storage levels.

Our modeling showed that lower annual water consumption under the renewables-and-efficiency




## FIGURE 12. Regional Variations in Power Plant Water Use

**All water is local: national projections of power plant water use (Figure 11) can mask important variations at smaller scales. Under a renewables-and-efficiency pathway, regional water results—both water withdrawals (left side of regional pairs) and consumption (right side of regional pairs)—would be lower than under business as usual in every region in both 2030 and 2050. Under business as usual, water consumption would actually increase in many regions including the Midwest, Southeast, and Southwest by 2030, and drop little from today's levels by 2050 in several regions. (100 billion gallons = 300,000 acre-feet)** Source: Macknick et al. 2012b.

scenario—if accumulated in reservoirs—could add on the order of 490 billion gallons (1.5 million acre-feet) of water stored in Lake Mead and Lake Powell by 2030, and 590 billion gallons (1.8 million acre-feet) by 2040 (Figure 13). That difference—equivalent to the annual water use of 3 million to 4 million U.S. households, or five to six times the annual water use in Phoenix—would represent almost 4 percent of the water storage of the two reservoirs (City of Phoenix 2013; EPA 2013d). That water could be used for other purposes.

Lower-water choices in the power sector would be even more important during times of water stress. In November 2010, Lake Mead, the nation's largest reservoir, was just 41 percent full (USBR 2013; Walton 2010). Some 4.5 trillion gallons (14 million acre-feet) had essentially gone missing since 1999, when the lake had last been nearly full (USBR 2013). Having another 590 billion gallons (1.8 million acre-feet)—almost 13 percent of that water shortfall—available, rather than consumed by power plants, could provide crucial flexibility for other water users in the face of drastically low storage levels.

The renewables-and-efficiency scenario would especially benefit the agriculture sector—already vulnerable to changes in the price and availability of water used for irrigation. That scenario would allow agricultural water deliveries 1 to 2 percent higher from 2040 to 2049 compared with the business-as-usual case. In a region where gallons count, especially during drought, such small differences matter.

And some basins in the Southwest would see greater benefits. In the South Platte Basin in Colorado, the renewables-and-efficiency scenario would allow 3 percent to 4 percent more water than business as usual for agriculture annually in the decade from 2040 to 2049—or 10 billion to 13 billion gallons (30,000 to 40,000 acre-feet) each year. A future of high air temperatures and more hydrologic variability may push the agriculture sector toward more efficient water use, but water use in the power sector can compound or lessen the challenges ahead for agriculture.

Energy choices that are lower in both carbon emissions and water use can help protect underground aquifers. The renewables-and-efficiency scenario would

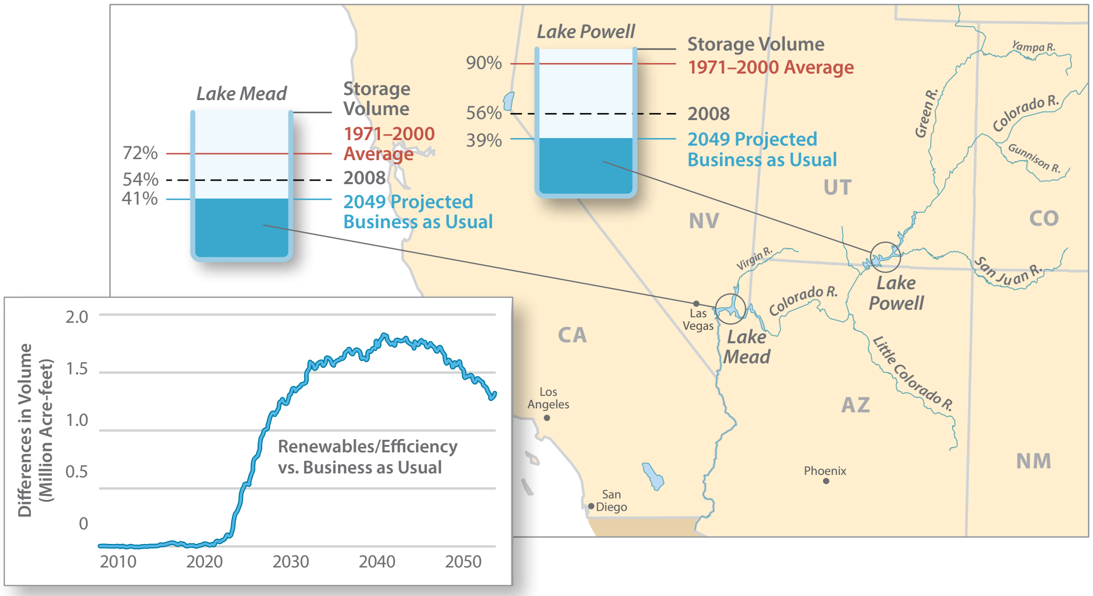



**FIGURE 13. The Impact of Electricity Choices on Reservoir Levels in Lake Mead and Lake Powell**

**Electricity choices that consume less water leave more for other uses. These choices can also markedly affect cumulative water supplies. Water levels in the Southwest's major reservoirs, Lake Mead and Lake Powell, have been well below capacity for many years, and could drop farther during extended droughts. Lower water consumption each year under the renewables-and-efficiency scenario (inset) could mean almost 600 billion gallons (1.8 million acre-feet) more stored water in those reservoirs by 2040, compared with business as usual. That amount is nearly 4 percent of the storage capacity of those two reservoirs, and more than 13 percent of the average annual natural flow of the Colorado River.** Sources: Yates, Meldrum, and Averyt 2013; NRCS 2008.

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***Electricity choices affect river flows.*** **The 3,800-megawatt coal- and gas-fired Wansley power plant along the Chattahoochee River is cooled by a recirculating system. Under the renewables-and-efficiency scenario, the stretch of the Chattahoochee below Wansley would have 5 percent to 10 percent higher flows in summer and autumn by 2025 compared with business as usual.**

reduce groundwater withdrawals in the Colorado River Basin by a cumulative 325 billion gallons (1 million acre-feet) by 2025, and by 2 trillion gallons (6 million acre-feet) by 2050 (Figure 14, p. 28). Measures that conserve these important stores could benefit water users over a very long time horizon.

The renewables-and-efficiency scenario would also benefit river flows, including in the ACF Basin. Flows of the Chattahoochee River below Georgia's Wansley power plant—a 3,800-megawatt coal- and gas-fired plant cooled by a recirculating system—would be 5 percent to 10 percent higher in summer and fall by 2025 than under the business-as-usual case.

Water-smart electricity choices can also reduce the impact of the power sector on water temperatures. Under the renewables-and-efficiency scenario, the Coosa River above Alabama's Weiss Lake would be 3°F (2°C) to 13°F (7°C) cooler in mid-summer in the decade from 2030 to 2039 than under business as usual, because coal plants, including those upstream, would have been phased out by then. And temperatures might stay below the 90°F (32°C) threshold from 2040

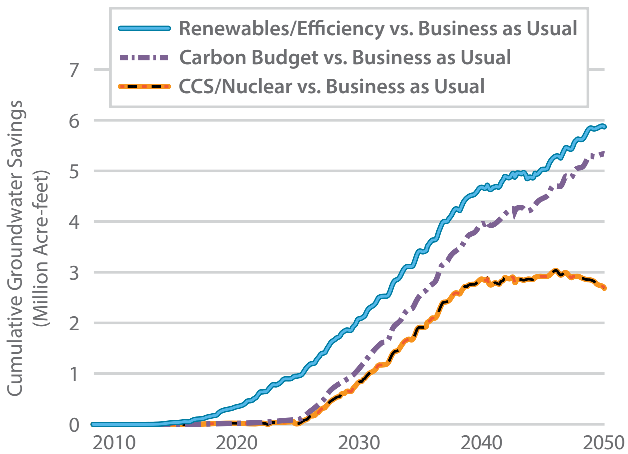


**FIGURE 14. Groundwater Savings in the Southwest across Scenarios**

**Scarce groundwater supplies are critical sources of water in the desert Southwest. Water-smart electricity choices can reduce pressure on aquifers appreciably over time. Under a renewables-and-efficiency scenario, water savings would total 6 million acre-feet (2 trillion gallons) by 2050, compared with business as usual. That is twice as much groundwater as Arizona withdraws from aquifers each year (Kenny et al. 2009).** Source: Yates, Meldrum, and Averyt 2013.

to 2049, versus the 18 days per year they would exceed that threshold under business as usual (Figure 15).

Overall, the renewables-and-efficiency pathway provides more opportunities to address not just average water use but also extremes—periods of low water or high temperatures that can lead to energy-water collisions. And with climate change, conditions that have historically been outliers are expected to become standard fare, underscoring the value of the water-smart pathway.

## How the Costs Add Up

Electricity prices (rates) would also differ markedly between these two pathways. If we assume no increases in the cost of water or a price on carbon emissions, prices would rise some 34 percent by 2050 under business as usual, and by 46 percent in the renewables-and-efficiency case (Figure 16) (Clemmer et al. 2013).

However, electricity customers pay bills, not rates, and how much they pay also depends on how much they use. Electricity bills would be 30 percent lower under the renewables-and-efficiency scenario than under

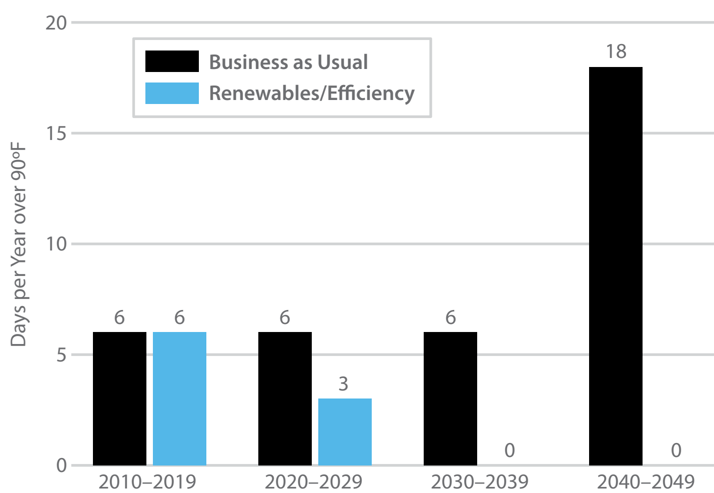


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**FIGURE 15. The Impact of Electricity Choices on Coosa River Temperatures**

**The Coosa River above Lake Weiss on the Alabama-Georgia border is one of a handful of landlocked river systems where striped bass—a species important to anglers but sensitive to high water temperatures—are reproducing naturally (ADCNR 2000; Beitinger et al. 1999). Temperatures on the Coosa River are expected to exceed 90° F (32° C) six days a year, on average, from 2010 to 2019. In a warming world, the conditions for such temperatures are expected to occur more often. Yet power plant choices can help counteract that warming. Under business as usual, water temperatures at that location would exceed 90° F an average of 18 days per year in the 2040-to-2049 period. Under the renewables-and-efficiency scenario, with the retirement of upstream power plants, river temperatures would be 3° F (2° C) to 13° F (7° C) cooler in mid-summer and stay below the 90° F threshold during that same period.** Source: Yates et al. 2013a.

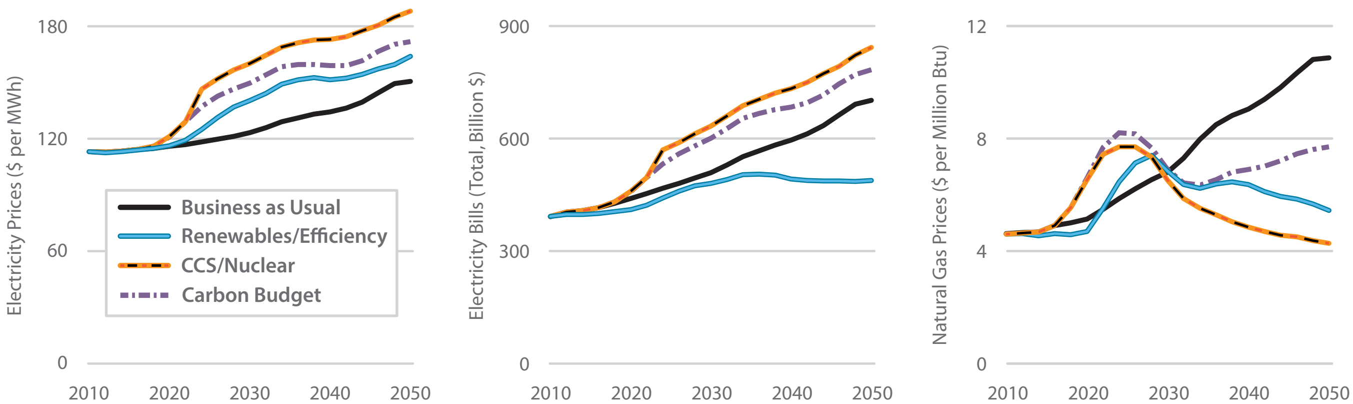


**FIGURE 16. Electricity Prices, Electricity Bills, and Natural Gas Prices under Two Scenarios**

**Under business as usual, electricity prices would rise roughly one-third by 2050, not including any costs for water use or a price on carbon emissions. Under the renewables-and-efficiency scenario, electricity rates would rise nearly 50 percent. However, total electricity bills would be about one-third lower under the latter scenario, not including the cost of investments in efficiency or reinvestment of any carbon revenues (see footnote 27). And natural gas prices would be only half as high because demand for that fuel would be lower. (MWh = megawatt-hour)** Source: Clemmer et al. 2013.

business as usual, not including the cost of investments in energy efficiency (Clemmer et al. 2013).[27]

The connections between natural gas, electricity, and other energy needs mean the different electricity pathways would also affect the price of natural gas differently. Under the renewables-and-efficiency scenario, natural gas prices would be roughly half those under the business-as-usual case because of the latter's heavier reliance on natural gas (Clemmer et al. 2013). Households and businesses that rely on natural gas for heating and other uses would benefit from lower prices.

## Other Pathways, Other Outcomes

Among the other scenarios we examined, the straight carbon budget scenario would affect water use much like the renewables-and-efficiency case because it would meet the carbon budget largely by expanding renewable energy. The water-related impact of the



***The water costs of a CCS-and-nuclear future.*** **Both carbon capture and storage and nuclear power are water-intensive compared with most other options, and the sheer size of nuclear power plants means that they affect local water sources. Even plants with recirculating cooling systems, such as the Sequoyah nuclear plant on the Tennessee River's Chickamauga Reservoir, can consume billions of gallons a year. Under a CCS-and-nuclear scenario, water consumption in the power sector would be almost eight times that under the renewables-and-efficiency scenario in 2050.**

27 Studies show that savings on electricity bills from energy efficiency typically more than offset investment costs (Laitner et al. 2012; Lovins 2011; Cleetus, Clemmer, and Friedman 2009; Granade et al. 2009; National Research Council 2009). Cleetus, Clemmer, and Friedman, for example, found that annual electricity bill savings were 2.5 times the annual incremental investment costs in 2020, and 3.1 times those costs in 2030. Also, while our modeling was policy-neutral, policies leading to a carbon budget could generate revenues that could be used for investing in energy efficiency or offsetting electricity bill impacts, for example (Cleetus, Clemmer, and Friedman 2009). Our analysis did not capture such options.

CCS-and-nuclear scenario, in contrast, would be very different from that of the renewables-and-efficiency case, unless the water profiles of those technologies improved dramatically.

Because of high water use per unit of electricity, the CCS-and-nuclear scenario would lead to greater water withdrawals and consumption by 2050 than under the other scenarios. Indeed, under the CCS-and-nuclear scenario, water consumption in the power sector would be 14 percent higher than today's levels, 42 percent higher than under business as usual, and almost eight times that under the renewables-and-efficiency case in 2050.

The CCS-and-nuclear case would also lead to appreciable increases in water consumption in almost every region by 2050—as much as 60 percent in Texas. Groundwater savings under the CCS-and-nuclear scenario would be only half those under the renewables-and-efficiency scenario by 2050—a difference of 1 trillion gallons (3.2 million acre-feet). And cumulative additions to Lake Mead and Lake Powell by 2050 would be only 86 percent of those under the renewables-and-efficiency scenario.

Our findings that electricity pathways that reduce carbon emissions do not necessarily reduce water use are consistent with those of other research. A recent study of the effects of putting a price on carbon emissions, for example, found that water withdrawals in the power sector would be just 2 percent to 14 percent lower by 2030 than under business as usual (Chandel, Pratson, and Jackson 2011). Water consumption would be comparable to business as usual, except under a scenario with significant deployment of CCS, which would drive consumption 14 percent higher by 2030.

An analysis of the effects of adding CCS to all U.S. coal plants by 2030 projected that water withdrawals by power plants would increase between 2 percent and 3 percent, while water consumption would rise between 52 percent and 55 percent (Chandel, Pratson, and Jackson 2011). Another study found that retrofitting all existing carbon-emitting power plants with CCS would increase water withdrawals slightly, but increase water consumption as much as 21 percent over 2009 levels (Tidwell et al. 2013). That analysis also found that 120 million to 250 million gallons (360 to 780 acre-feet) per day of new water consumption could occur in "watersheds with limited surface water availability." Retiring and replacing those plants instead could cut withdrawals by 60 percent and consumption by 28 percent.

A CCS-and-nuclear scenario would produce lower natural gas prices than even the renewables-and-efficiency case, because the former would entail little use of natural gas. Yet electricity rates under the CCS-and-nuclear case would rise by two-thirds—more than under any other scenario we examined—and might be 75 percent higher than under the renewables-and-efficiency case, because of the higher costs of CCS and nuclear.

Our scenarios are a very small set of the numerous possible electricity futures, of course. More energy efficiency is likely to be a strong plus in any scenario, however, in reducing carbon emissions, water effects, and consumer costs. Renewable energy similarly offers strong advantages. The technology leaders—wind and solar photovoltaics—do not use steam or cooling water, and renewable energy can be cost-effective (Macknick et al. 2012a; Cleetus, Clemmer, and Friedman 2009).

**With climate change, conditions that have historically been outliers are expected to become standard fare, underscoring the value of the water-smart pathway.**

CHAPTER 5

# Making Low-Carbon, Water-Smart Energy Choices Today

### *KEY FINDINGS*

- **We can make decisions now to reduce water and climate risk.** Fuel and technology options already available mean we can design an electricity system with far lower water and climate risks. These include prioritizing low-carbon, water-smart options such as renewable energy and energy efficiency, upgrading power plant cooling systems with those that ease water stress, and matching cooling needs with the most appropriate water sources.
- **Electricity decisions should meet water-smart criteria.** These criteria can point decision makers to options that reduce carbon emissions *and* exposure to water-related risks, make sense locally, and are cost-effective.
- **Actors in many sectors have essential roles to play.** No single platform exists for sound, long-term decisions at the nexus of electricity and water, but those made in isolation will serve neither sector. Instead, actors across sectors and scales need to engage. For example: plant owners can prioritize low-carbon options that are water-appropriate for the local environment. Legislators can empower energy regulators to take carbon and water into account. Consumer groups can ensure that utilities do not simply pass on to ratepayers the costs of risky, water-intensive plants. Investors in utilities can demand information on water-related risks and seek low-carbon, water-smart options. Researchers can analyze future climate and water conditions and extremes, allowing planners to consider low-probability but high-impact events. And scientists and engineers can improve the efficiency and reduce the cost of low-water energy options.
- **Getting this right is urgent business.** Near-term decisions in the power sector commit us to risk or resilience for much of this century. We can untangle the production of electricity from our water supply to a much greater degree, and we can build a low-carbon electricity system. But we cannot wait, nor do either in isolation, without compromising both. We must get this right.

## Securing Our Energy Future

Securing our energy future depends on understanding that the power sector's demand for water is high and its vulnerability significant, and that our choices in the coming years matter greatly. Our energy choices, analysis suggests, need to intentionally and decisively enable us to both mitigate and adapt to an increasingly water-stressed world, enhancing our collective resilience to climate change and extreme weather.

The business-as-usual pathway is clearly risky and unsustainable from a carbon perspective, incompatible with our need to swiftly and deeply reduce heat-trapping emissions. Business as usual is also unattractive from a water perspective because of the impact of climate change on water in many places, and because of lingering negative effects of power plant water use on water quantity and quality.

The strategies we choose for addressing carbon matter, however. Low-carbon pathways can be water-smart, but they are not necessarily so. Low-carbon choices such as nuclear and concentrating solar can have serious consequences, particularly in water-stressed regions, depending on cooling technology decisions.

Nationally, renewable energy and energy efficiency can be a strong combination for achieving cost-effective reductions in carbon emissions and water effects. As our research has shown, this combination leads to significant cuts in water use by the power sector, at the lowest cost to electricity ratepayers.

Regional considerations must also play a role in getting decisions right. The net effect of water withdrawal and consumption for power plants on water quantity and quality can vary significantly by region.

And different regions will have different priorities—water consumption in the Southwest, for example, and water temperature and withdrawals in the Southeast. Fortunately, our options today are abundant, our opportunity for improvement is great, and our mandate for low-carbon, water-smart electricity is clear.

## Moving Decisions Today

How do we achieve a low-carbon, water-smart electricity future? We can begin by addressing some of our more wasteful water practices. We can work, for example, to use wastewater instead of drinking water to cool power plants in water-stressed regions. By doing so, the Palo Verde nuclear plant outside Phoenix avoids withdrawing 11 billion gallons of freshwater per year in highly water-constrained Arizona (UCS 2012).

We can also deploy the many "no-regrets" options. Because they cut both carbon emissions and water use, all energy efficiency policies contribute to a low-carbon, water-smart future. States can create or strengthen renewable portfolio standards, which require utilities to obtain a share of their power from renewable sources, and favor water-appropriate options. States can also work to overcome barriers to the expansion of renewable energy—from siting concerns to unstable energy policies to financing challenges—on water and climate safety grounds.

We can also respond to the nation's aging power infrastructure, already in transition, by replacing more uneconomical power plants with less water-intensive options, reducing cooling water use further and faster than under business as usual (see Box 3).

**Smart electricity choices reduce exposure to water-related risks by phasing out water-intensive power plants in water-stressed areas, and by ensuring that any effort to reduce carbon emissions from the power sector also lowers water use.**


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***Low-water options.*** **Electricity options that require no water and emit little carbon, such as wind and solar photovoltaics, are spreading quickly and are poised for even wider use.**

### BOX 3. *The Impact of Coal Retirements on Water Use*

Replacing all U.S. coal plants announced for retirement by early 2013—a total of 51,000 megawatts—with water-efficient natural gas plants would cut annual water withdrawals for cooling by more than 4 trillion gallons, and water consumption by 29 billion gallons. Replacing all other economically vulnerable coal plants—another 52,000 megawatts—would cut annual water withdrawals by another 4 trillion gallons, and water consumption by another 49 billion gallons (UCS 2013).

That is because natural gas combined-cycle plants with recirculating cooling can reduce water withdrawals by 75 percent, and consumption by 70 percent, compared with coal plants with a similar cooling system. And such natural gas plants withdraw 99 percent less water and consume 18 percent less water than a coal plant with once-through cooling (Macknick et al. 2012a).

Replacing aging coal plants with low- or no-water renewable energy or energy efficiency measures can reduce the water impact of electricity even more. Replacing retiring and vulnerable coal plants with those technologies could save more than 8 trillion gallons of water withdrawals each year, and about 150 billion gallons of water consumption (UCS 2013). Reliance on renewable energy and energy efficiency would also cut carbon emissions much more than the use of natural gas plants.

## Water-Smart Criteria: Best Practice Today, Standard Practice Tomorrow

How do we actually make electricity choices in light of their impact on water? One critical piece is to apply water-smart criteria to decision making. Water-smart decisions:

- **Address carbon.** Any decisions to advance power plants that sustain or increase carbon emissions contribute to climate change and its effects on water. Thus, from a water standpoint, these choices are unsound. To be "water-smart," actions in the power sector must begin with carbon reductions and climate change mitigation.
- **Consider water.** Smart electricity choices reduce exposure to water-related risks by phasing out water-intensive power plants in water-stressed areas, and by ensuring that any effort to reduce carbon emissions from the power sector also lowers water use.
- **Build a resilient and reliable electricity supply.** The power sector needs to be able to withstand rising average temperatures and more extreme heat across the country, more intense summer droughts in the Southeast and Great Plains, and reductions in water availability in the Southwest and Southeast. Electricity decisions must consider the climate and hydrologic conditions that power plants could face in their 30- to 50-year life spans, including deep, extended drought.
- **Consider local needs.** Phoenix is not Atlanta, which is not Chicago. Making water-smart choices for electricity requires choosing options most suited to local circumstances. Those factors can be complex, but asking the right, locally relevant questions can help to distill the most appropriate choices. Low-water cooling, for example, may be a more appropriate choice in regions with existing or projected water stress than in regions with abundant water.
- **Choose cost-effective options.** Water-smart decision making considers both up-front and continuing costs to power producers and consumers, and the full range of environmental benefits and effects. In doing so, such decision making arrives at choices that are cost-effective in terms of electricity, water, *and* climate.

## Who Makes Water-Smart Decisions in the Real World?

Water has begun to figure more prominently in decision making by power companies, state legislators, and state regulators, and on Capitol Hill and at the White House. But water is not yet the fixed, prominent, and universal consideration it needs to be.

Opportunities to incorporate water more fully into such decision making abound, from near term to medium term to long term, and from local and project levels to system-wide and national levels. These decisions can include an existing or proposed power plant or transmission line, a utility's integrated resource plan, state- and basin-wide water planning, and regulatory and legislative decisions around energy, water, and carbon. (An integrated resource plan is a platform for utilities to propose—and public service commissions to evaluate—the costs and benefits of different approaches for meeting electricity demand reliably and at the lowest cost.[28])



***Locking in resilience—or risk.*** **New power plants will replace retiring plants to help meet future electricity demand. The impact of the water use and carbon emissions of those new plants will reverberate for decades. For example, the expansion of Georgia's nuclear Plant Vogtle, currently under way, would provide more power with no added carbon emissions. But only with low- or no-water cooling could operators limit the plant's effect on local water resources.**

28 All states in the Southwest except California, and a half-dozen Southeast states including North Carolina, South Carolina, and Georgia, require utilities to produce integrated resource plans (Wilson and Peterson 2011).


***Water-smart decision making.*** **Regulators and lawmakers have many opportunities to reward carbon- and water-smart decision making and penalize poor choices in the electricity sector.**

Some examples of decision makers and potential decisions:

- **Power companies and plant developers.** Electric utilities and other power plant owners and operators are primary players in water-smart electricity decision making, particularly given the large turnover of plants under way. Some plant owners assume a price on carbon emissions in their planning. Decisions on new plants should prioritize low-carbon options that are also locally water-appropriate, which may include natural gas combined-cycle plants with dry cooling, wind or solar, or energy efficiency. Plant owners can also retrofit existing units, switching from once-through cooling to recirculating or dry cooling, or replace existing plants with lower-carbon and more water-smart options, considering the full range of effects.

- **Regulators and lawmakers.** Today decision makers are neither rewarded for making carbon- and water-smart decisions nor penalized for making poor choices. Better laws and regulations would provide incentives to shift decisions toward water-smart options. In the 27 states with integrated resource planning, for example, public utility commissions (PUCs) should ensure that utilities consider the water-related risks of new facilities, including climate change and hydrologic variability. Requiring power contracts to specify these can turn environmental risks into investor and business risks.

  PUCs should also ensure that utilities, not customers, absorb the costs of decisions that fail to address significant water risks, leading, for example, to power plant shutdowns during periods of peak demand. Water resource agencies and regional water commissions should also consider long-term effects on the water supply when weighing in on power plant proposals.

  Legislatures and federal agencies should give clear and strong signals about the value of reducing carbon emissions and enhancing water preparedness. Congress, for example, should use tax policies, a price on carbon, and direct requirements for renewable energy and energy efficiency to accelerate their adoption. State legislatures should empower PUCs and other regulators to take carbon and water into account in energy decision making.

  Agencies such as the EPA and the U.S. Department of Energy should drive R&D on reducing carbon emissions from the power sector and promoting integrated management of energy and water. Existing tools such as the environmental impact process of the National Environmental Policy Act should more fully account for the water effects of major electricity projects, including transmission lines. And the Nuclear Regulatory Commission and the Federal Energy Regulatory Commission should incorporate water into their decisions on particular plants and transmission systems.

- **Scientists and engineers.** Water-smart decisions will sometimes require new information and tools. The science and engineering community has a role to play in:

  *Advancing data collection and analysis and decision-making tools.* Better understanding of water use, local water stress, and the water-saving potential of various technologies can aid water-smart decision making.

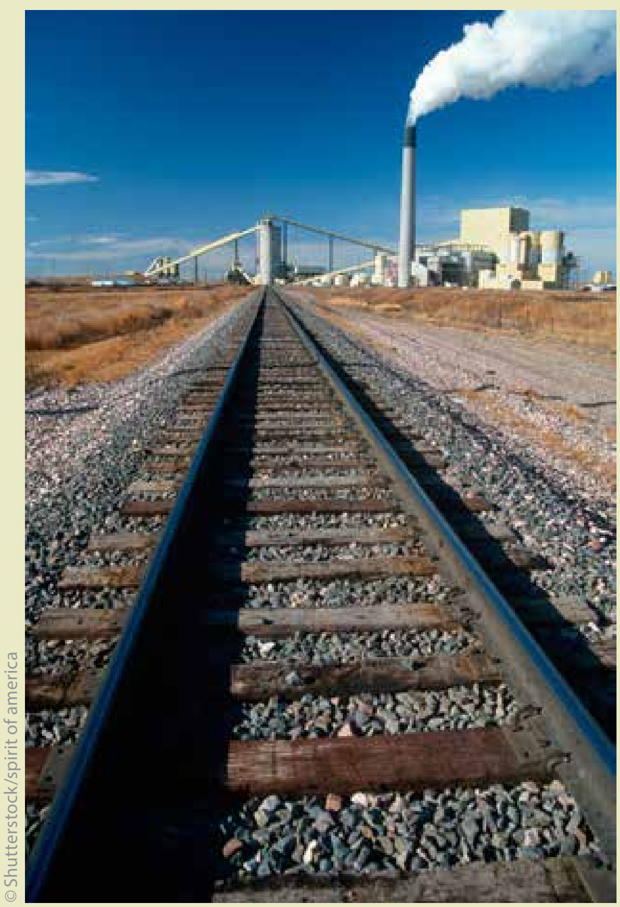
  *Research and modeling that better analyzes extremes in water conditions, at finer time scales.* This will allow decision makers to consider not just average conditions and vulnerabilities but also events of low probability but major consequence. Better tools will also allow decision makers to explore tradeoffs between less efficient options and reductions in water use and carbon emissions, or the water needs of competing users. Modeling platforms such as WEAP can enable decision makers to make locally appropriate choices. New models that enable decision makers to match water needs with water sources, such as by expanding wastewater use in the power sector, can help address local water constraints (CH2M HILL 2013).

*Improving technology.* Advances that help lower the cost of low-water renewable and energy efficiency technologies could accelerate their adoption and shrink water risk in the power sector. Smart investments in research by the U.S. Department of Energy, state energy offices, and the private sector can aim to minimize carbon emissions and water effects of existing options and to develop new ones (see Box 4).

### BOX 4. *Improving the Water Use of Energy Technologies*

Some technologies for producing electricity come with steep freshwater price tags, while others can undermine the fuel efficiency of power plants. Reducing those effects is key to avoid building energy-water collisions into our future.

- **Hydraulic fracturing** for extracting natural gas contaminates water or loses it underground. Conflicts between hydrofracking and other water uses, particularly when water supplies are tight, suggest that fracking may not be consistent with our water-strained future (Barringer et al. 2013). Any long-term U.S. reliance on hydrofracking should rest on advances that greatly reduce these effects—through more on-site treatment of water extracted from wells for reuse, for example.
- **Recirculating cooling systems** withdraw much less water than once-through systems. However, they consume much of what they do withdraw, typically operate less fuel-efficiently than once-through systems, and cost more to install. Advances in both the water and power efficiency of these systems could reduce their cost and expand their use in regions where they are most suitable.
- **Dry cooling systems** use essentially no water but drive fuel efficiency down and costs up, and grow appreciably less efficient at temperatures above 100° F (38° C) (King et al. 2013). These, too, would benefit greatly from efficiency improvements. Hybrid wet-dry systems with lower costs and better efficiency would also become more deployable.
- **Carbon capture and storage** requires substantial amounts of water for the chemical and physical processes used to capture carbon emissions from the burning of fossil fuels (Macknick et al. 2012a). CCS also requires power, which in turn can entail more water use (Freese et al. 2008). Widespread deployment of CCS would require major advances to reduce its direct use of freshwater in the capture process, as well as its indirect use of water from the added electricity needs. These challenges are in addition to the high costs and uncertainties about the viability of long-term carbon storage (Freese et al. 2008).



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***Dry cooling and carbon.*** **With limited local water supplies, the Wyodak power plant near Gillette, WY, uses dry cooling. Yet that technology requires more fuel to produce a given amount of electricity, meaning higher carbon emissions at coal or other fossil-fueled plants. Investments in improving the technology's performance and efficiency at high temperatures could make dry cooling a more viable option.**

- **Other stakeholders: consumers, investors, and more.** Consumers of electricity and water, and those who work or advocate on their behalf, have a large stake in a reliable supply of both at reasonable cost. Regional electricity reliability councils and independent system operators, which aim to ensure the efficient, reliable, and cost-effective delivery of power across large areas, should consider water risks and approaches for mitigating them in the long-term planning and operation of the grid. Consumer groups can work to ensure that utilities do not simply pass on the costs of risky, water-intensive decisions to ratepayers.

  Water-dependent stakeholders—cities, farmers, ecosystem and wildlife groups—also have clear reason to push electricity planning and decision making in low-carbon, water-smart directions. Intervenors could advocate at hearings on integrated resource planning, for example, on behalf of municipalities and farm interests to ensure adequate summer water levels, or on behalf of fishing and wildlife interests to reduce the thermal impact of power plants.

  Investors in power plants and utility companies can demand that utilities disclose their exposure to climate, hydrological, and regulatory risks and costs (Ceres 2013b). And public education can overcome resistance to low-carbon, water-smart power options such as the use of wastewater for power plant cooling, speeding their adoption.

## Promoting Integrated Decision Making

No single platform exists for making decisions at the nexus of electricity, water, and climate. Yet decisions made in isolation will not serve any sector. Integrated resource planning, which has yet to consider state- and basin-scale water management, has great potential to provide such a platform.

Water use in sectors other than electricity, such as agriculture, often offers less-expensive opportunities for addressing imbalances in water supply and demand or otherwise reducing water stress. The need to swiftly reduce carbon emissions—and the scale of that challenge—mean that the energy sector must remain a primary focus. However, all major opportunities to use water more wisely—including smaller-scale, more easily deployed options in agriculture such as improved irrigation technologies—have value in a warming world.

Decision making at the nexus of climate, energy, and water can be complicated—that is one reason it has been slow to mature. But experts can help by capturing and sharing key opportunities, challenges, and successes, and by developing a roadmap that clarifies the actors and the steps they can take. Ultimately, decision makers in many venues will need to build a new approach to ensuring a low-carbon, water-smart future.

## Conclusion

Understanding and addressing the water impact of our electricity choices is urgent business. Because most power sector decisions are long-lived, what we do in the near term commits us to risks or resiliencies for decades. We can untangle the production of electricity from the water supply, and we can build an electricity system that produces no carbon emissions. But we cannot wait, nor do either in isolation, without compromising both. For our climate—and for a secure supply of water and power—we must get this right.



***Building the future.*** **We need electricity to power our homes, schools, hospitals, and businesses. But power production does not have to use water or emit carbon. By choosing low-carbon and water-smart options, we help build an electricity system that can stand up to twenty-first-century challenges.**

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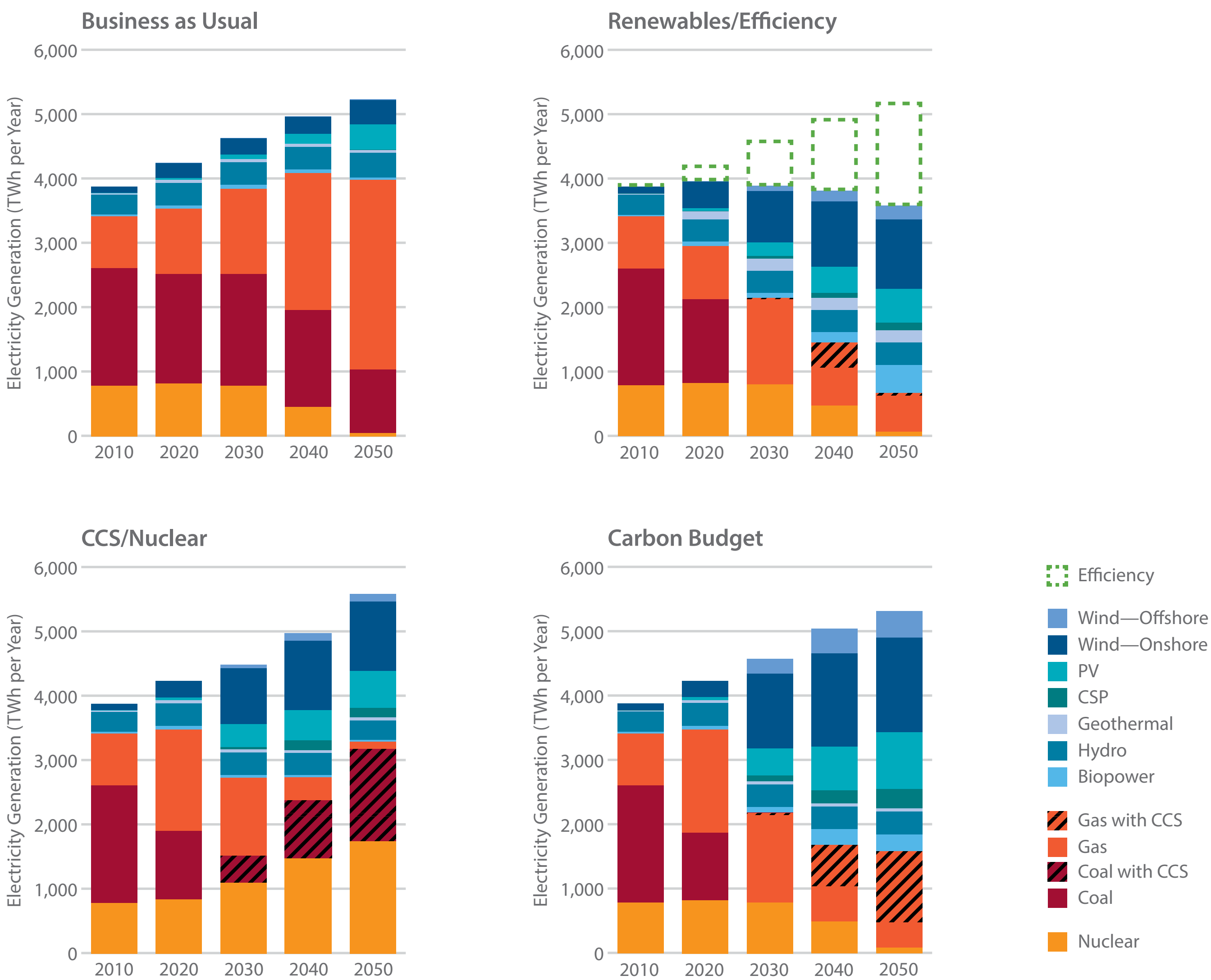
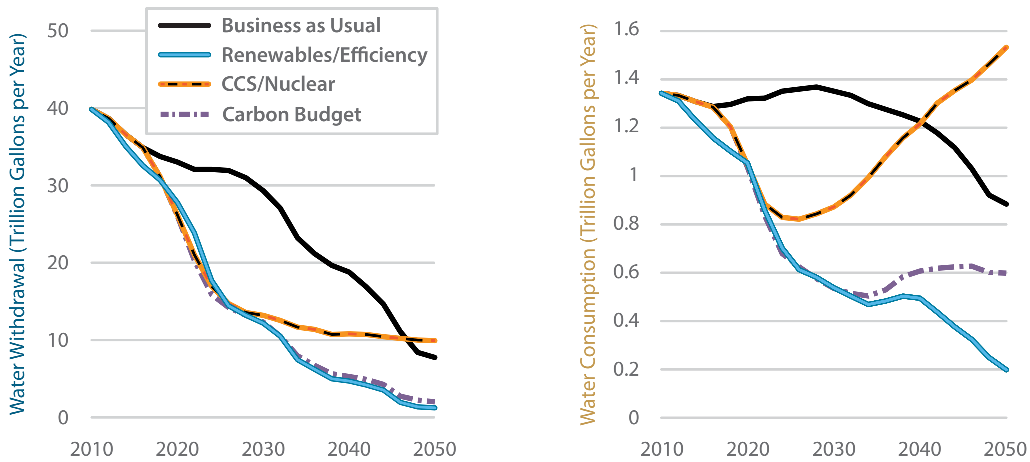
# Appendices

## APPENDIX A. *U.S. Electricity Mix under Four Scenarios*



## APPENDIX B. *U.S. Power Plant Water Use under Four Scenarios, 2010–2050*



## APPENDIX C1. *U.S. Power Plant Water Withdrawal across Scenarios, by State, 2010–2050 (billion gallons)*

| State | 2010 | Business as Usual | | Renewables/Efficiency | | CCS/Nuclear | | Carbon Budget | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
| AL | 2,540 | 2,310 | 240 | 1,180 | <5 | 1,190 | 1,230 | 1,170 | 40 |
| AR | 80 | 80 | 70 | 20 | <5 | 20 | 70 | 20 | <5 |
| AZ | 110 | 100 | 60 | 40 | 10 | 50 | 110 | 40 | 10 |
| CA | 60 | 60 | 60 | 30 | 20 | 20 | 40 | 20 | 30 |
| CO | 80 | 70 | 50 | <5 | <5 | <5 | 10 | <5 | <5 |
| CT | 90 | <5 | 10 | <5 | <5 | <5 | <5 | <5 | 10 |
| DE | 10 | <5 | <5 | <5 | <5 | <5 | 10 | <5 | 10 |
| FL | 690 | 1,040 | 1,360 | 790 | 680 | 800 | 500 | 930 | 600 |
| GA | 760 | 700 | 330 | 60 | 20 | 90 | 190 | 60 | 70 |
| IA | 480 | 380 | 190 | 10 | <5 | 10 | 10 | 10 | <5 |
| ID | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 |
| IL | 2,820 | 1,960 | 140 | 1,020 | 20 | 1,040 | 560 | 1,040 | 70 |
| IN | 1,350 | 1,380 | 630 | 40 | 40 | 50 | 80 | 40 | 50 |
| KS | 320 | 310 | 160 | 70 | <5 | 70 | 10 | 70 | <5 |
| KY | 880 | 470 | 200 | <5 | <5 | 30 | 50 | <5 | 10 |
| LA | 670 | 680 | 230 | 450 | <5 | 480 | 510 | 450 | 20 |
| MA | 110 | 30 | <5 | <5 | <5 | <5 | <5 | <5 | <5 |
| MD | 790 | 170 | 10 | <5 | <5 | <5 | 10 | <5 | 10 |
| ME | 20 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 |
| MI | 3,730 | 3,010 | 840 | 950 | 90 | 890 | 320 | 870 | 70 |
| MN | 820 | 700 | 220 | 360 | <5 | 360 | 10 | 360 | <5 |
| MO | 2,130 | 1,710 | 120 | 10 | <5 | 60 | 70 | 10 | <5 |
| MS | 160 | 160 | 110 | <5 | <5 | 10 | 10 | <5 | 10 |
| MT | 40 | 40 | 30 | <5 | <5 | <5 | <5 | <5 | <5 |
| NC | 2,760 | 1,590 | 70 | 1,420 | 10 | 1,420 | 270 | 1,420 | 20 |
| ND | 160 | 160 | 60 | <5 | <5 | <5 | <5 | <5 | <5 |
| NE | 760 | 720 | 270 | 430 | <5 | 440 | <5 | 440 | <5 |
| NH | 30 | 20 | <5 | <5 | <5 | <5 | <5 | <5 | <5 |
| NJ | 240 | 10 | 10 | 10 | <5 | <5 | 10 | <5 | 10 |
| NM | 210 | 170 | 100 | <5 | <5 | <5 | 10 | <5 | 10 |
| NV | 10 | 40 | 50 | <5 | 10 | 30 | 10 | 20 | 10 |
| NY | 1,640 | 630 | 20 | 540 | <5 | 960 | 520 | 540 | 20 |
| OH | 3,080 | 1,380 | 20 | 20 | <5 | 30 | 100 | 20 | 20 |
| OK | 140 | 160 | 150 | 20 | 10 | 10 | 10 | 10 | 10 |
| OR | 30 | <5 | 10 | <5 | <5 | <5 | <5 | <5 | <5 |
| PA | 1,960 | 890 | 20 | 830 | <5 | 860 | 570 | 830 | 140 |
| RI | 30 | <5 | <5 | <5 | <5 | 10 | <5 | 10 | <5 |
| SC | 2,130 | 2,250 | 240 | 1,900 | 120 | 1,920 | 2,180 | 1,900 | 450 |
| SD | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 |
| TN | 2,330 | 1,110 | 20 | 30 | 10 | 140 | 130 | 30 | 20 |
| TX | 1,740 | 1,520 | 1,100 | 330 | 100 | 540 | 1,020 | 340 | 160 |
| UT | 30 | 30 | 30 | <5 | <5 | <5 | <5 | <5 | <5 |
| VA | 2,030 | 1,810 | 240 | 1,210 | 10 | 1,220 | 900 | 1,220 | 30 |
| VT | 30 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 |
| WA | 10 | 10 | 10 | 10 | <5 | 10 | <5 | 10 | <5 |
| WI | 1,250 | 890 | 160 | 380 | <5 | 380 | 340 | 380 | <5 |
| WV | 490 | 490 | 60 | <5 | <5 | 10 | 20 | <5 | 10 |
| WY | 40 | 20 | <5 | <5 | <5 | <5 | 10 | <5 | <5 |

Note: Results are based on median values for withdrawal based on power plant fuels and cooling technologies from Macknick et al. 2012a, and rounded to the nearest 10 billion. Results for 2010 reflect outputs from modeling with a 2008 start year. The ReEDS model covers the 48 contiguous states, so calculations do not include Alaska and Hawaii.

## APPENDIX C2. *U.S. Power Plant Water Consumption across Scenarios, by State, 2010–2050 (billion gallons)*

| State | 2010 | Business as Usual | | Renewables/Efficiency | | CCS/Nuclear | | Carbon Budget | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
| AL | 42 | 51 | 22 | 19 | 1 | 35 | 56 | 19 | 29 |
| AR | 28 | 29 | 21 | 11 | <0.5 | 11 | 46 | 10 | 1 |
| AZ | 53 | 49 | 29 | 24 | 6 | 34 | 69 | 25 | 8 |
| CA | 26 | 38 | 44 | 24 | 23 | 19 | 40 | 16 | 30 |
| CO | 23 | 20 | 13 | 1 | 2 | 4 | 7 | 1 | 3 |
| CT | 2 | 2 | 5 | 1 | 1 | 1 | <0.5 | 1 | 10 |
| DE | 5 | 1 | 1 | 1 | <0.5 | 3 | 5 | 2 | 8 |
| FL | 67 | 86 | 99 | 39 | 37 | 50 | 106 | 49 | 77 |
| GA | 79 | 85 | 43 | 36 | 13 | 67 | 127 | 40 | 51 |
| IA | 16 | 24 | 18 | 4 | 1 | 5 | 7 | 5 | 2 |
| ID | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| IL | 84 | 74 | 14 | 49 | 1 | 51 | 52 | 51 | 24 |
| IN | 42 | 64 | 49 | 12 | 8 | 27 | 53 | 11 | 21 |
| KS | 27 | 26 | 14 | 6 | <0.5 | 6 | 12 | 6 | <0.5 |
| KY | 51 | 49 | 26 | <0.5 | <0.5 | 27 | 43 | 1 | 6 |
| LA | 26 | 30 | 31 | 11 | 1 | 38 | 56 | 12 | 19 |
| MA | 3 | 1 | 2 | 1 | <0.5 | 1 | <0.5 | <0.5 | 2 |
| MD | 13 | 10 | 7 | 2 | 2 | 2 | 7 | 2 | 4 |
| ME | 1 | <0.5 | 1 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| MI | 37 | 40 | 36 | 25 | 7 | 22 | 49 | 19 | 19 |
| MN | 23 | 22 | 14 | 7 | 1 | 8 | 8 | 8 | 2 |
| MO | 27 | 25 | 5 | 9 | 2 | 36 | 51 | 8 | 3 |
| MS | 14 | 14 | 12 | 2 | <0.5 | 7 | 6 | 2 | 5 |
| MT | 9 | 10 | 8 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| NC | 47 | 25 | 10 | 18 | 4 | 19 | 7 | 20 | 11 |
| ND | 14 | 14 | 9 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| NE | 7 | 7 | 4 | 3 | <0.5 | 3 | 1 | 3 | 2 |
| NH | 1 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| NJ | 6 | 6 | 10 | 8 | 3 | 3 | 11 | 2 | 10 |
| NM | 18 | 15 | 9 | 2 | 2 | 1 | 14 | 1 | 6 |
| NV | 6 | 8 | 12 | 4 | 5 | 3 | 4 | 3 | 4 |
| NY | 31 | 28 | 18 | 15 | 3 | 31 | 86 | 16 | 17 |
| OH | 54 | 45 | 12 | 14 | 2 | 21 | 71 | 13 | 18 |
| OK | 30 | 32 | 32 | 4 | 2 | 4 | 9 | 4 | 6 |
| OR | 3 | 4 | 4 | 1 | 1 | 1 | 1 | 1 | 1 |
| PA | 95 | 53 | 15 | 46 | 3 | 63 | 71 | 46 | 49 |
| RI | 2 | 2 | 3 | <0.5 | <0.5 | 2 | 1 | 1 | 2 |
| SC | 34 | 53 | 30 | 30 | 12 | 43 | 82 | 30 | 24 |
| SD | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| TN | 34 | 28 | 8 | 19 | 7 | 85 | 78 | 19 | 15 |
| TX | 137 | 149 | 135 | 60 | 22 | 109 | 228 | 66 | 77 |
| UT | 24 | 23 | 20 | 1 | 1 | 2 | 2 | 1 | 1 |
| VA | 28 | 25 | 13 | 13 | 5 | 12 | 20 | 12 | 22 |
| VT | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| WA | 7 | 8 | 5 | 6 | <0.5 | 6 | 2 | 6 | 1 |
| WI | 20 | 21 | 10 | 3 | <0.5 | 5 | 21 | 3 | 3 |
| WV | 44 | 50 | 8 | <0.5 | <0.5 | 6 | 21 | <0.5 | 6 |
| WY | 6 | 8 | 3 | 1 | 1 | 1 | 5 | 1 | 1 |

Note: Results are based on median values for consumption based on power plant fuels and cooling technologies from Macknick et al. 2012a, and rounded to the nearest 1 billion. Results for 2010 reflect outputs from modeling with a 2008 start year. The ReEDS model covers the 48 contiguous states, so calculations do not include Alaska and Hawaii.

# Energy and Water in a Warming World (EW3) Biographies

## Energy-Water Futures Research Team

**JOHN ROGERS**, a senior analyst in the Climate and Energy Program at the Union of Concerned Scientists (UCS), co-manages the Energy and Water in a Warming World initiative. Mr. Rogers formerly managed the UCS Northeast Clean Energy Project, working to implement a range of clean energy and climate policies. He serves on the board of directors of the U.S. Offshore Wind Collaborative and of Renewable Energy New England, and on the advisory boards of nonprofit organizations promoting U.S. renewable energy and global energy access. Mr. Rogers joined UCS in 2006 after working for 15 years on private and public clean energy initiatives, including as a co-founder of Soluz, Inc., a leading developer of clean energy solutions for rural markets, and as a Peace Corps volunteer in Honduras. He earned an M.S. in mechanical engineering at the University of Michigan and an A.B. at Princeton University.

**KRISTEN AVERYT** is the associate director of science for the Cooperative Institute for Research in Environmental Sciences at the University of Colorado–Boulder. She is also director of the university's Western Water Assessment, a program sponsored by the National Oceanic and Atmospheric Administration (NOAA) designed to connect climate science with decision making across the western United States. Before joining the University of Colorado in 2008, Dr. Averyt was a staff scientist for the Nobel Prize–winning Intergovernmental Panel on Climate Change. In 2005 she was a NOAA congressional fellow, where she worked as a legislative aid in the U.S. Senate. Her current research includes investigating the intersection of energy, water, and climate in the West, and evaluating strategies for adapting to climate change. Dr. Averyt trained as a geochemist specializing in paleoclimatology, and received her Ph.D. from Stanford University.

**STEVE CLEMMER** is the director of energy research for the UCS Climate and Energy Program, where he conducts research on the economic and environmental benefits of renewable energy technologies and policies at the state and national levels. He also directs UCS research on coal, natural gas, and nuclear power, and on solutions to reduce carbon emissions and water use in the electricity sector. Before joining UCS, Mr. Clemmer was the energy policy coordinator for the Wisconsin Energy Office from 1991 to 1997. Mr. Clemmer holds an M.S. in energy analysis and policy from the University of Wisconsin–Madison, and a B.A. in political science and history from Gustavus Adolphus College in St. Peter, MN.

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**DAVID YATES** is a scientist in the Research Applications Laboratory at the National Center for Atmospheric Research in Boulder, CO, and an associate of the Stockholm Environment Institute (SEI). His research has focused on local hydrologic challenges, and on the impact of climate change on water and agricultural systems and adapting to that impact. Dr. Yates has been part of the SEI team developing the WEAP model, and has used it to help water utilities with long-range planning, including planning for climate change. Dr. Yates received his Ph.D. in civil and environmental engineering from the University of Colorado–Boulder.

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# About UCS

The Union of Concerned Scientists puts rigorous, independent science to work to solve our planet's most pressing problems. Joining with citizens across the country, we combine technical analysis and effective advocacy to create innovative, practical solutions for a healthy, safe, and sustainable future.

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The Energy and Water in a Warming World initiative (EW3) is a collaborative effort between the Union of Concerned Scientists and a team of independent experts to build and synthesize policy-relevant research on the water demands of energy production in the context of climate variability and change. The initiative includes core research collaborations intended to raise the national profile of the water demands of energy, along with policy-relevant energy development scenarios and regional perspectives.

This report is based primarily on the research of the EW3 energy-water futures collaborators, which appears in a special issue of *Environmental Research Letters:* Focus on Electricity, Water and Climate Connections.

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