10. Water, Energy, and Land Use

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Key Messages

1. **Energy, land, and water systems interact in many ways. Climate change affects the individual sectors and their interactions; the combination of these factors affects climate vulnerability as well as adaptation and mitigation options for different regions of the country.**
2. **The dependence of energy systems on land availability and water supplies will influence their development and constrain some options for reducing greenhouse gas emissions.**
3. **Jointly considering risks, vulnerabilities, and opportunities associated with energy, water, and land use is difficult, but can improve the analysis of options for reducing climate change impacts.**

Energy, water and land systems interact in many ways. Energy projects – coal-fired power, biofuel, solar farms – require varying amounts of water and land; water projects – water supply, irrigation – require energy and land; and land activities – agriculture, forestry – depend upon energy and water. Increasing population and a growing economy intensify these interactions (Skaggs et al. 2012). Climate change impacts each of these sectors directly, and because of the many connections between them, sectoral responses are often intensified or offset.

The implications of climate change for the energy, land, and water sectors have been studied extensively (see Ch. 4: Energy, Ch. 13: Land Use and Land Cover Changes, and Ch. 3: Water Resources of this report). Bilateral relationships between energy and water, land and water, and energy and land have also received significant attention. There are few analyses, however, on how the competition for multiple resources such as water supply, land availability, or environmental considerations (for example, biodiversity) interacts with decision-making for future energy demand and production in a changing climate.

Recent events such as the drought and heat waves experienced across much of the U.S. during the summers of 2011 and 2012 do provide some insights. They demonstrated that weather impacts within each of these sectors create cascading interactions among energy, land, and water sectors. High temperatures caused increased demand for electricity for air conditioning, which corresponded to increased water withdrawal and consumption for electricity generation. Heat, increased evaporation, drier soils, and lack of rain led to higher irrigation demands, which added stress on water resources required for energy production. At the same time, low-flowing and warmer rivers resulted in temporarily suspended power plant production in several states due to environmental concerns, reducing the options for dealing with the concurrent increase in electricity demand.

Challenges from climate change will arise from longer-term, more gradual change, as well as from projected changes in weather extremes. Energy production already competes for water resources with agriculture, human consumption, and natural systems. It is projected that climate-driven changes in land cover and land use will further affect water quality and availability. In turn, diminishing water quality and availability requires more energy to purify water and more infrastructure on land to store and distribute water.

The availability of energy, water, and land resources and the ways in which they interact vary across U.S. regions. U.S. regions differ in their: a) energy mix (solar, wind, coal, hydropower); b) precipitation and temperature patterns; c) sources and quality of available water resources (for example, ground, surface, recycled); d) technologies for storing, transporting, and using water; and e) land use and land cover (see Ch. 13: Land Use and Land Cover Changes). Because of these unique regional characteristics, impacts and related risks and vulnerabilities to climate change vary widely. Mitigation and adaptation options also differ significantly across regions.

Interactions among water, energy, and land resources are influencing and will influence technologies deployed in the future energy system. Energy technologies vary widely in their demands for land and water. Current competition for water supplies is leading to deployment of more expensive, but less water-intensive technologies, such as dry cooling for thermoelectric generation and photovoltaics for solar energy production. Competition for land and water resources is expected to intensify and will further affect technology choices in the future.

In some situations, land and water constraints limit options for reducing greenhouse gas emissions aimed at mitigating future climate change. For example, rapidly growing energy options such as solar power, biofuels, or expanded use of natural gas reduce net greenhouse gas emissions. In addition, these fuels reduce U.S. dependence on foreign energy resources and, at least in the case of shale gas, provide greater geographic diversity and resilience in supply, reducing dependence on supplies from the Gulf of Mexico. But, as with other technologies, these energy sources utilize land and water resources and are often not consistent with existing management strategies. For example, utility-scale concentrated solar power plants require relatively large tracts of land, and early siting efforts have raised environmental concerns.

Current challenges in siting land- and water-intensive energy facilities are likely to intensify over time as competition for these resources grows. With most of the potential deployment of concentrating solar technologies in the Southwest, facilities will need to be extremely water-efficient in order to compete for limited water resources. Raising crops to produce biofuels uses arable land and water that might otherwise be available for food production. This fact came into stark focus during the summer of 2012 when drought caused poor corn harvests, raising concerns about allocation of the harvest for food versus ethanol. Natural gas production from shale formation presents similar resource challenges. Technology breakthroughs in hydraulic fracturing have made shale gas production economical and dramatically changed the U.S. gas supply and price outlook, potentially for decades. At current prices, natural gas is replacing coal-fired electric generation, and the U.S. Energy Information Administration (EIA) projects that natural gas will continue on this trajectory. The observed decline in U.S. carbon emissions in 2011 has been directly attributed to increased penetration of natural gas into the U.S. energy portfolio, among other factors (EIA 2012). However, shale gas production requires significant amounts of water at the local scale, which creates demands on regional water resources. Water quality issues have also been raised and are the subject of ongoing research. Competition for land and water in a changing climate influences technology choices and subsequently limits some technologies that could be positive contributors to mitigating greenhouse gas emissions. These kinds of tradeoffs – mitigation strategies to reduce greenhouse gasses versus land and water resources required to implement mitigation technologies – will need to be jointly considered.

Conflicting stakeholder perceptions, institutional commitments, and international concerns can limit options for reducing vulnerability to climate change, and interactions among water, energy, and land resource sectors have the potential to intensify such constraints. Resource management decisions are often focused on just one of these sectors. Where the three sectors are tightly coupled, options for mitigating or adapting to climate change and consideration of the tradeoffs associated with technological or resource availability may be limited. For example, the Columbia River Treaty between Canada and the U.S. emphasizes hydroelectric power and flood control (see Columbia River section below).

Cascading Events

Energy, land, and water systems interact in many ways. Climate change affects the individual sectors and their interactions; the combination of these factors affects climate vulnerability as well as adaptation and mitigation options for different regions of the country.

Energy production, land use, and water resources are linked in increasingly complex ways. Electric utilities and energy companies compete with farmers and ranchers for water rights in many parts of the country. Land use planners must consider the impacts of strained water supplies on cities, agriculture, and ecological needs. Across the country, these intertwined sectors will witness increased stresses due to climate changes that are projected to lower water quality and/or quantity in many regions and increase heat-related electricity demand, among other impacts.

In 2011, drought spread across the south-central U.S., causing a series of energy, water, and land impacts that demonstrate the connections among these sectors. Texans, for example, experienced the hottest and driest summer on record. Summer average temperatures were 5.2°F higher than normal, and precipitation was lower than previous records set in 1956. The associated heat wave, with temperatures above 100°F for 40 consecutive days, together with drought, strained the region's energy and water resources (Hoerling et al. 2012; NCDC 2012).

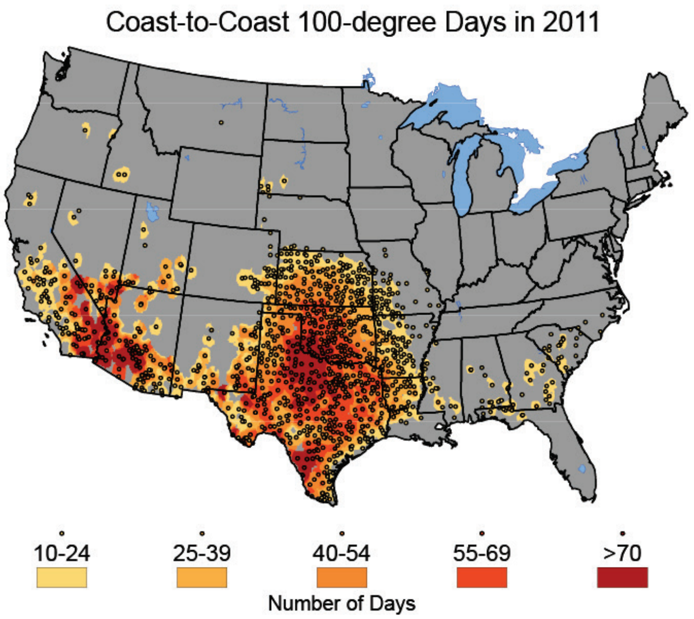

Figure 10.1: Coast-to-Coast 100-degree Days in 2011

Caption: Map shows the distribution of places around the country with days having high temperatures of 100ºF or more during the record-setting summer of 2011. The record temperatures and drought during the summer of 2011 represent conditions that will be more likely in the U.S. as climate change continues.

(Source: NOAA NCDC, 2012).

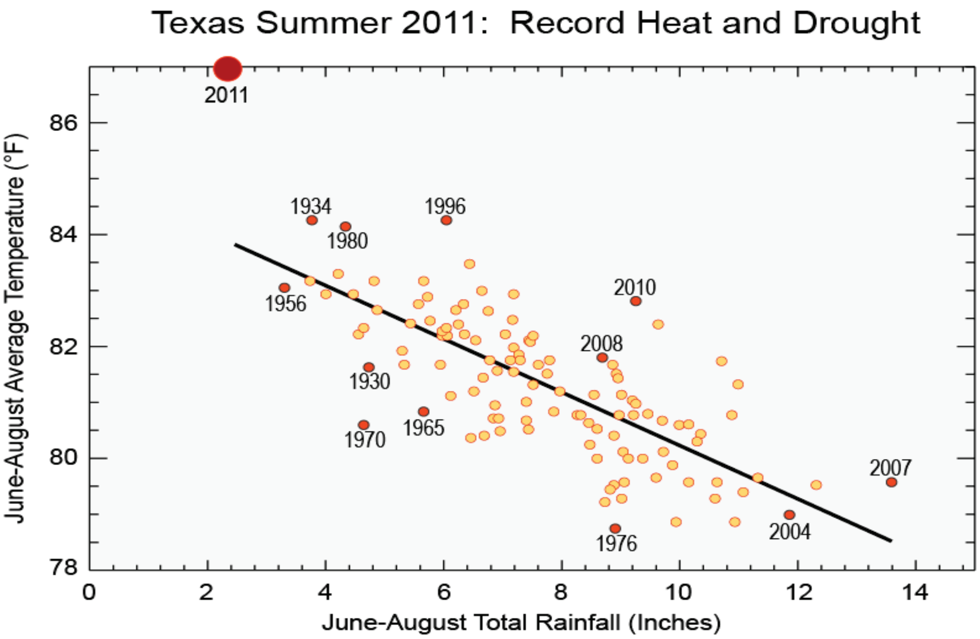

Figure 10.2: Texas, Summer 2011: Record Heat and Drought

Caption: Graph shows average summer temperature and total rainfall in Texas from 1919 through 2011. The record temperatures and drought during the summer of 2011 (red dot) represent conditions far outside those that have been registered since the instrumental record began (NCDC 2012). An analysis has shown that the probability of such an event has more than doubled as a result of human-induced climate change (Hoerling et al. 2012).

The impacts on land resources and land use were dramatic. Drought reduced crop yields and affected livestock, costing Texas farmers and ranchers more than $5 billion, a 27.7% loss compared to average revenues of the previous four years (Fannin 2011). With increased feed costs, ranchers were forced to sell livestock at lower value. Drought increased tree mortality (TFS 2011a), providing more fuel for record wildfires that burned 3.8 million acres (an area about the size of Connecticut) and destroyed 2,763 homes (TFS 2011b).

Energy, water, and land interactions complicated and amplified these impacts. With electricity demands at all-time highs, water shortages threatened more than 3,000 megawatts of generating capacity—enough power to supply more than one million homes (Smith 2011). As a result of record electricity consumption, marginal prices repeatedly hit $3,000 a megawatt hour, which is three times the maximum amount that generators can charge in deregulated electricity markets in the eastern U.S. (Giberson 2011). More than 16% of electricity production relied on cooling water from sources that shrank to historically low levels (ERCOT 2011), and water used to generate electricity competed with simultaneous demands for agriculture and other human activities.

City and regional managers rationed water to farms and urban areas, and in some instances, water was trucked to communities that lacked sufficient supplies (Fernandez 2012). As late as November 2011, about 20% of Texas public water systems were still affected by water restrictions. At the same time, changing vegetation attributes, grazing, cropping, and wildfire compromised water quality and availability, requiring more power for water pumping and purification. One community banned water use for shale gas extraction, and biofuel production was constrained.

The co-occurrence of a heat wave and drought could play out differently in other parts of the country because of relative differences in the manifestation of climate change impacts on energy, water, and land resources and in the manmade infrastructure. For example, sustained drought events in the Pacific Northwest will affect electricity supply directly by reducing hydropower resources and pose challenges for ecosystem services. Hydropower is increasingly being used to balance intermittent wind generation in the Northwest and seasonal hydroelectric restrictions have already created challenges to fulfill this role. Drought in the Midwest poses challenges to meeting electricity demands because diminished water availability and elevated water temperatures reduce the efficiency of electricity generation. Temporary plant shutdowns are mandated in many states if the temperature of water returned to streams after being used to cool power plants exceeds thresholds protecting water quality.

Interactions of Water, Energy, and Land Uses

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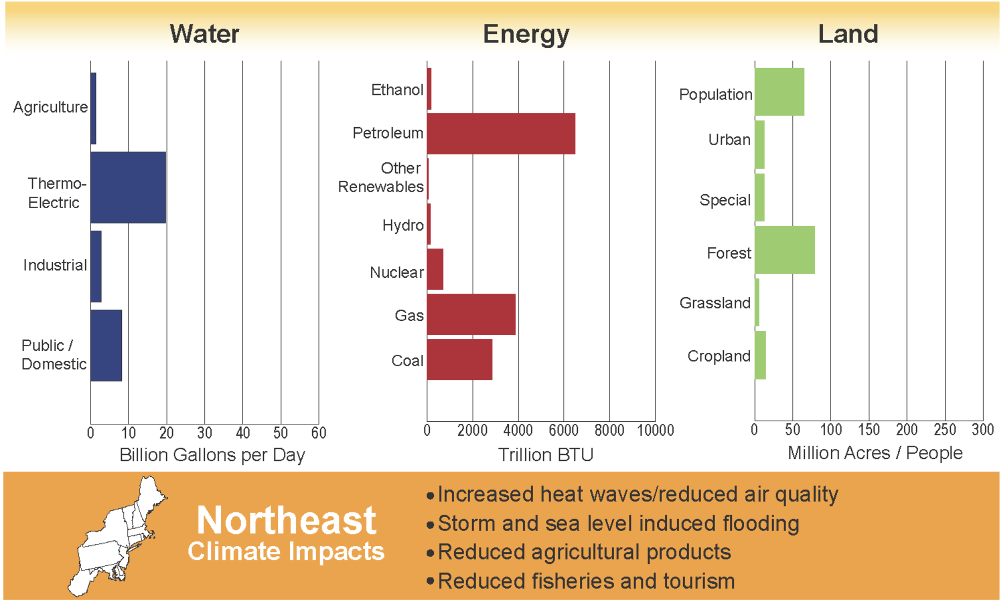

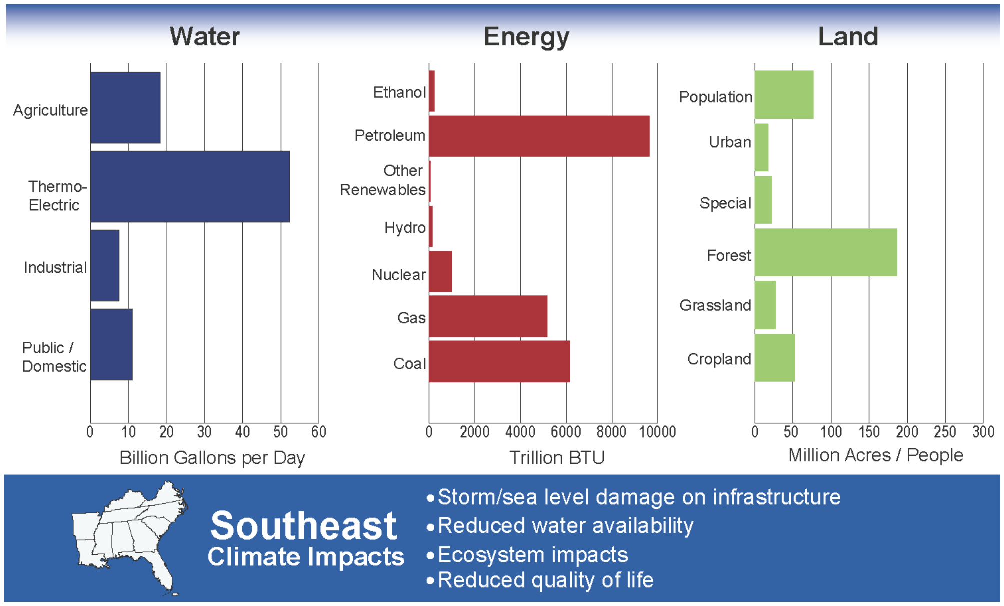

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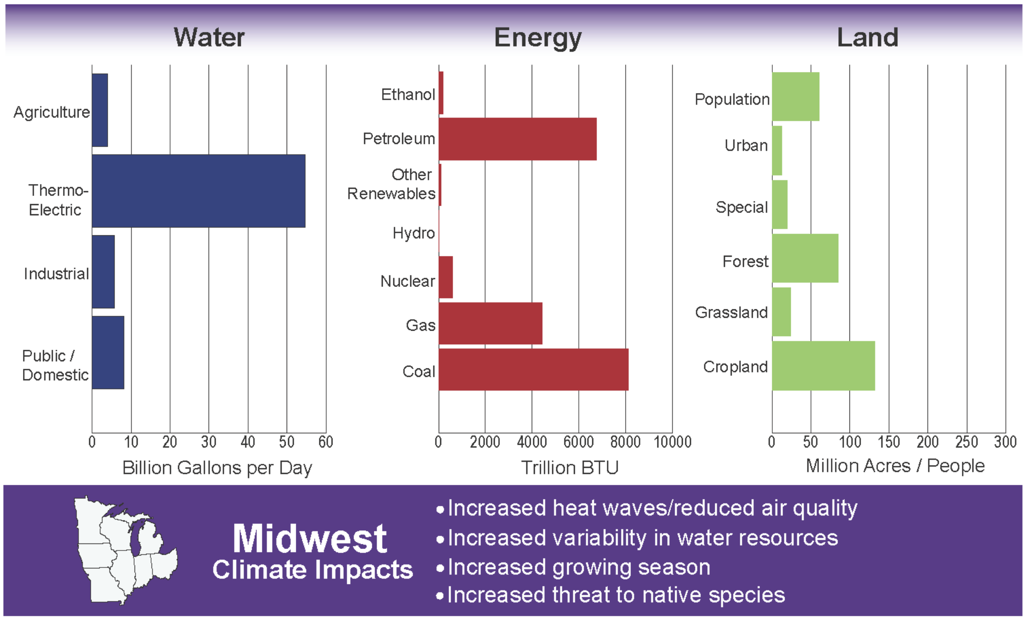

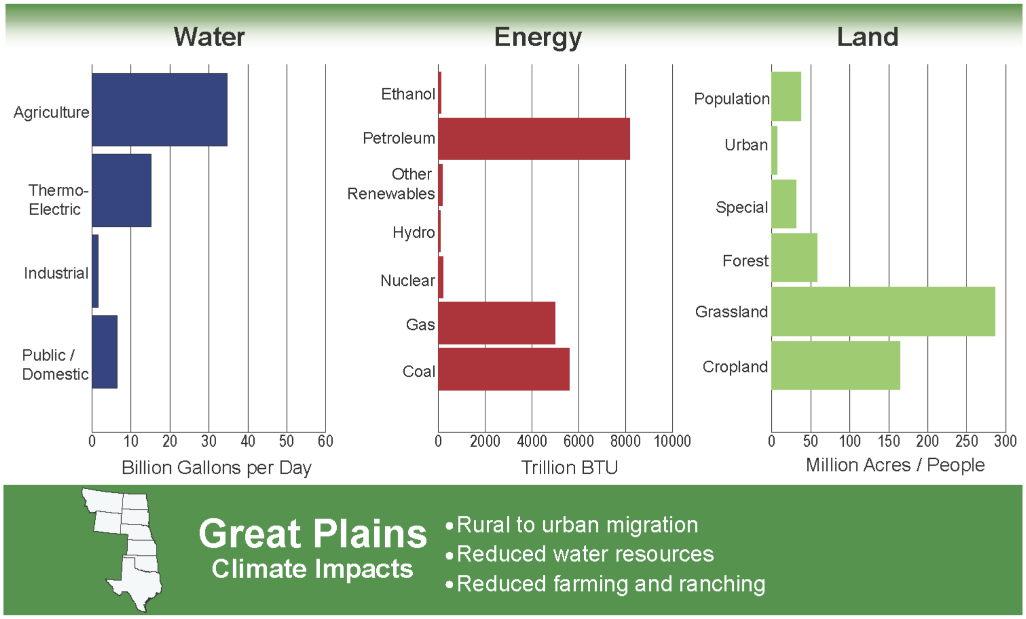

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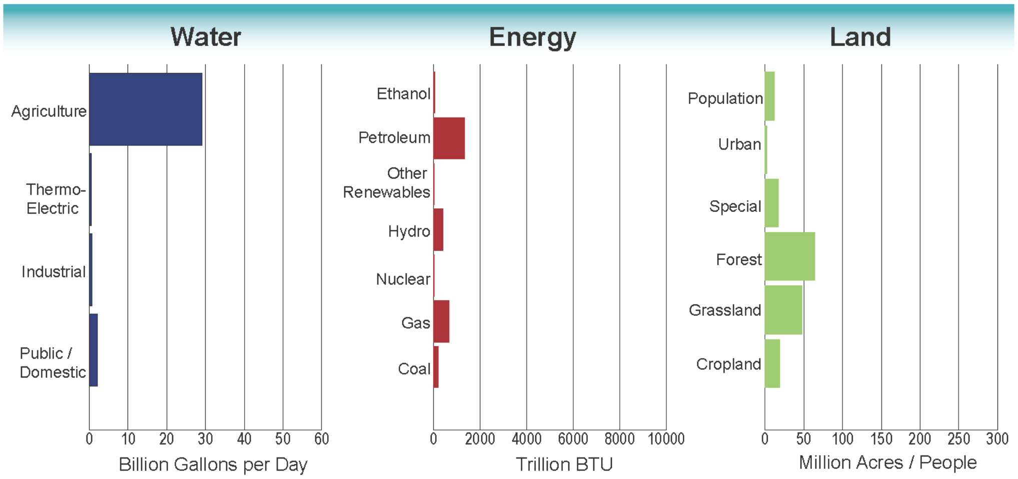
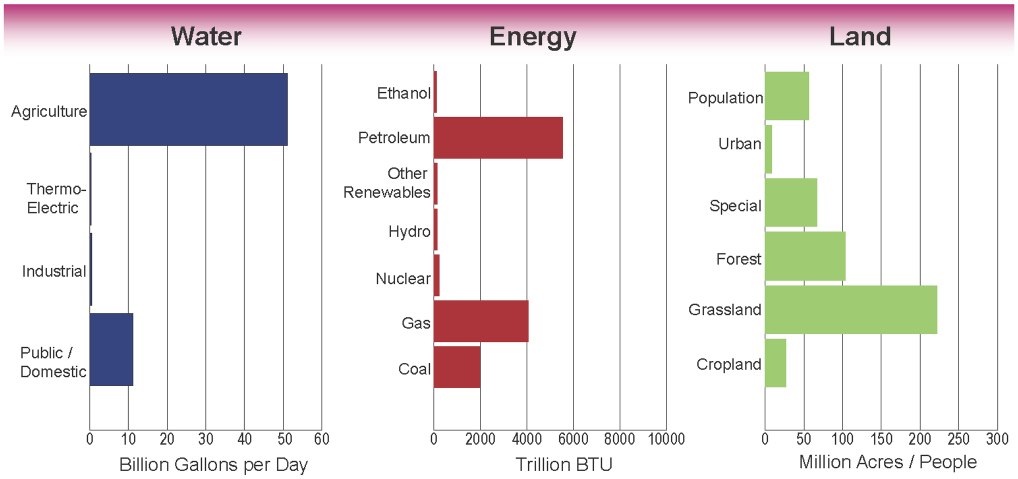
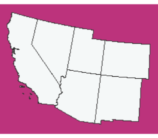


Northwest
Climate Impacts

- Reduced summer stream flows
- Reduced forest production
- Reduced salmon production
- Coastal erosion





Southwest
Climate Impacts

- Increased flooding risk to infrastructure
- Increased water stress
- Increased vegetation change
- Reduced forming tourism and urban growth

NOTE: THIS GRAPHIC IS INTENDED FOR INTERACTIVITY

Figure 10.3: Interactions of Water, Energy, and Land Uses

Caption: Breakout of unique regional characteristics of current use of land, energy, and water in the context of climate change. There is significant regional variation in how water is used in each region, notably the relative amounts used for agriculture and energy production. Energy mix also varies by region, with all regions showing a high reliance on petroleum and other fossil fuels. Agriculture includes irrigation, livestock, and aquaculture uses. (Sources: Energy data from EIA 2012; Water data from Kenny et al. 2009; Land data from USDA ERS 2007)

Options for Reducing Emissions

The dependence of energy systems on land availability and water supplies will influence their development and constrain some options for reducing greenhouse gas emissions.

Energy systems vary widely in their use of land and water. The chart below provides a perspective on water withdrawals and consumptive use, illustrating the wide variation across both generation technologies and the accompanying cooling technologies. Energy technology choices today are strongly influenced by water and land considerations. Land and water influences on energy production capacity are expected to get stronger in the future.

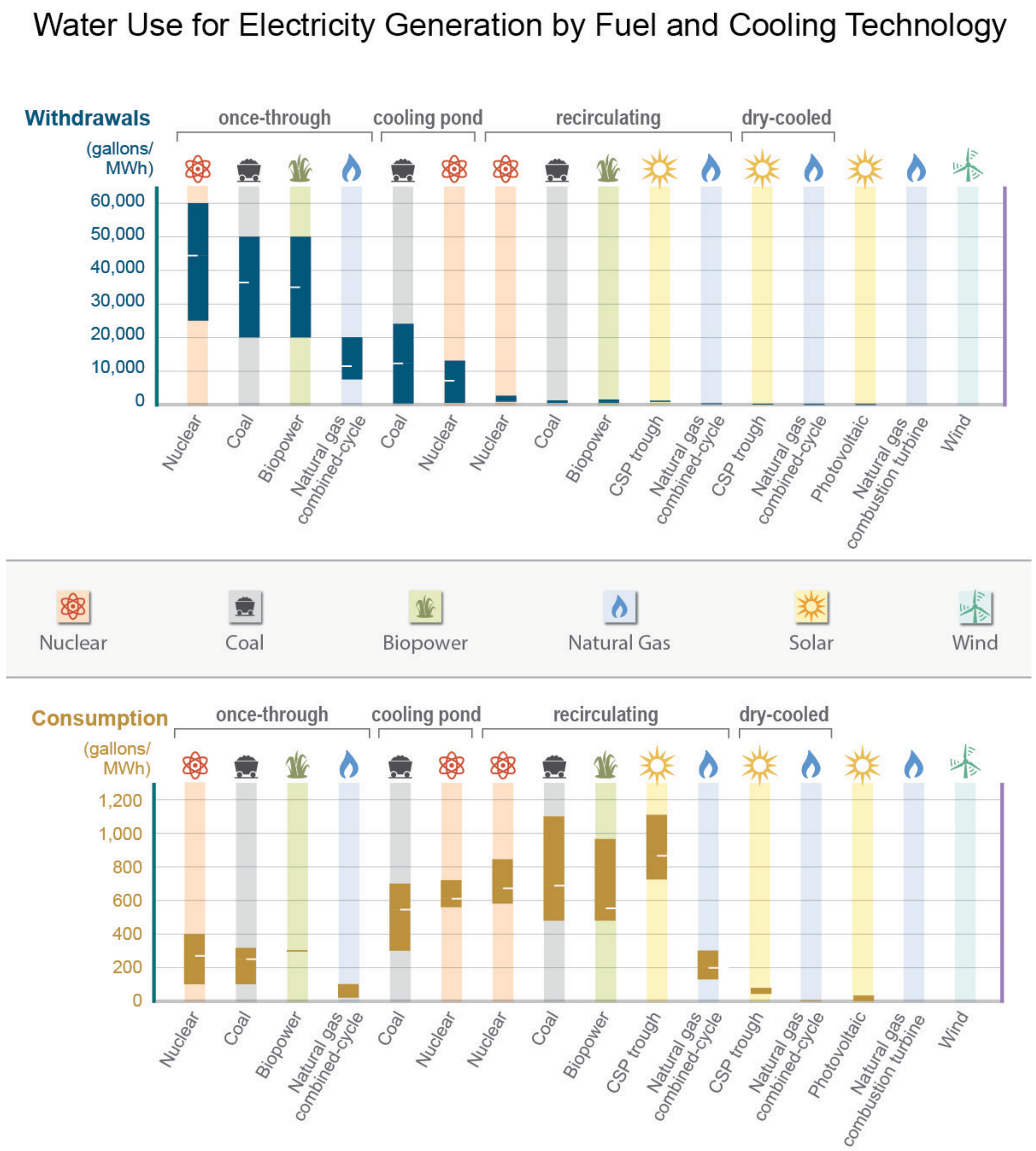


Figure 10.4: Water Use for Electricity Generation by Fuel and Cooling Technology

Caption: Technology choices can significantly affect both water withdrawals and consumption. For example, using cooling ponds versus once-through cooling for nuclear power generation can dramatically reduce water withdrawal from streams and rivers, but increases the amount of water consumed. Ranges reflect minimum and maximum amounts of water used for selected technologies.

Top panel shows water withdrawals for various electricity production methods. Some methods, like most conventional nuclear power plants that use "once-through" cooling systems, require large water withdrawals, and return most of that water to the source (usually rivers and streams). For nuclear plants, utilizing cooling ponds can dramatically reduce water withdrawal from streams and rivers, but increases the total amount of water consumed.

Bottom panel shows water consumption for various electricity production methods. Coal-powered plants using recirculating water systems have relatively low requirements for water withdrawals, but consume much more of that water, as it is turned into steam. Water consumption for various dry-cooled electricity generation is negligible.

(Source: Averyt et al. 2011; Macknick et al. 2011).

Technological advances create opportunities to take advantage of energy resources with reduced greenhouse gas emissions. Today, recent advances in natural gas extraction methods are providing low-cost, potentially abundant fuel for electricity generation with significantly reduced carbon dioxide emissions compared to coal-fired power plants. With substantial changes to the U.S. power system, renewable energy, including solar, wind, and biofuels, could meet a considerable fraction of the nation's demand for electricity in 2050 (Mai et al. 2012) with significantly reduced greenhouse gas emissions. Over the longer term, carbon dioxide capture and storage (CCS) technologies could play a key role in reducing emissions from fossil fuel use, but costs could be prohibitive (Ranjan and Herzog 2011). In combination with biofuels, however, costs of CCS technologies are reduced and may even provide a means of reducing atmospheric CO_2 levels (Keith et al. 2006; Lackner 2009).

The availability of water and/or land resources will impact design choices and operations of these technologies in the future and, in some cases, constrain their deployment. Changing climate conditions have the potential to intensify these effects. The following sections discuss energy, land, and water interactions for four key emerging or future technologies for reducing carbon emissions – natural gas from shale, solar power, biofuels, and CCS – and describe some of the technology options for addressing challenges that arise from these interactions.

Natural Gas

Natural gas provides a fossil fuel alternative to coal production with reduced carbon dioxide emissions. During 2010, U.S. natural gas production was the highest recorded since 1973 (EIA 2011). Horizontal drilling and hydraulic fracturing made possible much of this growth in domestic gas production. These techniques enable extraction of natural gas trapped in shale formations: fine-grained sedimentary rocks that are often rich sources of petroleum and natural gas. Horizontal wells sometimes extend 5,000 feet or more through a shale deposit. Hydraulic fracturing breaks apart relatively impermeable shale, allowing gas to flow into wells (Figure 4).

The U.S. Energy Information Administration projects a 29% increase in U.S. natural gas production by 2035, with lower CO_2 emissions where natural gas displaces other fossil fuels (EIA 2012). A natural gas combined-cycle power plant emits about 50% less CO_2 than does a modern coal plant. The projected increases in natural gas production would lead to a significant reduction in U.S. greenhouse gas emissions over other fossil fuel alternatives.

Hydraulic fracturing for shale gas production requires significant amounts of water. A typical horizontal well for shale gas production requires from 2.5 to 5 million gallons of water, frequently from streams, reservoirs, or groundwater (DOE 2009a), but also from private water, municipal and re-used produced water (http://www.naturalgas.org/shale/waterrequirements.asp). While not large compared to many other water demands, this water use can become an issue in specific locations. As the suspension of shale gas extraction activities in Texas during the 2011 drought demonstrated, in regions where climate change leads to drier conditions, hydraulic fracturing is vulnerable to climate-change related reductions in water supply, at least during times of water stress or limited water availability. The gas extraction industry has begun reusing water in order to lower demand. After the hydraulic fracture is made, gas and water are produced from the well. The produced water is a combination of water, chemicals, and sand that were injected, and local formation water that may contain radioisotopes and other compounds. The produced water stream may require treatment depending on whether it is re-injected or discharged to surface water. Recycling the water becomes more difficult as salts and other contaminants build up in the water with each reuse. Typically, flow-back water can be reused 3 to 4 times, but in some situations, it can be reused as many as 8 times (http://lingo.cast.uark.edu/LINGOPUBLIC/natgas/wellprod/index.htm), significantly reducing water demands.

The chemicals involved in hydraulic fracturing – both those injected and the natural elements in the produced water – have raised water quality concerns. Federal government and state-led efforts are underway to identify, characterize, and if necessary, find approaches to address these issues. At the federal level, the U.S. EPA has developed a 3-year research plan to study potential impacts on drinking water quality across the country (EPA 2011). In addition, regulatory and government agencies in a number of states have joined forces to create FracFocus.org – a public website for providing information on hydraulic fracturing and groundwater protection. Eight states have adopted the FracFocus system for official reporting of chemicals used in hydraulic fracturing.

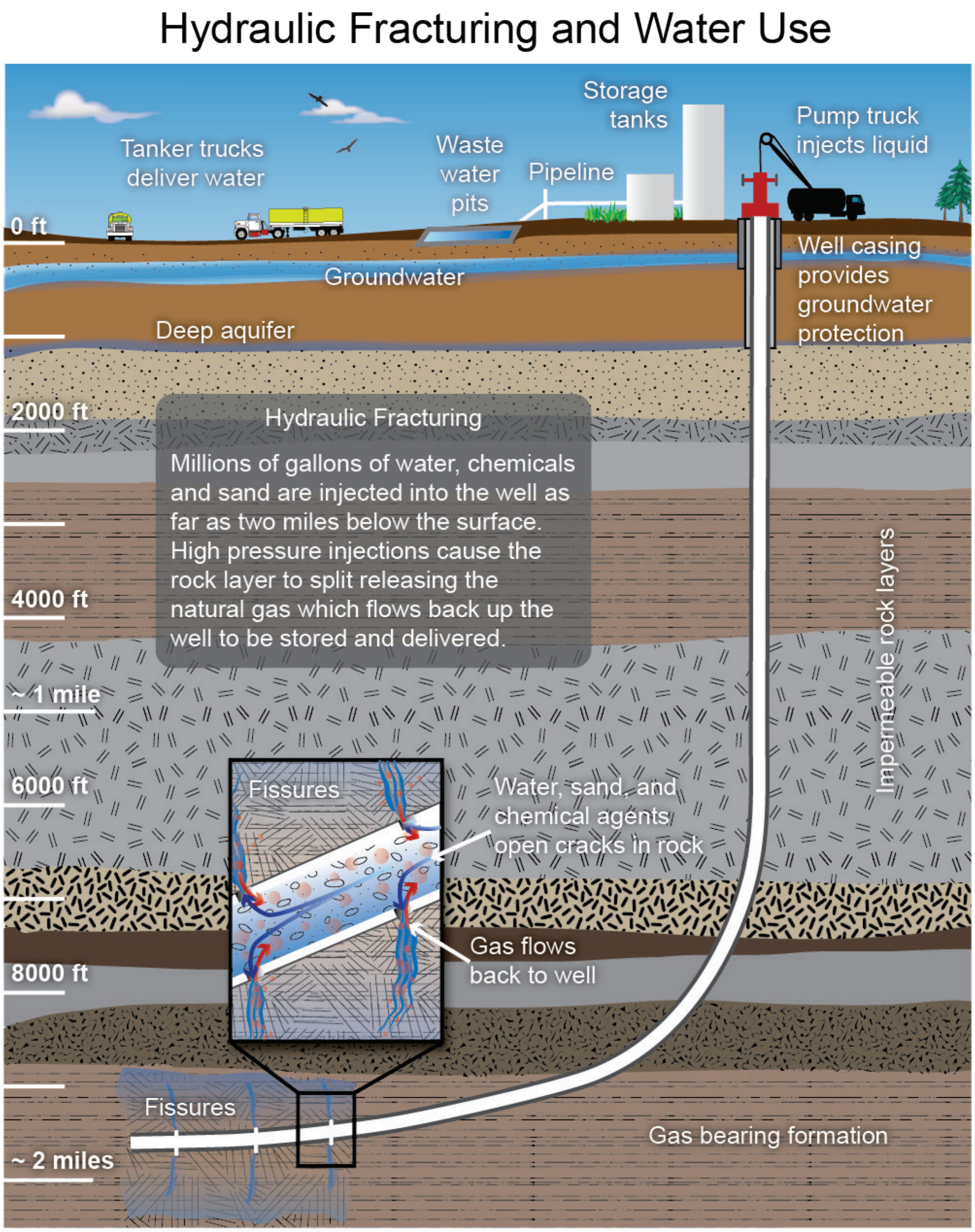


Figure 10.5: Hydraulic Fracturing and Water Use

Caption: Hydraulic fracturing, a drilling method used to retrieve deep reservoirs of natural gas, uses large quantities of water, sand, and chemicals that are injected at high pressure into horizontally drilled wells as deep as 10,000 feet below the surface. The pressurized mixture causes the rock layer to crack. Sand particles hold the fissures open so that natural gas from the shale can flow into the well. Questions about both the water quantity necessary for this extraction method, as well as the potential to affect water quality, have produced national debate about this method.

The competition for water is expected to increase in the future. State and local water managers will need to assess how gas extraction competes with other priorities for water, such as water for other energy production, irrigation, municipal supply, industry use, and livestock production. Collectively, such interactions between the energy and water resource sectors increase vulnerability to climate change, particularly in water-limited regions that are projected to, or become, significantly drier.

Solar Power Generation

Efficient solar power requires long days with few clouds. Such conditions are prominent across the Southwest U.S., and, with few exceptions, current and pending utility-scale solar facilities are located in the Southwest where sparsely populated land is available. Climate change, however, is projected to affect surface and groundwater supplies within this already arid region (see Ch. 20: Southwest).

Figure 10.6: Renewable Energy and Land Use

Caption: Photovoltaic panels convert sunlight directly into electricity. Utility-sized solar power plants require large tracts of land.

(Source: Duke Energy, under a creative commons license http://www.flickr.com/photos/dukeenergy/5187413025/)

Solar energy technologies have the potential to satisfy a major portion of U.S. electricity demands as an alternative to fossil fuels, reducing greenhouse gas emissions. But utility-scale solar power systems require substantial land, and at least in the case of solar thermal facilities, water is also required. A recent Department of Energy study concluded that meeting 14% of the U.S. demand for electricity with solar power by 2030 could require twice the land area of Delaware and, depending on the cooling technology, significant water resources (DOE 2012).

The land and water requirements for solar energy systems vary substantially among technologies. For utility-scale electricity generation, photovoltaic systems require 3 to 10 acres per megawatt (MW) of generating capacity and consume as much as 5 gallons of water per megawatt hour (MWh) of electricity production. Another technology for utility-scale electricity generation – concentrating solar systems, requires up to 15 acres per MW and wet cooling consumes 1,040 gallons of water per MWh (DOE 2012). Land and biodiversity constraints were amply illustrated with the suspension of a concentrating solar power (CSP) farm, the $2.2B BrightSource Energy solar farm in the Ivanpah Valley, CA, when desert tortoise relocation and protection cost the company as much as $40M (Cart 2012; Wang 2011). At this time, construction for the Ivanpah project is proceeding (Fehrenbacher 2012).

One of the world's largest concentrating solar systems, Solar Energy Generating Systems (SEGS), located in California's Mojave Desert, uses water for cooling as well as to produce steam for electricity generation. But recognizing water limitations and the need for cooling, most large-scale solar systems now in planning or development will be dry cooled and will rely on molten salt or other materials for heat transfer, substantially reducing water demands. Although warmer air resulting from climate change will reduce the efficiency of electricity production, these newer solar systems will be less vulnerable to the drier conditions projected to occur in the region with climate change. However, dry cooling systems are more expensive and result in lower plant thermal efficiency. Dry cooling systems also have a higher upfront capital cost than wet systems and require a significant amount of energy to operate. The Beacon solar energy project (WorleyParsons Group Inc. 2008) reported that air cooling resulted in a "parasitic" loss of 7.5% of net electricity produced, and hybrid cooling (a combination of dry and wet cooling) technologies led to a 4.6% loss. Moreover, the losses are greater on hot days— typically when and where peak power is most in need (DOE 2009b; Maulbetsch and DiFilippo 2006). Thus plant designs will have to carefully balance cost, operating issues, and water availability.

Biofuels

Biofuels made from grains, sugar and oil crops, starch, grasses, trees, and biological waste can reduce U.S. dependence on foreign energy resources, while reducing greenhouse gas emissions. Under the Renewable Fuel Standard (RFS2), which is overseen by the EPA, there is a production goal of 36 billion gallons of biofuels annually by 2022, including 16 billion gallons of cellulosic biofuel, 15 billion gallons of conventional biofuels (mostly corn-based ethanol), and at least 1 billion gallons of biodiesel (EPA 2012). The remaining amount of the goal will be satisfied by the Advanced Biofuel Requirement, which is expected to be mostly sugarcane ethanol from Brazil (NRC 2011).

Currently, most U.S. biofuels, primarily ethanol and diesel fuel, are produced from edible parts of corn grown on rain-fed land. About 40% of the 2011 U.S. corn crop was used to produce more than 13 billion gallons of ethanol, which helped satisfy around 10% of U.S. gasoline demand. While ethanol production competes with food production and other uses of corn, the fermentation process used to create ethanol produces a variety of economically valuable co-products. For example, dried distillers' grains (DDGs), a direct byproduct of corn ethanol production, are an important component of animal feed (NRC 2011; USDA ERS 2011). In the U.S., about 50% of biodiesel is made from soybeans, with the rest made from animal fats, recycled fats and oils, and other crop oils. However, total U.S. biodiesel production is much lower than ethanol production, and is very limited compared to other parts of the world where diesel engines are more common

Approximately 40 million acres of cropland in the United States were used for ethanol production in 2011, roughly 16% of the land planted to the eight major field crops (USDA 2012).

Several long-term factors influence commodity and food prices, including global growth in population and per capita incomes, related increases in world per capita consumption of animal products, depreciation of the U.S. dollar, rising energy prices, and expansion of global biofuel production that is more rapid than overall growth in agricultural productivity. Recent crop price increases have been driven by a series of adverse weather events in a number of major world producing regions that occurred in a relatively compressed time period from June 2010 to April 2011 (Trostle et al. 2012). Biofuels have the potential to provide net environmental benefits compared to petroleum-based fuels. However, the extent of these benefits depend on many site-specific factors: the type of feedstock, management practices used to produce them, prior land use, and land-use changes caused by their production. For example, biofuel production has been cited for contributing to harmful algal blooms, eutrophication (an influx of nutrients that can lead to the excessive growth of algae), and hypoxic conditions (oxygen-depleted "dead zones") in the Gulf of Mexico and elsewhere (NRC 2011). Consumptive water use over the life cycle of corn-grain ethanol varies widely, from 15 gallons of water per gallon of gasoline equivalent for rain-fed corn-based ethanol in Ohio, to 1,500 gallons of water per gallon of gasoline equivalent for irrigated corn-based ethanol in New Mexico; in comparison, petroleum-based fuels use 1.9 to 6.6 gallons of water per gallon of gasoline (NRC 2011).

Looking forward, the current production level of conventional corn-based ethanol is very close to its RFS2 target level of 15 billion gallons annually. The greatest expansion is targeted for cellulosic biofuels – biofuels derived from the entire plant rather than just the food portions, principally cellulose, hemicelluloses, or lignin. No commercially viable refineries currently exist for cellulosic biofuel production (though several commercial refineries are in development in the U.S.), and the estimated cost of producing cellulosic ethanol is currently much higher than the cost of corn ethanol (NRC 2011). Cellulosic feedstocks necessary to meet the aggressive RFS2 target of 16 billion gallons annually could require an additional 30 to 60 million acres of land (NRC 2011). Additionally, cellulosic biomass potentially has several advantages over corn, including fewer water quality concerns (for example, Costello et al. 2009), less water consumption, and the potential for use of forest products (NRC 2011).

To the extent that further expansion of land for biofuel feedstock production is located in more arid, less arable regions, irrigation and fertilizer uses will increase (Graham-Rowe 2011). The impacts of climate change (See Ch. 2: Our Changing Climate, Ch. 3: Water Resources, and Ch. 6: Agriculture), however, may make it increasingly difficult to raise crops in arid regions of the country. The use of crops such as switchgrass that are better suited to arid conditions and are efficient in recycling nutrients can reduce the vulnerability of biofuel production to climate change.

Carbon Dioxide Capture and Storage

Carbon capture and storage (CCS) technologies have the potential to reduce emissions from coal- and natural gas-fired plants by 90%, allowing continued use of fossil fuel in a carbon-constrained future. In addition, capturing and storing carbon dioxide emissions from the combustion of biofuels represents one of very few potential options for reducing atmospheric CO_2 (IPCC 2005). Carbon from the atmosphere accumulates in growing plants that are used to produce a biofuel. When the biofuel is combusted, the CO_2 is captured and stored, constituting a net removal of CO_2 from the atmosphere for as long as storage continues and the standing stock of plants is sustained.

CCS substantially increases the cost of building and operating a power plant. In addition to the upfront capital expense, the CCS process requires about 15% to 30% of the plant output to operate. Substantial amounts of water are also used to separate CO_2 from emissions (Newmark et al. 2010). However, the technology is just emerging. The only facilities currently operating are at the pilot scale, and many opportunities exist to reduce these impacts. For example, gasification technologies, where coal or biomass are converted to gases and CO_2 is separated before combustion, reduce the energy penalty and water requirements but currently have higher capital costs. Thus, as with solar power, technology and design choices for CCS need to be balanced with water requirements when deployed in dryer regions.

Challenges to Reducing Vulnerabilities

Jointly considering risks, vulnerabilities, and opportunities associated with energy, water, and land use is difficult, but can improve the analysis of options for reducing climate change impacts.

Because of the complex nature of the interactions among land, energy, and water systems, considering the complete picture of climate impacts and potential adaptations can help provide better solutions. The Columbia River basin is one example of an area where risks, vulnerabilities, and opportunities are being jointly considered. The Columbia River is the fourth largest river on the continent, crossing the U.S. and Canadian border, and drives the production of more electricity than any other river in North America. Approximately 15% of the Columbia River Basin lies within British Columbia (Figure 8), but an average of 30% of the total average discharge originates from the Canadian portion of the watershed. To provide flood control for the U.S. and predicted releases for hydropower generation, the Columbia River system is managed through a treaty that established a cooperative agreement between the U.S. and Canada to regulate the river for these two uses (Center for Columbia River History 2012). The basin also supports a range of other uses, such as navigation, irrigation, fish and wildlife habitat, recreation, and water resources for agricultural, industrial, and individual use. For all multi-use river basins, understanding the combined vulnerability of water, energy, and land use to climate change is essential to planning for water management and climate change adaptation.

The National Climate Assessment climate outlook for the Northwest shows a warmer annual and drier summer climate (Ch. 21: Northwest), potentially affecting both the timing and amounts of water availability. For example, if climate change reduces streamflow at certain times, fish and wildlife, as well as recreation, may be vulnerable (Dalton et al. 2012). Climate change stressors will also increase the vulnerability of the region’s vast natural ecosystems and forests in multiple ways (see Ch. 7: Forests and Ch. 8: Ecosystems). Currently, only 30% of annual Columbia River Basin runoff can be stored in reservoirs (Bruce et al. 2003). Longer growing seasons might provide opportunities for greater agricultural production, but the projected warmer and drier summers could increase demand for water for irrigation, perhaps at the expense of other water uses due to storage limitations. Wetter winters might offset increased summer demands, but existing hydropower storage capacities were not designed to accommodate significant increases in winter precipitation.

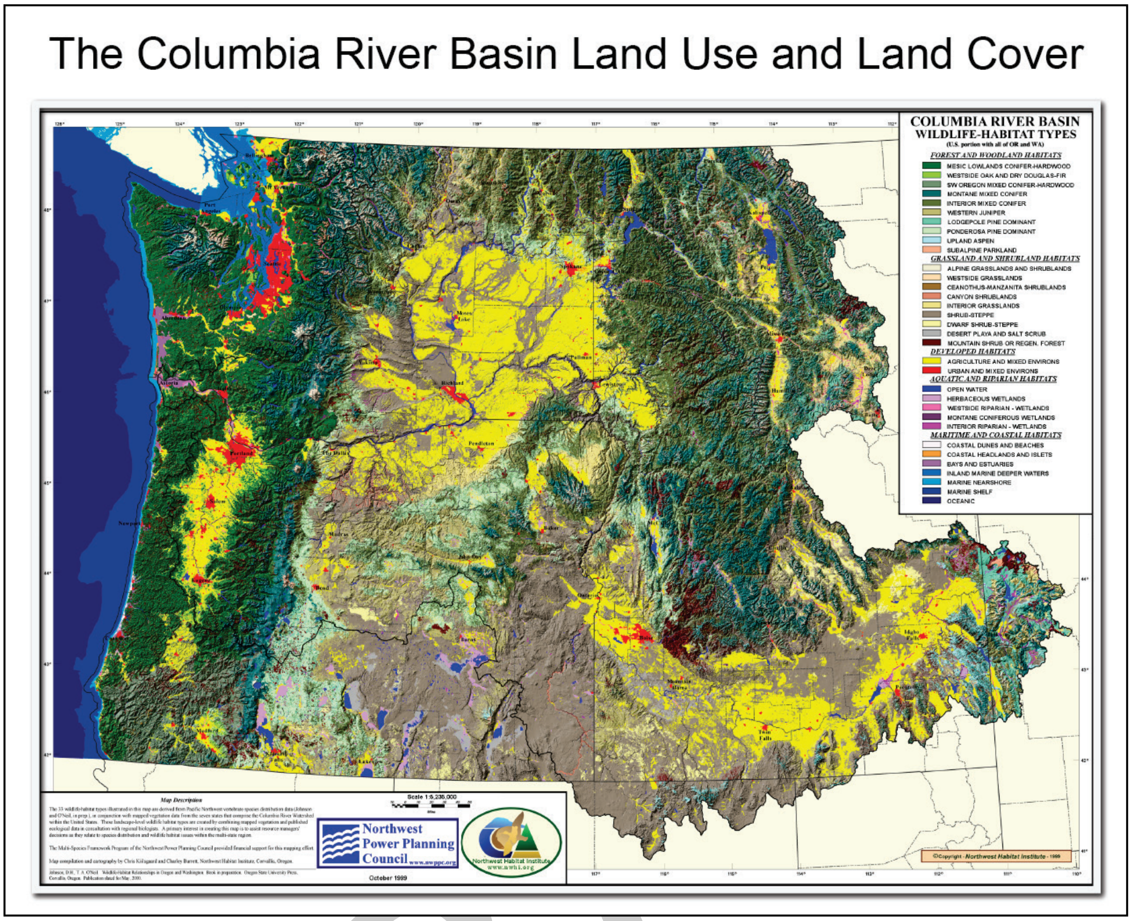


Figure 10.7: The Columbia River Basin Land Use and Land Cover

Caption: Agriculture is in yellow, forests are shades of green, shrublands are gray, and red are urban areas. The river is used for hydropower generation, flood control, agriculture irrigation, recreation, support of forest and shrubland ecosystems, and fish and wildlife habitat. Climate change may impact the timing and supply of the water resources, affecting the multiple uses of this river system.

(See http://www.nwcouncil.org/library/2003/2003-14/default.htm).

Conclusions

A changing climate, particularly in areas projected to be warmer and drier, is expected to lead to drought and stresses on water supply, impacting energy, water, and land sectors in the U.S. But the risks associated with these impacts are not isolated to individual sectors. As the Texas drought of 2011 illustrates, impacts to a particular sector, such as energy production, generates consequences for the others, such as water resource availability. Similarly, new energy development and production will require careful consideration of land and water sector resources. As a result, vulnerability to climate change depends on the intersecting risks within and among all three sectors. Understanding of this cross-sector nature of climate change impacts is improving, and assessments will increasingly evaluate risks and vulnerability from this standpoint.

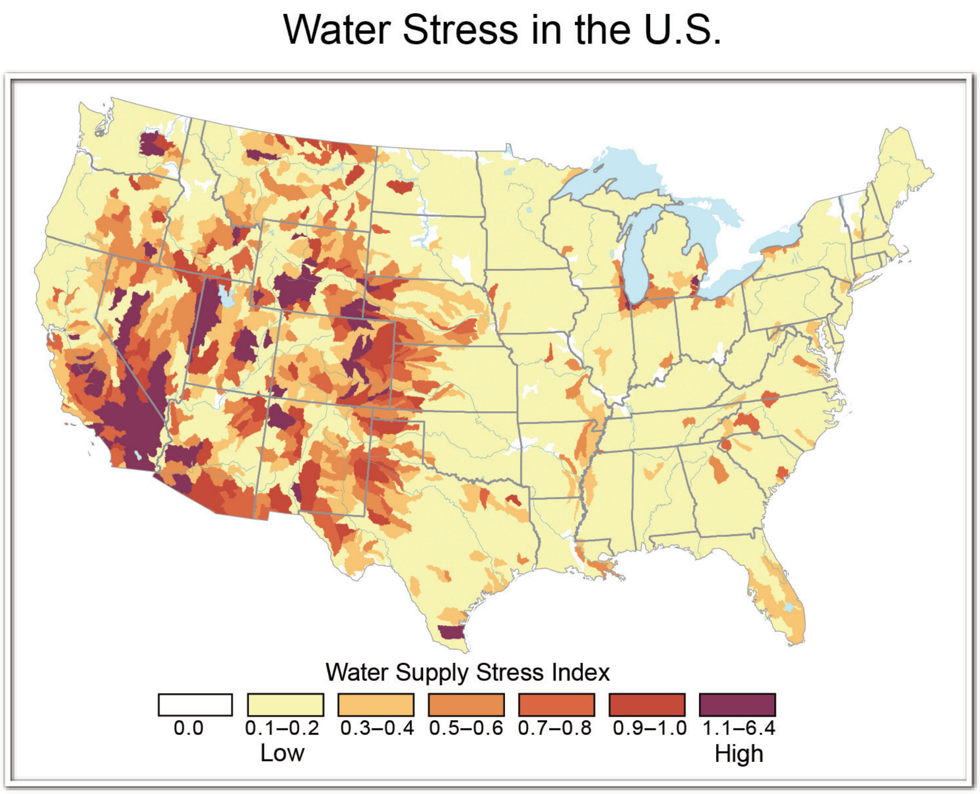


Figure 10.8: Water Stress in the U.S.

Caption: In many parts of the country, competing demands for water create stress in local and regional watersheds. Map shows a "water supply stress index" for the U.S. based on observations, with widespread stress in much of the Southwest, western Great Plains, and parts of the Northwest (Averyt et al. 2011). Watersheds are considered stressed when water demand (by power plants, agriculture and municipalities) exceeds 40% of available supply.

The complex nature of interactions among land, energy, and water systems, particularly in the context of climate change, does not lend itself to simple solutions. Interactions between water and energy will vary among regions, with water being too scarce in some regions, too abundant in others, or too warm to meet thermal regulations for discharge water used for power plant cooling. Similarly, land-use issues, like those identified in the temporary suspension of concentrating solar power systems to address environmental concerns, will also require joint consideration. The complex nature of water and energy systems are also highlighted in Chapter 3 (Water Resources), which discusses water constraints in the southern states and across the Southwest, and in Chapter 4 (Energy Supply and Use), where it is noted that there will be challenges across the nation for water quality to comply with thermal regulatory needs for energy production.

Adaptation to climate change occurs in large part locally or regionally, and conflicting stakeholder priorities, institutional commitments, and international agreements have the potential to complicate or even compromise adaption strategies with regard to energy, water, and land resources. Effective adaptation to the impacts of climate change requires a better understanding of the interactions between the energy, water, and land resource sectors. Whether managing for water security in the context of energy systems, or land restrictions, or both, an improved dialogue and between the scientific and decision-making communities will be necessary to understand tradeoffs and compromises needed to manage and understand this complex system. This will require not only integrated and quantitative analyses of the processes that underlie the climate and natural systems, but also an understanding of decision criteria and risk analyses to communicate effectively with stakeholders and decision-makers.

Traceable Accounts

Chapter 10: Water, Energy, and Land Use

Key Message Process: The authors met for a one-day face-to-face meeting and held teleconferences approximately weekly from March through August 2012. They considered a variety of technical input documents, including a document prepared through an interagency process, Skaggs et al., 2012, and a number of other reports submitted through the Federal Register Notice request for public input. The key messages were selected based on expert judgement, derived from the set of examples assembled to demonstrate the character and consequences of interactions between the water, energy, and land resource sectors.

Key message #1/3	**Energy, land, and water systems interact in many ways. Climate change affects the individual sectors and their interactions; the combination of these factors affects climate vulnerability as well as adaptation and mitigation options for different regions of the country.**
Description of evidence base	The key message and supporting text summarizes extensive evidence documented in the water, energy, and land use Technical Input (Skaggs et al. 2012) Climate and Energy-Water-Land System Interactions: Technical Report to the U.S. Department of Energy in Support of the National Climate Assessment. Report No. PNNL-21185, Pacific Northwest National Laboratory, Richland, WA.). Technical Input reports (59) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input. A technical input report prepared for the NCA by the Department of Energy describes the framework within which the energy, water, and land resource sectors interact (Skaggs et al. 2012). While developing this technical input report, the author team convened a workshop of experts and stakeholders. The report incorporates the findings of the workshop. The report summarizes numerous examples of interactions between specific sectors, such as energy and water or water and land use. A synthesis of these examples provides insight into how climate change impacts the interactions between these sectors. Skaggs et al. (2012) show that the character and significance of interactions between energy, water, and land resource sectors vary regionally. Additionally, the influence of impacts on one sector within the others will depend on the specific impacts involved. Thus, as a general statement, the key message states that impacts affects these interactions, but does not state that this will occur in all circumstances. Chapter 10 uses the NCA Climate Scenarios (e.g., Kunkel et al. 2012) and in particular the climate outlooks where statements depend on potential climate change associated with different emissions levels. Regional climate outlooks are invoked by cross-reference to the appropriate regional chapter of the report. Chapter 10 provides an example of cascading effects by describing the consequences of drought across Texas during 2011 (Hoerling et al. 2012; NCDC 2012; Peterson et al. 2012). The Texas drought provides a clear example of cascading impacts through interactions among the water, energy, and land resource sectors (ERCOT 2011; Fannin 2011; Fernandez 2012; TFS 2011a, 2011b). The U.S. Drought Monitor (http://droughtmonitor.unl.edu/) provides relevant historical data. Articles appearing in the public press, on Internet media, in briefings to government institutions, and in various government reports characterize specific attributes and impacts of the Texas drought of 2011. Ken Kunkel and Laura Stevens, NOAA, National Climate Data Center, created Figure 1 based on historical data assembled by the Cooperative Observer Network of

	the National Weather Service. These data are the basis for many of the historic trends included in the NCA Climate Scenarios developed for this report.
New information and remaining uncertainties	There are no major uncertainties regarding this key message. There are major uncertainties, however, in the magnitude of impacts in how decisions in one sector might affect another, and the intensity of interactions will be difficult to assess under climate change.
Assessment of confidence based on evidence a	**High**. The primary limitation on the confidence assigned to this key message is with respect to its generality. The degree of interactions among the water, energy, and land sectors varies regionally as does the character and intensity of climate change. The Texas drought of 2011 demonstrates the occurrence of cascading impacts involving these sectors; however, the Texas example cannot be generalized to all parts of the country or to all instances of climate change. The technical input report by Skaggs et al. (2012) provides numerous additional examples and a general description of interactions that underlie cascading impacts between these resource sectors.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Chapter: Water, Energy, and Land Use

Key Message Process: See KM #1

Key message #2/3	**The dependence of energy systems on land availability and water supplies will influence their development and constrain some options for reducing greenhouse gas emissions.**
Description of evidence base	The key message and supporting text summarizes extensive evidence documented in the water, energy, and land use Technical Input (Skaggs et al. 2012) Climate and Energy-Water-Land System Interactions: Technical Report to the U.S. Department of Energy in Support of the National Climate Assessment. Report No. PNNL-21185, Pacific Northwest National Laboratory, Richland, WA.). Technical Input reports (59) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input. A technical input report to the NCA prepared for the Department of Energy describes the framework within which the energy, water, and land resource sectors interact (Skaggs et al. 2012). Synthesis and Assessment Product 2.1 of the Climate Change Science Program (Clarke et al. 2007) describes relationships among different future mixtures of energy sources and associated radiative forcing of climate change as a context for evaluating emissions mitigation options. Chapter 10 describes evolving water and land requirements of four energy technologies [natural gas (EIA 2012), solar power (DOE 2012), biofuels, and carbon dioxide capture and storage (IPCC 2005) that involve lower greenhouse gas emissions than, for example, coal-fired electricity production, or in the case of CCS, reduce emissions with potential to lower atmospheric CO2 levels (Mai et al. 2012). In each case, the dependence of these energy technologies on water and land resources raised issues about their deployment and resource priorities. The availability of water and land resources constrains the use of these technologies; however, in recent experience, technological advances have reduced dependence on water and allowed use of land less suitable to other purposes. Statements about energy production and use are derived from U.S. Government reports (EIA 2011, 2012) (DOE 2009b). The contributions of horizontal drilling and hydraulic fracturing to natural gas production are based on a brief article by EIA (EIA 2012) and a primer by DOE (2009a). Information about water and energy demands for utility-scale solar power facilities is derived from two major Department of Energy reports (DOE 2012; Mai et al. 2012). Distribution of U.S. solar energy resources is from Web based products of the National Renewable Energy Laboratory (http://www.nrel.gov/gis/).
New information and remaining uncertainties	There are no major uncertainties regarding this key message. As demonstrated by progress in development and deployment of the technologies described, potential constraints arise because of dependence on water and land resources that motivate advances in technology to reduced dependence or adjustments of priorities. There are uncertainties however, in how energy systems' dependence on water will be limited by other resources, such as land or economics on technological development.
Assessment of confidence based on evidence and agreement or, if defensible, estimates of the likelihood of	**High**. The primary limitation on confidence assigned to this key message is with respect to its generality and dependence on technological advances. In the cases described, technological development is reducing water and land requirements. It is difficult to forecast success in this regard for technologies such as CCS that are still in early phases of development.

impact or consequence	

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Chapter: Water, Energy, and Land Use

Key Message Process: See KM #1

Key message #3/3	**Jointly considering risks, vulnerabilities, and opportunities associated with energy, water, and land use is difficult, but can improve the analysis of options for reducing climate change impacts**
Description of evidence base	The key message and supporting text summarizes extensive evidence documented in the water, energy, and land use Technical Input (Skaggs et al. 2012) Climate and Energy-Water-Land System Interactions: Technical Report to the U.S. Department of Energy in Support of the National Climate Assessment. Report No. PNNL-21185, Pacific Northwest National Laboratory, Richland, WA.). Technical Input reports (59) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input. Chapter 10 demonstrates that interactions among water, energy, and land resource sectors can lead to stakeholder concerns that reduce options for reducing vulnerability and thus for adapting to climate change. The Columbia River System provides a good example (Bruce et al. 2003; Dalton et al. 2012).
New information and remaining uncertainties	There are no major uncertainties regarding this key message, however, the extent to which local, state and national policies will impact options for vulnerability options under climate change is highly uncertain.
Assessment of confidence based on evidence	**High**. The primary limitation on confidence assigned to this key message is with respect to its generality.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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