4. Energy Supply and Use

Convening Lead Authors
Jan Dell, CH2MHill
Susan Tierney, Analysis Group Consultants

Lead Authors
Guido Franco, California Energy Commission
Richard G. Newell, Duke University
Rich Richels, Electric Power Research Institute
John Weyant, Stanford University
Thomas J. Wilbanks, Oak Ridge National Laboratory

Key Messages

1. **Extreme weather events are affecting energy production and delivery facilities, causing supply disruptions of varying lengths and magnitudes and affecting other infrastructure that depends on energy supply. The frequency and intensity of extreme weather events are expected to increase.**
2. **Higher summer temperatures will increase electricity use, causing higher summer peak loads, while warmer winters will decrease energy demands for heating. Net energy use is projected to increase as rising demands for cooling outpace declining heating energy demands.**
3. **Both episodic and long-lasting changes in water availability will constrain different forms of energy production.**
4. **In the longer term, sea level rise will affect coastal facilities and infrastructure on which many energy systems, markets, and consumers depend.**
5. **As new investments in energy technologies occur, future energy systems will differ from today's in uncertain ways – depending on the character of changes in the energy mix, climate change will introduce new risks as well as opportunities.**

Introduction

The U.S. energy supply system is diverse and robust in its ability to provide a secure supply of energy with only occasional interruptions. However, projected impacts of climate change will amplify seasonal patterns of energy use and affect energy infrastructure, posing additional risks to energy security. Extreme weather events and water shortages are already interrupting energy supply, and impacts are expected to increase in the future. Most vulnerabilities and risks to energy supply and use are unique to local situations; others are national in scope.

The impacts of climate change in other countries will also affect U.S. energy systems through global and regional cross-border markets and policies. Increased energy demand within global markets due to industrialization, population growth, and other factors will influence U.S. energy costs through competition for imported and exported energy products.

Adaptation actions can allow energy infrastructure to adjust more readily to climate change, and many investments toward adaptation provide short-term paybacks because they address current vulnerabilities as well as future risks, and thus, entail "no regrets." Such actions can include a focus on increased efficiency of energy use as well as improvements in the reliability of production and transmission of energy.

Disruptions from Extreme Weather

Extreme weather events are affecting energy production and delivery facilities, causing supply disruptions of varying lengths and magnitudes and affecting other infrastructure that depends on energy supply. The frequency and intensity of extreme weather events are expected to increase.

Much of America's energy infrastructure is vulnerable to extreme weather events. Because so many components of U.S. energy supplies – like coal, oil, and electricity – move from one area to another, extreme weather events affecting energy infrastructure in one place can lead to supply consequences elsewhere.

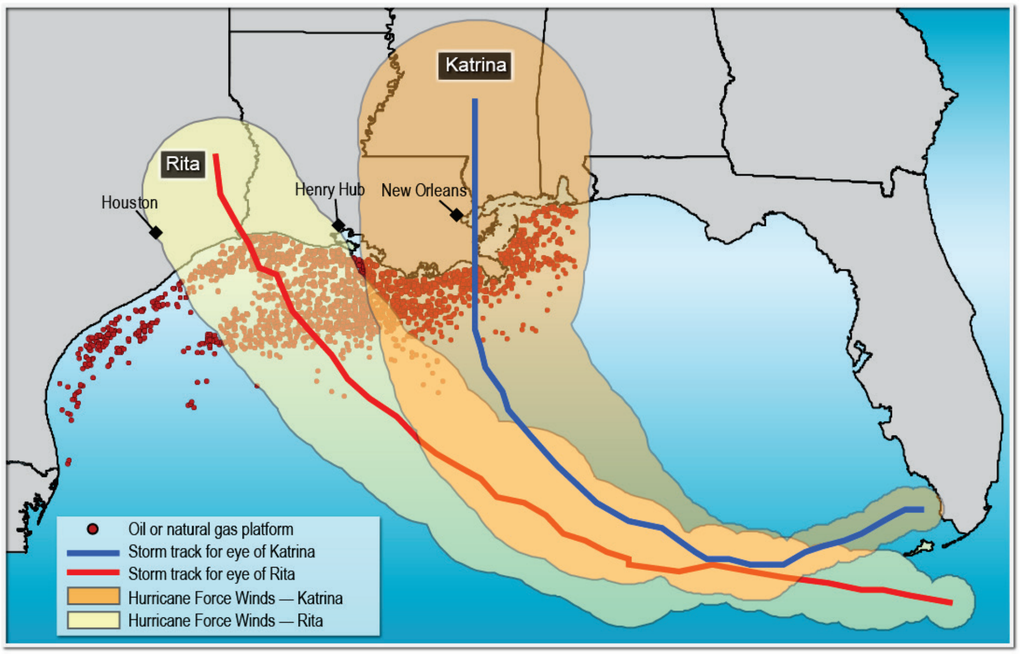
Climate change has begun to affect the frequency, intensity, and length of many extreme weather events (Peterson et al. 2012; Solomon et al. 2007). What is considered an extreme weather or climate event varies from place to place (See Ch. 2: Our Changing Climate). Across the U.S., observed changes include increased frequency and intensity of extreme precipitation events, winter storms, heat waves, and droughts.

Most areas in the U.S. are projected to experience increases in the number of days with precipitation exceeding one inch. It is projected that future climate change will include increases in some types of extreme weather events, particularly heat waves, wildfire, flooding, longer and more intense drought, heavy precipitation in winter storms, and extreme coastal high water due to storm events and sea level rise which will increasingly disrupt infrastructure services in some locations (Wilbanks et al. 2012a). Disruptions in services in one infrastructure system (such as energy) will lead to disruptions in one or more other infrastructures (such as communications and transportation) that depend on other affected systems. Infrastructure that is located in areas exposed to extreme weather, where it is also stressed by age or by demand levels that exceed what it was designed to deliver, is particularly vulnerable (See Ch. 11: Urban and Infrastructure).

Like much of the nation's infrastructure that has been affected by the increasing occurrence of "billion dollar weather events" (NOAA 2011), U.S. energy facilities and systems, especially those located in coastal areas, are vulnerable to extreme weather events. Wind and storm surge damage by hurricanes already causes significant infrastructure losses on the Gulf Coast.

Economic losses arising from weather and climate events are large and have been increasing. Damage to oil and gas production and delivery infrastructure by Hurricanes Katrina and Rita affected natural gas, oil, and electricity markets in most parts of the U.S. (Entergy Corporation 2012; Wilbanks et al. 2012a). Market impacts were felt as far away as New York and New England (Hibbard 2006; Rosenzweig et al. 2009), highlighting the interdependencies among various types of infrastructure that can amplify the vulnerabilities of energy infrastructure alone to climate-related impacts.

Paths of Hurricanes Katrina and Rita Relative to Energy Production Facilities



Source: GAO analysis of data provided by the National Weather Service and the Minerals Management Service.

Figure 4.1: Paths of Hurricanes Katrina and Rita Relative to Energy Production Facilities

Caption: A substantial portion of U.S. energy facilities are located on the Gulf Coast as well as offshore in the Gulf of Mexico, where they are particularly vulnerable to hurricanes and other storms and sea level rise. (Source: Wilbanks et al. 2012a).

Various aspects of climate change will affect energy systems. It is projected that wildfires will affect extensive portions of California's electricity transmission grid (Sathaye et al. 2011). Extreme surge events at high tides are expected to increase (Cayan et al. 2003), raising the risk of inundating energy facilities such as power plants, refineries and pipelines. Rail transportation lines that carry coal to power plants, which produced 42% of U.S. electricity in 2011, often follow riverbeds, especially in the Appalachian region. More intense rainstorms, both observed and projected, can lead to river flooding that degrades or washes out nearby railroads and roadbeds.

Climate Change and Seasonal Energy Demands

Higher summer temperatures will increase electricity use, causing higher summer peak loads, while warmer winters will decrease energy demands for heating. Net energy use is projected to increase as rising demands for cooling outpace declining heating energy demands.

Over the last 20 years, annual average temperatures typically have been higher than the long-term average; nationally, temperatures were above average during 12 of the last 14 summers (Kunkel et al. 2012a; Ch. 2: Our Changing Climate). These increased temperatures are already affecting the demand for energy needed to cool buildings within the U.S.

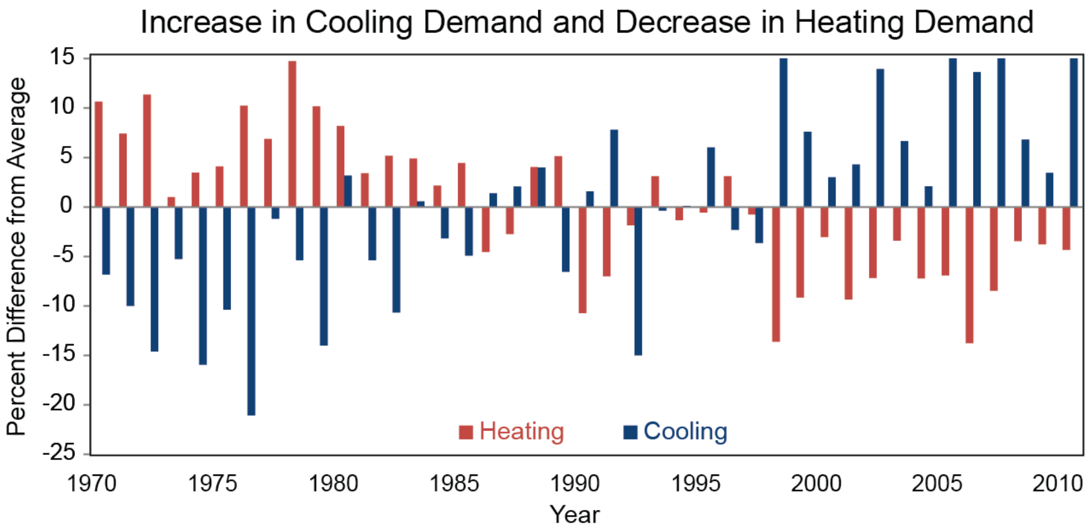


Figure 4.2: Increase in Cooling Demand and Decrease in Heating Demand

Caption: The amount of energy needed to cool (or warm) buildings is proportional to cooling (or heating) degree days. The figure shows increases in "cooling degree days," which result in increased air conditioning use, and decreases in "heating degree days," meaning less energy required to heat buildings in winter, compared to the average for 1970-2000. Cooling degree days are defined as the number of degrees that a day's average temperature is *above* 65ºF, while heating degree days are the number of degrees a day's temperature is *below* 65ºF. As shown, the increase in cooling needs is greater than the decrease in heating needs (Source: EIA 2008; 2009; U.S. Department of Energy 2012; National Climatic Data Center 2012).

The rate of temperature change has increased in recent decades. In response, the Energy Information Administration began using 10-year average weather data instead of 30-year data in order to estimate energy demands for heating and cooling purposes. The shorter period is more consistent with the observed trend of warmer winters and summers (EIA 2008).

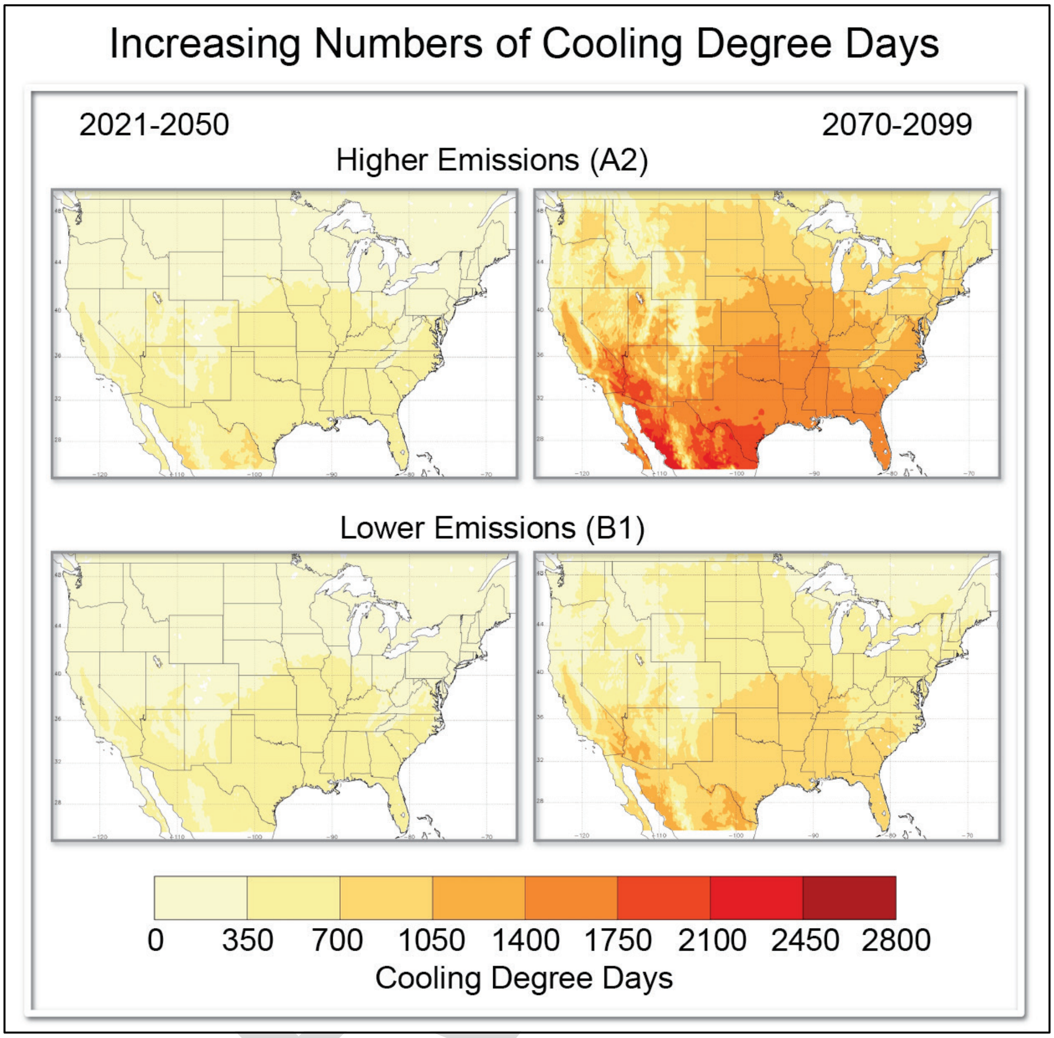


Figure 4.3: Increasing Numbers of Cooling Degree Days

Caption: A recent analysis (Kunkel et al. 2012b) projects continued increases in cooling degree days (and decreases in heating degree days) over the next several decades. The higher the number of cooling degree days, the more people tend to use air conditioning.

These maps show projected average changes in cooling degree days compared to the baseline period (1971-2000) for two periods in the rest of this century (2021-2050 and 2070-2099), assuming climate change associated with continued increases in emissions (A2, top maps) and significant reductions in emissions of heat-trapping gases (B1, bottom maps).

The projections show significant regional variations, with the greatest increases in the southern U.S. By the end of this century, the increases in cooling degree days will be more pronounced for the higher emissions (A2) scenario. Furthermore, projections suggest continued population shifts toward areas that require air conditioning in the summer, thereby increasing the impact of temperature changes on increased energy demand (U.S. Census Bureau 2012). (Figure source: NOAA NCDC / CICS-NC. Data from CMIP3 Daily Statistically Downscaled.)

While recognizing that many factors besides climate change affect energy demand (including population changes, economic conditions, energy prices, consumer behavior, conservation programs, and changes in energy-using equipment), increases in temperature will result in increased energy use for cooling and decreased energy use for heating. These impacts differ among regions of the country and indicate a shift from predominantly heating to predominantly cooling in some regions with moderate climates. For example, in the Pacific Northwest, energy demand for cooling is projected to increase over the next century due to population growth, increased cooling degree days, and increased use of air conditioners as an adaptation response to higher temperatures (Hamlet et al. 2010). Population growth is also expected to increase energy demand for heating. However, the projected increase in energy demand for heating is about half as much when the effects of a warming climate are considered along with population growth (Hamlet et al. 2010).

Table 4.1: Changing Energy Use for Heating and Cooling Will Vary by Region

	Consequences: Challenges and Opportunities	
Region	**Electricity Use**	**Natural Gas (Heating)**
Physical Impacts - High Likelihood	**Warmer and longer summers** Number of Additional Extreme Days(> 95°F) and % Increase in Cooling Degree Days in 2041-2070 above 1971-2000 Level	**Warmer winters** Number of Fewer Extreme (< 10°F) Cold Days and % Decrease in Heating Degree Days in 2041-2070 below 1971-2000 Level
Northeast	+ 10 days, +77%	- 12 days, - 17%
Southeast	+23 days, 43%	- 2 days, - 19%
Midwest	+ 33 days, +64%	- 14 days, - 15%
Great Plains	+ 22 days, +37%	- 4 days, -18%
Southwest	+ 20 days, +44%	- 3 days, - 20%
Northwest	+ 5 days, +89%	- 7 days, - 15%
Alaska	Assumed Neutral - Not modeled	Assumed - Not modeled
Pacific Islands	Assumed - Not modeled	Assumed Neutral – Not modeled

Red cells denote negative impacts; green cells denote positive impacts.

Title: Changing Energy Use for Heating and Cooling Will Vary by Region

Caption: Warmer and longer summers will increase the amount of electricity necessary to run air conditioning, especially in the Southeast and Southwest. Warmer winters will decrease the amount of natural gas required to heat buildings, especially in the Northeast, Midwest and Northwest. Table information is adapted from multi-model means from 8 NARCCAP regional climate simulations for the high (A2) emissions scenario considered in this report, (Figure Source: adapted from Kunkel et al. 2012f, 2012g; Kunkel et al. 2012h; Kunkel et al. 2012c; Kunkel et al. 2012d; Kunkel et al. 2012e) weighted by population.

Increases in average temperatures and temperature extremes are expected to lead to increasing demands for electricity for cooling in every U.S. region. Virtually all cooling load is handled by the electrical grid, while the heating load is distributed among electricity, natural gas, heating oil, passive solar, and biofuel. In order to meet increased demands for peak electricity, additional generating and distribution facilities will be needed, or demand will have to be managed through a variety of mechanisms. Electricity at peak demand typically is more expensive to supply than at average demand (Wilbanks et al. 2012b). Because the balance between heating and cooling differs by location, the balance of energy use among delivery forms and fuel types will likely shift – from natural gas and fuel oil used for heating, to electricity used for air conditioning. In hotter conditions, more fuel and energy are required to generate and deliver electricity; so a shift to more air conditioning in regions with moderate climates will increase primary energy demands. Also, because of greater energy losses for generating and delivering energy in hotter conditions, the expected shift (due to climate change) from heating to cooling in regions with moderate climates can increase primary energy demand (Wilbanks et al. 2012a).

Climate-related temperature shifts are expected to cause a net increase in residential energy use. Increased energy demands for cooling exceed energy savings resulting from lower energy demands for heating. One study examining state-level energy consumption, weather data, and high emission scenarios (SRES A1Fi and A2) found a net increase of 11% in residential energy demand (Deschênes and Greenstone 2011). Another study reported annual increases in net energy expenditures for cooling and heating of about 10% ($26 billion in 1990 U.S. dollars) by the end of this century for 4.5°F of warming, and 22% ($57 billion in 1990 dollars) for overall warming of about 9°F (Mansur et al. 2008). New energy efficient technology could help to offset growth in demand.

Several studies suggest that if substantial reductions in emissions of heat-trapping gases were required, the electricity generating sector would decarbonize first, given the multiple options available to generate electricity from sources that do not emit heat-trapping gases, such as wind and solar power. Under these circumstances, electricity would displace direct use of fossil fuels for some applications, such as heating, to reduce overall emissions of heat-trapping gases (Clarke et al. 2007; Wei 2012; Williams et al. 2012). The implications for peak electricity demand could be significant. In California, for example, the estimated increase in use of electricity for space heating would shift the peak in electricity demand from the summer to the winter (Wei 2012).

Implications of Less Water for Energy Production

Both episodic and long-lasting changes in water availability will constrain different forms of energy production.

Producing energy from fossil fuels (coal, oil, and natural gas), nuclear power, biofuels, hydropower, and some solar power systems often depends on the availability of adequate and sustainable supplies of water. Issues related to water already pose challenges to production from existing power plants and the permitting of new facilities (Averyt et al. 2011; Wilbanks et al. 2012b; Ch. 10: Water, Energy, and Land Use).

In the future, long-term precipitation changes, drought, and reduced snowpack are projected to alter water availability. Recent climate data indicate an overall upward trend in annual precipitation across most of the nation (Ch. 2: Our Changing Climate). However, the Southwest faces lower precipitation year round. The widespread trend toward more heavy downpours is expected to continue, with precipitation becoming less frequent but more intense. Most of the U.S. is projected to have 15 more days per year with little precipitation.

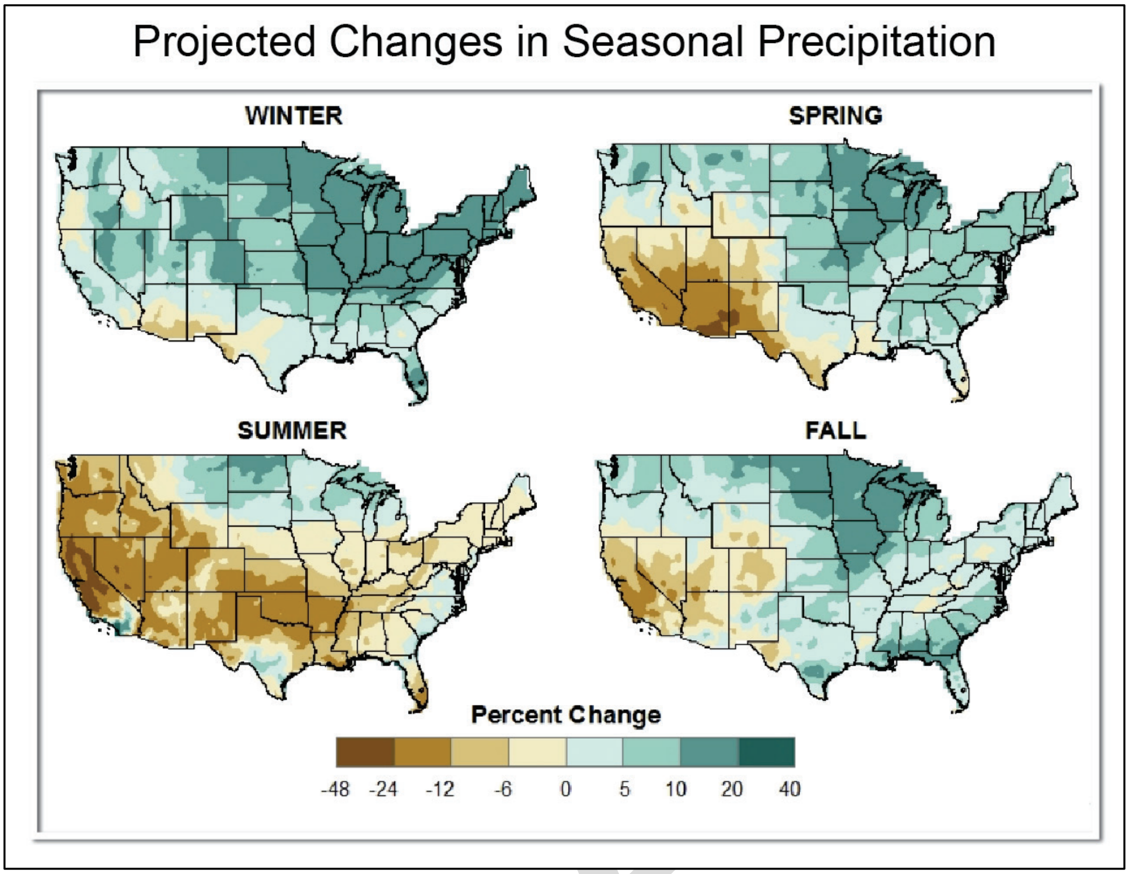


Figure 4.4: Projected Changes in Seasonal Precipitation

Caption: Climate change affects precipitation patterns as well as temperatures. The maps show projected changes (percent) in average precipitation by season for 2041–2070 compared to 1971–2000, assuming emissions of heat-trapping gases continue to rise (A2 scenario). Note significantly drier conditions in the Southwest spring and Northwest summer, as well as significantly more precipitation (some of which could fall as snow) projected for northern states in winter and spring.

(Figure source: NOAA NCDC / CICS-NC. Data from NARCCAP.)

Reduced availability of water for cooling, for hydropower, or for absorbing warm water discharges into water bodies without exceeding temperature limits, will continue to constrain power production at existing facilities and permitting of new power plants. Increases in water temperatures may reduce the efficiency of thermal power plant cooling technologies, potentially leading to warmer water discharge from some power plants, which in turn can affect aquatic biota. Studies conducted during 2012 indicate that water shortages are more likely to limit power plant electricity production in many regions (Skaggs et al. 2012; Wilbanks et al. 2012b). Regional or seasonal water constraints, particularly in the Southwest and Southeast, will result from chronic or seasonal drought, growing populations, and increasing demand for water for various uses (Averyt et al. 2011; Ch. 10: Water, Energy, and Land Use).

Hydropower plants in the West depend on the seasonal cycle of snowmelt to provide steady output throughout the year. Expected reductions in snowpack in parts of the West will reduce hydropower production. There will also be increases in energy (primarily electricity) demand in order to pump water for irrigated agriculture and to pump and treat water for municipal uses. (Wilbanks et al. 2012b).

The Electric Power Research Institute's (EPRI) scenario-based technical projections of water demand in 2030 find that one-quarter of existing power generation facilities (about 240,000 megawatts) nationwide are in counties that face some type of water sustainability (EPRI 2011). Many regions face water sustainability concerns, with the most significant water-related stresses in the Southeast, Southwest, and Great Plains regions.

Sea Level Rise and Infrastructure Damage

In the longer term, sea level rise will affect coastal facilities and infrastructure on which many energy systems, markets, and consumers depend.

Significant portions of the Nation's energy production and delivery infrastructure are in low-lying coastal areas; these facilities include oil and natural gas production and delivery facilities, refineries, power plants, and transmission lines.

Global sea level has risen by about 8 inches since reliable record keeping began in 1880, affecting countries throughout the world, including the U.S. The rate of rise increased in recent decades and is not expected to slow. Global average sea level is projected to rise 1 to 4 feet by 2100, though considering potential increases of up to 6.6 feet during this century may be useful for decision makers with a low tolerance for risk (Ch.2: Our Changing Climate). Sea level change at any particular location can deviate substantially from this global average (Parris et al. 2012; Ch. 2: Our Changing Climate) .

Rising sea levels, combined with normal and potentially more intense coastal storms and local land subsidence, threaten coastal energy equipment as a result of inundation, flooding, or erosion. In particular, sea level rise and coastal storms pose a danger to the dense network of Outer Continental Shelf marine and coastal facilities in the central Gulf Coast region (Burkett 2011). Many of California's power plants are at risk from sea level rise and the more extensive coastal storm flooding that results, especially in the low-lying San Francisco Bay area. Power plants and energy infrastructure in the coastal areas of U.S. regions face similar risks.

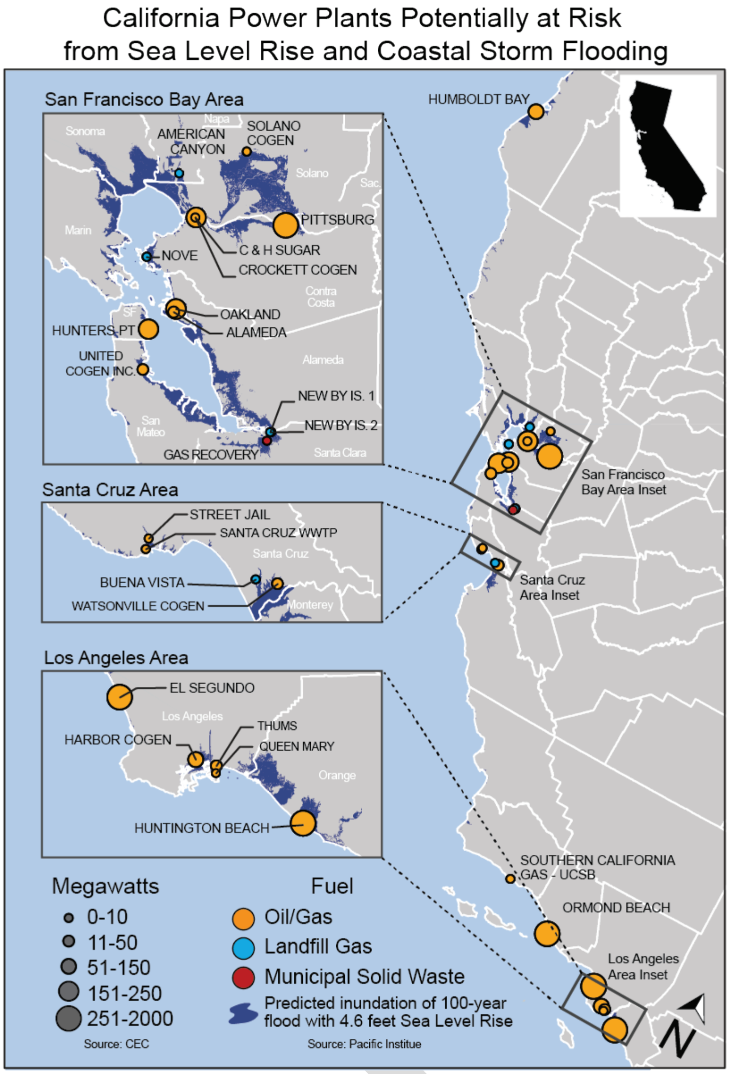


Figure 4.5: California Power Plants Potentially at Risk from Sea Level Rise and Coastal Storm Flooding

Caption: Rising sea levels will combine with storm surges and high tides to threaten power-generating facilities located in California coastal communities and around the San Francisco Bay (Source: Sathaye et al. 2011)

Possible Climate Resiliency and Adaptation Actions in Energy Sector

Table 2 summarizes actions that can be taken to increase the ease with which energy systems can adjust to climate change. Many of these adaptation investments entail “no regrets,” providing short-term paybacks because they address current vulnerabilities as well as future risks.

Table 4.2. Possible Climate Resilience and Adaptation Actions in Energy Sector

Caption: Future energy production will be affected by a range of climate change impacts. Chart shows possible responses to anticipate and respond to these changes.

	Key Challenges Addressed			
Possible Actions	**Extreme Weather Events**	**Increase in Peak Energy Loads**	**Water Constraints on Energy Production**	**Sea Level Rise**
Supply: System and Operational Planning				
Diversifying Supply Chains	X	X	X	X
Strengthening and Coordinating Emergency Response Plans	X	X	X	
Providing remote/protected emergency-response coordination centers	X			
Developing flood-management plans or improving stormwater management	X			X
Developing drought-management plans for reduced cooling flows			X	
Developing hydropower management plans/policies addressing extremes			X	
Supply: Existing Equipment Modifications				
Hardening/building redundancy into facilities	X	X		
Elevating water-sensitive equipment or redesigning elevation of intake structures	X			X
Building coastal barriers, dikes, or levees	X			X
Improving reliability of grid systems through back-up power supply, intelligent controls, and distributed generation	X	X	X	
Insulating equipment for temperature extremes	X			

Implementing dry (air-cooled) or low-water hybrid (or recirculating) cooling systems for power plants			**X**	
Adding technologies/systems to pre-cool water discharges			**X**	
Using non-fresh water supplies: municipal effluent, brackish or seawater			**X**	
Relocating vulnerable facilities	**X**		**X**	**X**
Supply: New Equipment				
Adding peak generation, power storage capacity, and distributed generation	**X**	**X**	**X**	**X**
Adding back-up power supply for grid interruptions	**X**	**X**	**X**	
Increasing transmission capacity within and between regions	**X**	**X**	**X**	**X**
Use: Reduce Energy Demand				
Improving building energy, cooling-system and manufacturing efficiencies, and demand-response capabilities (for example, smart grid)	**X**	**X**		
Setting higher ambient temperatures in buildings	**X**	**X**		
Improving irrigation and water distribution/reuse efficiency		**X**	**X**	
Allowing flexible work schedules to transfer energy use to off-peak hours		**X**		

Future Energy Systems

As new investments in energy technologies occur, future energy systems will differ from today's in uncertain ways – depending on the character of changes in the energy mix, climate change will introduce new risks as well as opportunities.

Today's energy systems vary significantly by region, with differences in climate-related impacts also introducing considerable variation by locale. Table 3 shows projected impacts of climate change on, and potential risks to, energy systems as they currently exist in different regions. Most vulnerabilities and risks for energy supply and use are unique to local situations, but others are national in scope. For example, biofuels production in three regions (Midwest, Great Plains and Southwest) could be impacted by the projected decrease in precipitation during the critical growing season in the summer months (Ch. 10: Water, Energy, and Land Use; Ch. 7: Forestry).

One certainty about energy systems in the future is that they will be different than today's, but in ways not yet known. Many uncertainties – financial, economic, regulatory, technological, and so on – will affect private and public consumption and investment decisions on energy fuels, infrastructure, and systems. Energy systems will evolve over time, depending upon myriad choices made by countless decision-makers responding to changing conditions in markets, technologies, policies, consumer preferences, and climate. A key challenge to understanding the nature and intensity of climate impacts on future energy systems is the amount of uncertainty regarding future choices about energy technologies and their deployment. An evolving energy system is also an opportunity to develop an energy system that is less vulnerable to climate change.

Table 4.3: Energy Supply: Summary of National and Regional Impacts, Challenges and Opportunities

Caption: Increased temperatures, changing precipitation patterns, and sea level rise will affect many sectors and regions, including energy production, agriculture yields, and infrastructure damage.

	Consequences[1]: Challenges and Opportunities								
	Fuel Extraction, Production, and Refining		Fuel Distribution	Electricity Generation					Electricity Distribution
Region	Hydrocarbons[2]	Biofuels	Transport/ Pipelines	Hydropower	Solar PV Wind	Thermal Power Generation[3]			
Physical Impacts – High Likelihood	Increased ambient temperature of air and water	Increased extremes in water availability	Coastal erosion and sea level rise	Increased extremes in water availability	Impacts projected but not well defined at this time.	Increased ambient temperature of air and water	Increased extremes in water availability	Coastal erosion and sea level rise	Hot summer periods
National Trend Summary[6] - Consequence	Decreased production and refining capacity	Decreased agricultural yields	Damage to facilities	Reduced electricity production		Reduced plant efficiency and cooling capacity	Interruptions to cooling systems	Damage to facilities	Reduced capacity/ damage to lines
Key Indicator (2071-2099 vs 1971-2000)	Mean Annual Temperature[4]	Summer Precipitation[4]	Sea Level Rise[5] (2100)	Days <0.1 inch[6] (2055)		Mean Annual Temperature[4]	Summer Precipitation[4]	Sea Level Rise[5] (2100)	# Days > 90F[6,7] (2055)
Northeast	+ 4.3 to 7.9 F	- 5 to + 6%	0.5 – 1.2 m	+1 day		+ 4.3 to 7.9 F	- 5 to + 6%	0.5 – 1.2 m	+ 13 days
Southeast	+ 4.3 to 7.9 F	- 22 to + 9%	0.5 – 1.2 m	+ 2 days		+ 4.3 to 7.9 F	- 22 to + 9%	0.5 – 1.2 m	+ 31 days
Midwest	+ 4.5 to 8.1 F	- 22 to + 6%	No coast	+ 0 days		+ 4.5 to 8.1 F	- 22 to + 6%	No coast	+ 19 days
Great Plains	+ 4.5 to 8 F	- 27 to + 5%	0.5 – 1.2 m	+ 3 days		+4.5 to 8 F	- 27 to + 5%	0.5 – 1.2 m	+ 20 days
Southwest	+ 4.5 to 8.3 F	-13 to +3%	0.5 – 1.2 m	+ 10 days		+ 4.5 to 8.3 F	-13 to +3%	0.5 – 1.2 m	+ 24 days
Northwest	+ 4.2 to 7.9 F	- 34 to – 11%	0.5 – 1.2 m	+ 6 days		+ 4.2 to 7.9 F	- 34 to – 11%	0.5 – 1.2 m	+ 4 days
Alaska	+ 4.4 to +8.1 F	+14 to +25%	0.5 – 1.2 m	No projection		+ 4.4 to 8.1 F	+14 to +25%	0.5 – 1.2 m	No projection.
Pacific Islands	+2.5 to + 4.5 F	Range from little change to increases	0.5 – 1.2 m	No projection		+2.5 to + 4.5 F	Range from little change to increases	0.5 – 1.2 m	No projection

Notes

1. Excludes extreme weather events.
2. Hydrocarbons includes coal, oil, and gas including shales.
3. Thermal power generation includes power plants fired from nuclear, coal, gas, oil, biomass fuels, solar thermal, and geothermal energy.
4. CMIP3 15 GCM Models: 2070–2099 Median Projection SRES B1 – A2 (versus 1971–2000)
5. 2100: Low Intermediate to High Intermediate Scenario from Sea Level Change Scenarios for the US National Climate Assessment (Parris et al. 2012). Range is similar to the 1 to 4 feet of sea level rise projected in Ch. 2: Our Changing Climate, Key Message 9.
6. 2055 NARCCAP
7. References: (Clarke et al. 2007; Wilbanks et al. 2012a)
8. Notes: Red cells denote negative impacts; green cells denote positive impacts.

Very different future energy supply portfolios are possible depending upon key economic assumptions including what a carbon management program, if any, looks like (Clarke et al. 2007; EIA 2008; EPRI 2011), and whether significant changes in consumption patterns occur for a variety of other reasons. Renewable energy sources, including solar, wind, and biofuels, are meeting a larger portion of U.S. demand, and there is the opportunity for this contribution to increase in the future (Ch. 6: Agriculture; Ch. 7: Forestry). This fundamental uncertainty about the evolving character of energy systems contributes another layer of complexity to understanding how climate changes will impact energy systems.

As they consider actions to enhance the resiliency of energy systems, decision makers confront issues with current energy systems as well as possible future configurations. The systems will evolve, and will be more resilient over time if actions tied to today's systems features do not make future systems less resilient as a result. For example, if moving toward biomass as an energy source involves more water-consumptive energy supplies that could be constrained by drier future climate conditions, then decisions about energy choices should be made in the context of understanding these trends.

Because U.S. energy decisions tend to be made in regulated markets rather than centrally planned, these decisions are unpredictable, even though they can be expected to evolve with the changing climate conditions. These trends in use patterns may continue into the future; this is an opportunity to increase resilience but also a major uncertainty for energy utilities and policy makers. Energy infrastructure tends to be long-lived, so resiliency can be enhanced by more deliberate applications of risk-management techniques and information about anticipated climate impacts and trends (NRC 2011).

For example, risk-management approaches informed by evolving climate conditions could be used to project the value of research and development on, or investments in, construction of dikes and barriers for coastal facilities or for dry-cooling technologies for power plants in regions where water is already in short supply. Solar and wind electricity generation facilities could be sited in areas that are initially more expensive (such as offshore areas) but less subject to large reductions in power plant output resulting from climatic changes. Target installed reserve margins for electric generating capacity and capacity of power lines can be established using certain temperature expectations, but adjusted as conditions unfold over time.

Traceable Accounts

Chapter 4. Energy Supply and Use

Key Message Process: The author team met bi-weekly by teleconference. Early in the development of key messages and a chapter outline, the authors reviewed all relevant technical input reports. Selected authors participated in a DOE sponsored workshop on Energy Supply and Use, December 29-30, 2011 in Washington, D.C. The workshop was organized specifically to inform a DOE technical input report and the 2013 NCA and to engage stakeholders in this process. The authors selected key messages based on the risk and likelihood of impacts, associated consequences, and available evidence. Relevance to decision support within the energy sector was also an important criteria.

The U.S. maintains extensive data on energy supply and use. The Energy Information Administration (EIA) of the U.S. Department of Energy is a primary organization in this activity, and data with quality control, quality assurance, and expert review are available through EIA Web pages.

Key message #1/5	**Extreme weather events are affecting energy production and delivery facilities, causing supply disruptions of varying lengths and magnitudes and affecting other infrastructure that depends on energy supply. The frequency and intensity of extreme weather events are expected to increase.**
Description of evidence base	A series of NCA workshops reviewed potential influences of climate change thus far on the frequency and intensity of extreme events (Peterson et al. 2012). Numerous past extreme events demonstrate damage to energy facilities and infrastructure. Data assembled and reviewed by the Federal Government summarize typical costs associated with damage to energy facilities by major extreme events. State and regional reports as well as data provided by public utilities document specific examples. Damage to Gulf Coast energy facilities and infrastructure by Hurricanes Katrina and Rita provides excellent examples to support this key message (Entergy Corporation 2012; Hibbard 2006; Rosenzweig et al. 2009). Wildfire also damages transmission grids (Sathaye et al. 2011). The authors benefited from Agency sponsored technical input reports summarizing relevant data and information on energy supply and use as well as urban systems and infrastructure(Wilbanks et al. 2012b; Wilbanks et al. 2012a). A number of other technical input reports were relevant as well. These were reviewed carefully, particularly with regard to the identification of key messages.
New information and remaining uncertainties	A series of NCA workshops provided a summary of current evidence for influences of climate change on the frequency and intensity of extreme events. These summaries provide succinct evidence that certain extreme events that damage energy facilities and infrastructure can be expected to increase in number and intensity with climate change. Documentation of damage to energy facilities and infrastructure continues to accumulate, increasing confidence in this key message (EIA 2008; NOAA 2011). The regional and local character of extreme events varies substantially, and this variability is a source of significant uncertainty regarding the impacts of climate change and consequences in terms of damage to energy facilities by extreme events. Additionally, damage to energy infrastructure in a specific location can have far-reaching consequences for energy production and distribution, and synthesis of such indirect consequences for production and distribution does not yet support detailed

	projections.
Assessment of confidence based on evidence	**High**. There is high consensus with moderate evidence that extreme weather events associated with climate change will increase disruptions of infrastructure services in some locations.

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 4: Energy Supply and Use

Key Message Process: See key message #1.

Key message #2/5	**Higher summer temperatures will increase electricity use, causing higher summer peak loads, while warmer winters will decrease energy demands for heating. Net energy use is projected to increase as rising demands for cooling outpace declining heating energy demands.**
Description of evidence base	The key message and supporting text summarizes extensive evidence documented in the energy supply and use technical input (Wilbanks et al. 2012a). Global climate models simulate increases in summer temperatures, and the NCA climate outlooks (Kunkel et al., 2012) describe this aspect of climate change projections for use in preparing the 2013 report (Ch. 2: Our Changing Climate). Data used by (Kunkel et al. 2012a) and Census Bureau population data, synthesized by the EIA were the basis for calculating population-weighted heating and cooling degree-days over the historic period as well as projections assuming SRES B1 and A2 scenarios. (Kunkel et al. 2012a) projects an increase in the number of cooling days and decrease in heating days, with peak electricity demand in some regions shifting from winter to summer (Wei 2012) and shifting to electricity needs for cooling instead of fossil fuels for heating (Clarke et al. 2007; Wei 2012; Williams et al. 2012).
New information and remaining uncertainties	While there is little uncertainty that peak electricity demands will increase with warming by climate change, substantial regional variability is expected. Climate change projections do not provide sufficient spatial and temporal detail to fully analyze these consequences. Socioeconomic factors including population changes, economic conditions, energy prices as well as technological developments in electricity generation and industrial equipment will have a strong bearing on electricity demands, specific to each region of the country.
Assessment of confidence based on evidence	**High**. Assuming specific climate change scenarios, the consequences for heating and cooling buildings are reasonably predictable, especially for the residential sector. With a shift to higher summer demands for electricity, peak demands for electricity can be expected to increase.

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 4: Energy Supply and Use

Key Message Process: See key message #1.

Key message #3/5	**Both episodic and long-lasting changes in water availability will constrain different forms of energy production.**
Description of evidence base	Technical input reports summarize data and studies showing that changes in water availability will affect energy production (Skaggs et al. 2012; Wilbanks et al. 2012a), and more specifically, that water shortages will constrain electricity production (Averyt et al. 2011). Ch. 10: Water, Energy, and Land Use describes the impacts of drought in Texas during 2011 as an example of the consequences of water shortages for energy production as well as other uses (Ch. 10: Water, Energy, and Land Use). Electric utility industry reports document potential consequences for operation of generating facilities (EPRI 2011). A number of power plants across the country have experienced interruptions due to water shortages. Climate outlooks prepared for the NCA (Kunkel et al. 2012a) describe decreases in precipitation under the SRES A2 scenario, with the largest decreases across the Northwest and Southwest in the spring and summer.
New information and remaining uncertainties	An increasing number of documented incidents of interruptions in energy production due to water shortages provide stronger evidence that decreased precipitation or drought will have consequences for energy production. There is little uncertainty that water shortages due to climate change would affect energy production. But uncertainty about changes in precipitation and moisture regimes simulated by global climate models is significantly higher than for simulated warming. Additionally, climate change simulations lack the spatial and temporal detail required to analyze the consequences for water availability at scales relevant to decisions about changes in energy facilities to reduce risk or adapt to water shortages associated with climate change.
Assessment of confidence based on evidence	**High**. The evidence is compelling that insufficient water availability with climate change will affect energy production; however, simulations of climate change lack the detail needed to provide more specific information for decision support.

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 4: Energy Supply and Use

Key Message Process: See key message #1.

Key message #4/5	**In the longer term, sea level rise will affect coastal facilities and infrastructure on which many energy systems, markets, and consumers depend.**
Description of evidence base	The sea level change scenario report prepared for the NCA (Parris et al. 2012, in press) and Ch. 2: Our Changing Climate provide further information about sea level change. Data available through the EIA provide high-quality information about the locations and distribution of energy facilities. A substantial portion of the Nation's energy facilities and infrastructure are located along coasts or off-shore, and sea level rise will affect these facilities (Burkett 2011; Sathaye et al. 2011; Wilbanks et al. 2012b; Wilbanks et al. 2012a).
New information and remaining uncertainties	Projections of sea level change are relatively uncertain compared to other aspects of climate change. More importantly, there will be substantial variability in region and local sea level change, and facilities exposed to more frequent and intense extreme wind and precipitation events will be at higher risk. Data and analyses to understand regional and local sea level change are improving, but substantial uncertainty remains and decision support for adaptation is challenged by these limitations.
Assessment of confidence based on evidence	**High**. There is high confidence that increases in global mean sea level will affect coastal energy facilities; however, regional and local details are less certain.

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 4: Energy Supply and Use

Key Message Process: See key message #1.

Key message #5/5	**As new investments in energy technologies occur, future energy systems will differ from today's in uncertain ways – depending on the character of changes in the energy mix, climate change will introduce new risks as well as opportunities.**
Description of evidence base	A number of studies describe U.S. energy system configurations in terms of supply and use assuming different scenarios of climate change, including SRES B1 and A2 (Clarke et al. 2007; EIA 2008; EPRI 2011). A technical input report to the NCA by DOE (Wilbanks et al. 2012b; Wilbanks et al. 2012a) provides details and updates earlier studies. The potential role of biofuels is described within Chapters 6 and 7 of this report (Ch. 6: Agriculture; Ch. 7: Forestry).
New information and remaining uncertainties	As the EIA and other organizations update data and information about U.S. energy systems as well as projections of the mix of primary energy under various assumptions about demographic, economic, and factors, understanding of options for future energy supply and use within the U.S. improves. With additional data and better models, alternative energy mixes can be explored with respect to climate change adaptation and mitigation. But numerous factors that are very difficult to predict affect the deployment of actual facilities and infrastructure.
Assessment of confidence based on evidence	**High**. There is high confidence that U.S. energy systems will evolve in ways that affect risk with respect to climate change and options for adaptation or mitigation.

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

References

Averyt, K., J. Fisher, A. Huber-Lee, A. Lewis, J. Macknick, N. Madden, J. Rogers, and S. Tellinghuisen, 2011: Freshwater use by US power plants: Electricity's thirst for a precious resource. A report of the Energy and Water in a Warming World initiative, Union of Concerned Scientists, Cambridge, MA

Burkett, V., 2011: Global climate change implications for coastal and offshore oil and gas development. Energy Policy

Cayan, D., M. Dettinger, R. Redmond, G. McCabe, N. Knowles, and D. Peterson, 2003: Chap 11: The transboundary setting of California's water and hydropower systems, linkages between the Sierra Nevada, Columbia, and Colorado hydroclimates. Climate and Water: Transboundary Challenges in the Americas, Eds. H. Diaz and B. Morehouse, Kluwer Press, Dordrecht/Boston/London.

Clarke, L., J. Edmonds, H. Jacoby, H. Pitcher, J. Reilly, and R. Richels, 2007: Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations, 154 pp. [Available online at http://www.globalchange.gov/publications/reports/scientific-assessments/saps/sap2-1]

Deschênes, O. and M. Greenstone, 2011: Climate change, mortality, and adaptation: Evidence from annual fluctuations in weather in the US. American Economic Journal: Applied Economics, 3, 152-185

EIA, 2008: Annual Energy Outlook

——, 2009: Annual Energy Outlook 2010. [Available online at http://www.eia.gov/forecasts/aeo/er/]

Entergy Corporation, 2012: Building a Resilient Energy Gulf Coast: Executive Report, [Available online at http://www.entergy.com/gulfcoastadaptation]

EPRI, 2011: Water Use for Electricity Generation and Other Sectors: Recent Changes (1985-2005) and Future Projections (2005-2030). 2011 Technical Report.

Hamlet, A.F., S.Y. Lee, K.E.B. Mickelson, and M.M. Elsner, 2010: Effects of projected climate change on energy supply and demand in the Pacific Northwest and Washington State. Climatic Change, 102, 103-128

Hibbard, P.J., 2006: US Energy Infrastructure Vulnerability: Lessons From the Gulf Coast Hurricanes, prepared for National Commission on Energy Policy.

Kunkel, K.E., L. E. Stevens, S. E. Stevens, E. Janssen, and D. Wuebbles, 2012a: Climate of the Contiguous United States

Kunkel, K.E., L.E. Stevens, S.E. Stevens, L. Sun, E. Janssen, D. Wuebbles, and J.G. Dobson, 2012b: Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 9. Climate of the Contiguous United States.

Kunkel, K.E., L.E. Stevens, S.E. Stevens, L. Sun, E. Janssen, D. Wuebbles, K. Redmond, and J.G. Dobson, 2012f: Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 5. Climate of the Southwest U.S.

——, 2012g: Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 6. Climate of the Northwest U.S.

Kunkel, K.E., L.E. Stevens, S.E. Stevens, L. Sun, E. Janssen, D. Wuebbles, J. Rennells, A. DeGaetano, and J.G. Dobson, 2012h: Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 1. Climate of the Northeast U.S.

Kunkel, K.E., L.E. Stevens, S.E. Stevens, L. Sun, E. Janssen, D. Wuebbles, S.D. Hilberg, M.S. Timlin, L. Stoecker, N.E. Westcott, and J.G. Dobson, 2012c: Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 3. Climate of the Midwest U.S.

Kunkel, K.E., L.E. Stevens, S.E. Stevens, L. Sun, E. Janssen, D. Wuebbles, C. Konrad, C. Fuhrman, B. Keim, M.C. Kruk, A. Billet, H. Needham, M. Schafer, and J.G. Dobson, 2012d: Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 2. Climate of the Southeast U.S.

Kunkel, K.E., L.E. Stevens, S.E. Stevens, L. Sun, E. Janssen, D. Wuebbles, M.C. Kruk, D.P. Thomas, M. Shulski, N. Umphlett, K. Hubbard, K. Robbins, L. Romolo, A. Akyuz, T. Pathak, T. Bergantino, and J.G. Dobson, 2012e: Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 4. Climate of the U.S. Great Plains.

Mansur, E., R. Mendelsohn, and W. Morrison, 2008: A discrete continuous model of energy: measuring climate change impacts on energy. *Journal of Environmental Economics and Management*, **55,** 175-193

National Climatic Data Center, 2012: Increasing Numbers of Cooling Degree Days NOAA/NCDC.

NOAA, cited 2011: Billion Dollar U.S. Weather/Climate Disasters. . National Oceanic and Atmospheric Administration ([Available online at http://www.ncdc.noaa.gov/billions]

NRC, 2011: Climate stabilization targets: emissions, concentrations, and impacts over decades to millennia. S. Solomon, and Coauthors, Eds., National Academies Press, Washington.

Parris, A., P. Bromirski, V. Burkett, D. R. Cayan, M. Culver, J. Hall, R. Horton, K. Knuuti, R. Moss, J. Obeysekera, A. Sallenger, and J. Weiss, 2012: Global sea Level Rise Scenarios for the United States National Climate Assessment

——, 2012, in press: Global sea Level Rise Scenarios for the United States National Climate Assessment

Peterson, T.C., P.A. Stott, and S. Herring, 2012: Explaining Extreme Events of 2011 from a Climate Perspective. *Bulletin of the American Meteorological Society*, **93,** 1041-1067

Rosenzweig, C., W. Solecki, R. Blake, M. Bowman, A. Castaldi, C. Faris, V. Gornitz, K. Jacob, A. LeBlanc, and R. Leichenko, 2009: Climate Risk Information. *New York City Panel on Climate Change*

Sathaye, J., L. Dale, P. Larsen, G. Fitts, K. Koy, S. Lewis, and A. Lucena, 2011: Estimating Risk to California Energy Infrastructure from Projected Climate Change

Skaggs, R., T. Janetos, K. Hibbard, and J. Rice, 2012: Climate and Energy-Water-Land System Interactions Technical Report to the U.S. Department of Energy in Support of the National Climate Assessment

Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K. Averyt, M. Tignor, and H. Miller, 2007: Climate change 2007: the physical science basis

U.S. Census Bureau, 2012: U.S. Population Projections, [Available online at http://www.census.gov/population/www/projections/index.html]

Wei, M., 2012: California's Carbon Challenge. Scenarios for Achieving 80% Emissions Reductions in 2050. [Available online at http://censeps.soe.ucsc.edu/sites/default/files/2011-wei.pdf]

Wilbanks, T., D. Bilello, D. Schmalzer, and M. Scott, 2012b: Climate Change and Energy Supply and Use

Wilbanks, T., G. Backus, S. Fernandez, P. Garcia, K. Jonietz, P. Kirshen, M. Savonis, B. Solecki, and L. Toole, 2012a: Climate Change Infrastructure, Urban Systems, and Vulnerabilities

Williams, J.H., A. DeBenedictis, R. Ghanadan, A. Mahone, J. Moore, W.R. Morrow III, S. Price, and M.S. Torn, 2012: The Technology Path to Deep Greenhouse Gas Emissions Cuts by 2050: The Pivotal Role of Electricity. *Science*, **335,** 53-59