EXPERT PEER REVIEW DRAFT

EFFECTS OF CLIMATE CHANGE ON ENERGY PRODUCTION AND USE IN THE UNITED STATES

U.S. CLIMATE CHANGE SCIENCE PROGRAM
Synthesis and Assessment Product 4.5

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PREFACE

(To be added)

SUMMARY

Climate change is expected to have noticeable effects in the United States: a rise in average temperatures in most regions, changes in precipitation amounts and seasonal patterns in many regions, changes in the intensity and pattern of extreme weather events, and sea level rise. Some of these effects have clear implications for energy production and use. For instance, average warming can be expected to increase energy requirements for cooling and reduce energy requirements for warming. Changes in precipitation could affect prospects for hydropower, positively or negatively. Increases in storm intensity could threaten further disruptions of the sorts experienced in 2005 with Hurricane Katrina. Concerns about climate change impacts could change perceptions and valuations of energy technology alternatives. Any or all of these types of effects could have very real meaning for energy policies, decisions, and institutions in the United States, affecting discussions of courses of action and appropriate strategies for risk management.

This report summarizes what is currently known about effects of climate change on energy production and use in the United States. It focuses on three questions, which are listed below along with general short answers to each. Generally, it is important to be careful about answering these questions, for two reasons. One reason is that the available research literatures on many of the key issues are limited, supporting a discussion of issues but not definite conclusions about answers. A second reason is that, as with many other categories of climate change effects in the U.S., the effects depend on more than climate change alone, such as patterns of economic growth and land use, patterns of population growth and distribution, technological change, and social and cultural trends that could shape policies and actions, individually and institutionally.

The report concludes that, based on what we know now, there are reasons to pay close attention to possible climate change impacts on energy production and use and to consider ways to adapt to possible adverse impacts and take advantage of possible positive impacts. Although the report includes considerably more detail, here are the three questions along with a brief summary of the answers:

- How might climate change affect energy consumption in the United States? The research evidence is relatively clear that climate warming will mean reductions in heating requirements and increases in cooling requirements for buildings. These changes will vary by region and by season, but they will affect household energy costs and demands on energy supply institutions. In general, the changes imply increased demands for electricity, which supplies virtually all cooling energy services but only some heating services. Other effects on energy consumption are less clear.

- How might climate change affect energy production and supply in the United States? The research evidence about effects is not as strong as for energy consumption, but climate change could affect energy production and supply (a) if extreme weather events become more intense, (b) where regions dependent on water supplies for hydropower and/or thermal power plant cooling face reductions in water supplies, (c) where changed conditions affect facility siting decisions, and (d) where conditions change (positively or negatively) for biomass production. Most effects are likely to be modest except for possible regional effects of extreme weather events and water shortages.

- How might climate change have various other effects that indirectly shape energy production and consumption in the United States? The research evidence about indirect effects ranges from abundant information about possible effects of climate change policies on energy technology choices to extremely limited information about such issues as effects on energy prices or energy security. Based on this mixed evidence, it appears that climate change is very likely to affect risk management in the investment behavior of some energy institutions, and it is very likely to have some effects on energy technology R&D investments and energy resource and technology choices. In addition, climate change can be

> expected to affect other countries in ways that in turn affect U.S. energy conditions through their participation in global and hemispheric energy markets, and climate change concerns could reinforce some driving forces behind policies focused on U.S. energy security, such as reduced reliance on oil products.

Because of the lack of research to date, prospects for adaptation to climate change effects by energy providers, energy users, and society at large are speculative, although the potentials are considerable. It is possible that the greatest challenges would be in connection with possible increases in the intensity of extreme weather events and possible significant changes in regional water supply regimes. But adaptation prospects depend considerably on the availability of information about possible climate change effects to inform decisions about adaptive management.

Given that the current knowledge base is so limited, this suggests that expanding the knowledge base is important to energy users and providers in the United States. Priorities for such research – which should be seen as a broad-based collaboration among federal and state governments, industry, non-governmental institutions, and academia – are identified in the report.

CHAPTER 1. INTRODUCTION

As a major expression of its objective to provide the best possible scientific information to support decision-making and public discussion on key climate-related issues, the U.S. Climate Change Science Program (CCSP) has commissioned 21 "synthesis and assessment products" (SAPs) to summarize current knowledge and identify priorities for research, observation, and decision support in order to strengthen contributions by climate change science to climate change related decisions.

These reports arise from the five goals of CCSP (http://www.climatescience.gov), the fourth of which is to "understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes." One of the seven SAPs related to this particular goal is to be concerned with analyses of the effects of global change on energy production and use (SAP 4.5). The resulting SAP, this report, has been titled "Effects of Climate Change on Energy Production and Use in the United States."

This topic is relevant to policy-makers and other decision-makers because most discussions to date of relationships between the energy sector and responses to concerns about climate have been very largely concerned with roles of energy production and use in climate change mitigation. Along with these roles of the energy sector as a *driver* of climate change, the energy sector is also subject to *effects* of climate change; and these possible effects – along with adaptation strategies to reduce any potential negative costs from them – have received much less attention. For instance, the U.S. National Assessment of Possible Consequences of Climate Variability and Change (NACC, 2001) considered effects on five sectors, such as water and health; but energy was not one of those sectors, even though the Global Change Research Act of 1990 had listed energy as one of several sectors of particular interest.

Because the topic has not been a high priority for research support and institutional analysis, the formal knowledge base is in many ways limited. As a starting point for discussion, this product compiles and reports what is known about likely or possible effects of climate change on energy production and use in the United States, within a more comprehensive framework for thought about this topic, and it identifies priorities for expanding the knowledge base to meet needs of key decision-makers.

1.1 BACKGROUND

Climate change is expected to have certain effects in the United States: a rise in average temperatures in most regions, changes in precipitation amounts and seasonal patterns in many regions, changes in the intensity and pattern of extreme weather events, and sea level rise [(IPCC, 2001a; NACC, 2001; also see other SAPs, including 2.1b and 3.2)].

Some of these effects have clear implications for energy production and use. For instance, average warming can be expected to increase energy requirements for cooling and reduce energy requirements for warming. Changes in precipitation could affect prospects for hydropower, positively or negatively. Increases in storm intensity could threaten further disruptions of the sorts experienced in 2005 with Hurricane Katrina. Concerns about climate change impacts could change perceptions and valuations of energy technology alternatives. Any or all of these types of effects could have very real meaning for energy policies, decisions, and institutions in the United States, affecting discussions of courses of action and appropriate strategies for risk management.

According to CCSP, a SAP has three end uses: (1) informing the evolution of the research agenda; (2) supporting adaptive management and planning; and (3) supporting policy formulation. This product will inform policymakers, stakeholders, and the general public about issues associated with climate change implications for energy production and use in the United States, increase awareness of what is known and not yet known, and support discussions of technology and policy options at a stage where the knowledge base is still at an early stage of development.

The central questions addressed by SAP 4.5 are:

- How might climate change affect energy consumption in the United States?

- How might climate change affect energy production and supply in the United States?

- How might climate change affect various contexts that indirectly shape energy production and consumption in the United States, such as energy technologies, energy institutions, regional economic growth, energy prices, energy security, and environmental emissions?

SAP 4.5 is to be completed by the end of the second quarter of CY 2007 (June 30, 2007), following a number of steps required for all SAPs in scoping the study, conducting it, and reviewing it at several stages (see the section below on How the Report Was Developed).

1.2 THE TOPIC OF THIS SYNTHESIS AND ASSESSMENT REPORT

This report summarizes the current knowledge base about possible effects of climate change on energy production and use in the United States as a contributor to further studies of the broader topic of effects of global change on energy production and use. It also identifies where research could reduce uncertainties about vulnerabilities, possible effects, and possible strategies to reduce negative effects and increase adaptive capacity and considers priorities for strengthening the knowledge base. As is the case for most of the SAPs, it does not include new analyses of data, new scenarios of climate change or impacts, or other new contributions to the knowledge base, although its presentation of a framework for thought about energy sector impacts is in many ways new.

As indicated above, the content of SAP 4.5 includes attention to the following issues:

- Possible effects (both positive and negative) of climate change on energy *consumption* in the United States (Chapter 2)

- Possible effects (both positive and negative) on energy *production and supply* in the United States (Chapter 3)

- Possible *indirect effects* on energy consumption and production (Chapter 4)

These chapters are followed by a final chapter which provides conclusions about what is currently known, prospects for adaptation, and priorities for improving the knowledge base.

1.3 PREVIOUS ASSESSMENTS OF THIS TOPIC

As mentioned on page 1, unlike some of the other sectoral assessment areas identified in the Global Change Research Act of 1990—such as agriculture, water, and human health—energy was not the subject of a sectoral assessment in the *National Assessment of Possible Consequences of Climate Variability and Change*, completed in 2001 (NACC, 2001). As a result, SAP 4.5 draws upon a less organized knowledge base than these other sectoral impact areas. On the other hand, by addressing an assessment area not covered in the initial national assessment, SAP 4.5 will provide new information and perspectives.

The subject matter associated with SAP 4.5 is incorporated in two chapters of the Working Group II contribution to the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (Impacts, Adaptation, and Vulnerability), scheduled for completion in 2007. Chapter 7, "Industry, Settlement, and Society," section 7.4.2.1, is briefly summarizing the global knowledge base about possible impacts of climate change on energy production and use, reporting relevant research from the United States but not assessing impacts on the United States. Chapter 14, "North America," is summarizing the knowledge base about possible impacts of climate change in this continent, including the U.S., in sections 14.2.8 and 14.4.8.

1.4 HOW THE REPORT WAS DEVELOPED

SAPs are developed according to guidelines established by CCSP based on processes that are open and public. These processes include a number of steps before approval to proceed, emphasizing both stakeholder participation and CCSP reviews of a formal prospectus for the report, a number of review steps including both expert reviewers and public comments, and final reviews by the CCSP Interagency Committee and the National Science and Technology Council (NSTC).

The process for producing the report was focused on a survey and assessment of the available literature, in many cases including documents that were not peer-reviewed but the authors determined to be valid. using established analytic-deliberative practices, It included identification and consideration of relevant studies carried out in connection with CCSP, the Climate Change Technology Program (CCTP), and other programs of CCSP agencies (e.g., the Energy Information Administration), and consultation with stakeholders such as the electric utility and energy industries, environmental non-governmental organizations, and the academic research community to determine what analyses have been conducted and reports have been issued. Where quantitative research results are limited, the process considers the degree to which qualitative statements of possible effects may be valid as outcomes of expert deliberation, utilizing the extensive review processes built into the SAP process to contribute to judgments about the validity of the statements.

SAP 4.5 is authored by staff from the DOE national laboratories, drawing on their own expertise and knowledge bases and also upon other knowledge bases, including those within energy corporations and utilities, consulting firms, non-governmental organizations, state and local governments, and the academic research community. DOE has assured that authorship by DOE national laboratory staff will in no way exclude any relevant research or knowledge, and every effort is being made to identify and utilize all relevant expertise, materials, and other sources. For the author team of SAP 4.5, see Box 1.1.

Box 1.1. SAP 4.5 Author Team

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Stakeholders participated during the scoping process, have provided comments on the prospectus, and will submit comments on the product during a public comment period, as well as other comments via the SAP 4.5 web sit. The development of SAP 4.5 has included active networking by authors with centers of expertise and stakeholders to assure that the process is fully informed about their knowledge bases and viewpoints.

1.5 HOW TO USE THIS REPORT

The audience for SAP 4.5 includes scientists in related fields, decision-makers in the public sector (federal, state, and local governments), the private sector (energy companies, electric utilities, energy equipment providers and vendors, and energy-dependent sectors of the economy), energy and environmental policy interest groups, and the general public. Even though this report is unable—based on existing knowledge—to answer all relevant questions that might be asked by these interested parties, the intent is to provide information and perspectives to inform discussions about the issues and to clarify priorities for research to reduce uncertainties in answering key questions. As indicated above, because of limitations in available research literatures, in some cases the report is only able to characterize categories of possible effects without evaluating what the effects are likely to be. In other cases, the report offers preliminary judgments about effects, related to degrees of likelihood: likely (2 chances out of 3), very likely (9 chances out of 10), or virtually certain (99 chances out of 100).

This report avoids the use of highly technical terminology, but a glossary and list of acronyms are included at the end of the report (to be completed).

CHAPTER 2. EFFECTS OF CLIMATE CHANGE ON ENERGY USE IN THE UNITED STATES

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2.1 INTRODUCTION

As the climate of the world warms, the consumption of energy in climate-sensitive sectors is likely to change. Possible effects include:

- Changes in the amount of energy consumed in residential, commercial, and industrial buildings for space heating and cooling.

- Changes in energy used directly in certain processes such as residential, commercial, and industrial water heating, residential and commercial refrigeration, and industrial process cooling (e.g., in thermal power plants or steel mills).

- Changes in energy used to supply other resources for climate-sensitive processes, such as pumping water for irrigated agriculture and municipal uses.

- Changes in the balance of energy use among delivery forms and fuel types, as between electricity used for air conditioning and natural gas used for heating.

- Changes in energy consumption in key climate-sensitive sectors of the economy, such as transportation, construction, agriculture, and others.

In the United States, some of these effects of climate change on energy consumption have been studied to the extent that there is a body of literature with empirical results. This is the case with energy demand in residential and commercial buildings, where studies have been occurring for about 20 years. There is very little literature for any of the other effects mentioned above.

This chapter summarizes current knowledge about what potential effects of climate change on energy demand in the United States. The chapter mainly focuses on the effects of climate change on energy consumption in buildings (including mainly space heating and space cooling, but also addressing net energy use, peak loads, and adaptation) that is summarized in the next section. The following sections briefly address impacts of climate change on energy use in other sectors, including transportation, construction, and agriculture, for which empirical studies are far less available. The final section presents conclusions and issues for future research.

2.2 ENERGY CONSUMPTION IN BUILDINGS

U.S. residential and commercial buildings currently use about 41 exajoules of energy per year and account for 0.6 GT of carbon emitted to the atmosphere (38% of U.S. total emissions of 1.6 GT and approximately 9% of the world fossil-fuel related anthropogenic emissions of 6.7 GT (EIA, 2004a, b). U.S. residential and commercial energy consumption is expected to increase to 55 exajoules and corresponding carbon emissions to 0.8 GT by the year 2025 (EIA 2004c). These projections do not account for any temperature increases that occur as a result of global warming.

Generally speaking, the net effect of 21st century warming on demand for energy used in buildings is expected to be at most a few percent increase or decrease, with a shift away from consumption of fuels used directly for heating (mostly natural gas in the north) toward additional consumption of electricity for cooling (especially in the south). The extent of this shift is expected to depend in part on the strength of residential adoption of air conditioning as the length of the air conditioning season and the warmth of summer increases in the north, where the market penetration of air conditioning is still quite low. The potential reaction of consumers to the longer and more intense air conditioning season has been addressed in only a handful of studies (e.g., Sailor and Pavlova, 2003) and must be considered highly uncertain. There is even less information available on the offsetting effects of adaptations such as improved energy efficiency or changes in urban form that might reduce exacerbating factors such as urban heat island effects.

Amato et al. (2005) observe that many studies worldwide have analyzed the climate sensitivity of energy use in residential, commercial, and industrial buildings and have used estimated relationships to explain energy consumption and to assist energy suppliers with short-term planning (Quayle and Diaz, 1979; Le Comte and Warren, 1981; Warren and LeDuc, 1981; Downton et al., 1988; Badri, 1992; Lehman, 1994; Lam, 1998; Yan, 1998; Morris, 1999; Pardo et al., 2002). The number of studies in the U.S. analyzing the effects of climate *change* on energy demand, however, is much more limited. One of the very early studies was of the electricity sector, projecting that between 2010 and 2055 climate change could increase capacity addition requirements by 14–23% relative to non-climate change scenarios, requiring investments of $200–300 billion ($1990) (Linder and Innglis, 1989). Following on that study in the early and mid-1990s, there have been a handful of studies that have attempted an “all fuels” approach and have focused on whether net energy demand (decreases in heating balanced against increases in cooling) would increase or decrease in residential and commercial buildings as a result of climate change (e.g., Loveland and Brown 1990; Rosenthal et al. 1995; Belzer et al. 1996; Hadley et al. 2004; Mansur et al. 2005; Scott et al. 2005; Huang 2006).

Previous authors have taken a number of approaches to estimate the impact of climate change on energy use in U.S. buildings. Most of these researchers used simple increases in annual average temperature as the “climate” scenario and rather transient temperature increase scenarios from general circulation models such as those developed for the Intergovernmental on Climate Change (IPCC). The exceptions are Rosenthal et al. 1995, Hadley et al. 2004, Scott et al. 2005, and Huang 2006. For instance, building energy simulation models have been used to analyze the impact of climate warming on the demand for energy in individual commercial buildings only (Scott et al. 1994) and on energy consumption in a variety of commercial and residential buildings in a variety of locations (Loveland and Brown 1990, Rosenthal, et al. 1995, Scott et al. 2005, and Huang 2006). Other researchers have used econometrics and statistical analysis techniques (most notably the various Mendelsohn papers discussed herein, but also Belzer et al. 1996, Amato et al. 2005, Ruth and Amato 2002, and Franco and Sanstad 2006). In the subsections that follow on buildings energy consumption, this chapter discusses the impacts of climate warming on space heating in buildings (divided between residential and commercial),on space cooling (again divided between residential and commercial buildings), and on net energy demand. The cooling subsection discusses the effects of increased market penetration of air conditioning. The third subsection deals with net energy consumption. The final subsection also discusses the likely effects of adaptation actions such as increased energy efficiency and changes to urban form, which could reduce the impacts of some compounding effects such as urban heat islands.

2.3 EFFECTS ON ENERGY USE FOR SPACE HEATING

2.3.1 Residential Buildings and Equipment

The impact of climate change on space heating has been projected in a number of studies for the U.S. residential sector. The studies all concluded that temperature increases from global warming would reduce the amount of energy needed for space heating, with the amount of the reduction in any specific study mainly depending on the amount of temperature change in the climate scenario, the calculated sensitivity of the building stock to warming, and the adjustments allowed in the building stock over time.

One technique to estimate the impact of climate change has been to calculate the differences in energy use between warmer and cooler locations at a point in time and then to assume that these differences reflect how energy use in the building stock and equipment responds to climate and market conditions. All locations are then assumed to would respond to warming over time in a similar way. Mendelsohn performed cross-sectional econometric analysis using data on U.S. states to determine how energy use in the residential and commercial building stock relates to climate (Morrison and

Mendelsohn 1999; Mendelsohn 2001), and used these cross-sectional relationships to then estimate the impact of climate change in the year 2060 on all residential and commercial buildings. Mendelsohn (2003) later expanded on this approach by providing a two-step cross-sectional model of commercial and residential building stock, which uses U.S. data and accounts for the probability that a building be cooled (which increases with the amount of warming), and its overall energy consumption as a function of climate (matched on a county basis to Energy Information Administration buildings in the Residential Energy Consumption Survey and Commercial Building Energy Consumption Survey). This was further elaborated by Mansur et al. (2005) into a complete and separate set of discrete-continuous choice models of energy demand in residential and commercial commercial buildings. In this work, the impact of climate change on consumption of energy in heating is relatively modest. When natural gas is available, the marginal impact of a 1° C increase in January temperatures in their model reduces residential electricity consumption by 3% for electricity only consumers and 2% for natural gas customers.

Scott et al. (2005), working with directly with residential end uses end uses in a building energy simulation model, projected about a 16% to 60% reduction in the demand for residential space heating energy by 2080, given no change in the housing stock and winter temperature increases ranging from 2° to 10° C, or roughly 6% and 8% decrease in space heating per degree C increase. This is roughly twice the model sensitivity of Mansur et al. (2005). The Scott, et al. analysis was driven by a variety of global circulation models (GCMs) and climate scenarios used in the IPCC 3rd Assessment Report in 2001, regionalized to sub-continent level by the Finnish Environment Institute for the IPCC (Ruosteenoja, et al. 2003).

Most recently, Huang (2006) used results from the U.K. Meteorological Service Hadley Centre GCM of projected changes in temperature, daily temperature range, cloud cover, and relative humidity by month for 0.5° grids of the earth's surface under four IPCC carbon scenarios (A1FI, A2M, B1, and B2M) for the year 2080 to adjust hourly TMY2 (Typical Meteorological Year) weather files for 16 US locations. These modified weather files were then used with the DOE-2 building energy simulation program to simulate the energy demand of a set of 112 prototypical single-family houses covering 8 vintages in each of the 16 locations, which span the U.S. climate zones. For the entire U.S. residential sector, the simulations showed an increase in energy use from 0 to 7%, representing up to a 10% increase in space conditioning energy use. Regional results depended on whether the climate zone was already cool or warmer. For example, in Boston the net impacts varied from a 9% to 12% decrease in energy use (12% to 16% decrease in space conditioning), while in Miami there was a 29% to 58% with the space conditioning increase from 46% to 92%. Across the different building vintages, the impact was most adverse in current houses (2% to 11% increases of total, 2% to 18% of space conditioning for 90's vintage houses) and less so in older houses (-1% to 6% increases of total, -1% to 10% of space-conditioning).

2.3.2 Commercial Buildings and Equipment

Impacts in the commercial sector are similar to those in the residential sector. Belzer, et al. (1996) used a detailed data set on U.S. commercial buildings, and calculated the effect of building characteristics and temperature on energy consumption in all U.S. commercial buildings. With building equipment and shell efficiencies frozen at 1990 baseline levels, a 3.9° C temperature change decreased annual space heating energy requirements by 29% to 35%, or about 7.4% to 9.0% per degree C, a set of percentage increases that was not affected by either expected changes in the commercial building stock projected by the EIA, or by an "advanced" building envelope. Mansur et al. (2005) estimated that a 1° C increase in January temperatures would produce a reduction in electricity consumption of 3% for electricity. The marginal effect also reduces gas consumption by 3% and oil demand by a sizeable 12% per degree C. Huang (2006) made computer simulations of a set of 180 prototypical commercial buildings in five US climates for four IPCC carbon scenarios in 2080. Similar to the study's residential findings, these showed that the impact of carbon change on commercial building energy use varies greatly depending on climate and building type. For the entire US commercial sector, the simulations showed an increase in energy use from 2% to 5%. While this may seem small, it represents from 4% to 13% increase in space conditioning energy use. At the regional level, the impacts vary from a 0% to 2% decrease in energy use (0% to 5% decrease in space conditioning) in a cold climate such as Minneapolis, to as much as 8% to 16% increase in a hot climate such as Houston, where the space conditioning may increase from 22% to 43%). Among building types, the most adversely affected were supermarkets (7% to 15% increases of total energy use, 21% to 43% increase of space conditioning energy use) and hotels (4.4% to 8.9% increases of total energy use, 14% to 29% of space-conditioning energy use). The least affected were schools (6% decrease of total energy use 11% decrease of space-conditioning energy use) and warehouses (2% decrease of total, 7% decrease of space-conditioning energy use). The reason for these decreases was the minimal amount of air-conditioning in schools and warehouses, meaning that the impact was mostly energy savings due to reduced heating. There is also an interesting energy reduction for service hot water in this study, with the simulations showing from 5-15% reductions in all climates due to increased inlet water temperature.

2. 4 EFFECTS ON ENERGY USE FOR SPACE COOLING AND OTHER REFRIGERATION

2.4.1 Residential Buildings and Equipment

According to all studies surveyed for this chapter, climate warming is expected to increase the demand for space cooling, which is provided entirely by electricity. The effect in most studies is somewhat but not entirely linear with respect to temperature and humidity, meaning that the impact in *percentage* terms increases as the temperature does. It also means that increases in cooling eventually would dominate decreases in heating as temperature rises, although that effect is not necessarily observed for the temperature increases expected in the United States during the 21st century. Electricity demand for increases roughly 5% to 15% per 1ºC over the range of temperature increases projected in the studies surveyed. The impact on all electricity consumption is somewhat lower because electricity is used for a variety of non-climate-sensitive loads all regions and for space heating and water heating in some regions). Some initial work was done on energy consequences of global warming by Loveland and Brown (1990) for the residential sector in a number of different locations across the country. Total energy consumption decreased by up to 22% or increased by up to 48%, for a temperature increase of 3.2°C to 4°C, depending on whether the location was cold and therefore was dominated by saved heating energy, or was warm and therefore was dominated by increases in cooling. This implies about a 7% to 12% increase in cooling energy consumption per degree C. Similarly, based on a conditional consumption analysis with an econometric model, Similarly, Mansur et al. (2005) projected that when July temperatures were increased by 1ºC, electricity-only customers increased their electricity consumption by 5%, gas customers increased their demand for electricity by 6%, and oil customers bought 15% more electricity. Using a similar model in the special case of California, where space heating is dominated by space cooling, Mendelsohn (2003) found that total energy used for space cooling (electricity) increased non-linearly and net overall energy demand increases with a 1ºC warming. In such mild cooling climates, relatively small increases in temperature can have a large impact on air-conditioning energy use by reducing the potentials for natural ventilation or night cooling. Looking specifically at residential sector cooling demand (rather than all electricity) in 2080 with a fixed building stock, Scott et al. (2005) projected nationally that an increase of 1.8° to 9.1° C summer temperatures results in a 29% to 155% increase in national annual cooling energy consumption, or roughly a 16% to 17% increase per degree C.

2.4.2 Commercial/Industrial Buildings and Equipment

Studies during the last five years generally confirm earlier work that showed a small net change in the demand for energy in buildings as a result of a 2°C average annual warming, but a significant increase in demand for electricity, mainly for space cooling (Sailor and Muñoz, 1997; Morrison and Mendelsohn, 1999; Mendelsohn, 2001; Sailor, 2001; Sailor and Pavlova, 2003). Most of these studies do not directly account for improvements in energy efficiency or changes in per capita building space over time. EIA (2006) projects an increase in building residential floorspace per household of 14% during the period 2003-2030 and the ratio of commercial floorspace per member of the

U.S. labor force to increase by 23% in the same period. These effects are not captured by the cross-sectional econometric studies.

With a cross-sectional market of commercial energy demand and with building equipment and shell efficiencies frozen at 1990 baseline levels, Belzer et al. (1996) found that a 3.9°C temperature change decreased annual space heating energy requirements by 53.9% or about 9.0% to 13.8% per degree C, a set of percentage increases that was not affected by either expected changes in the commercial building stock projected by the EIA, or by an "advanced" building envelope.

2.4.3 Penetration of Air Conditioning, Heat Pumps (All-Electric Heating and Cooling) and Changes in Humidity

Although the effects of air conditioning market penetration were not explicitly identified, the late-1990s econometrically based cross sectional studies of Mendelsohn and colleagues might be argued to account for increased long run market saturations of air conditioning. (This is because warmer locations in the cross sectional studies also have higher market saturations of air conditioning as well as higher usage rates.) However, more recent studies have examined the effects directly. In one example, Sailor and Pavlova (2003) have found that potential increases in market penetration of air conditioning in response to warming might have an effect several times larger on electricity consumption than the warming itself. Using cross-sectional data and econometric techniques Mendelsohn (2003) and Mansur et al. (2005) also have estimated the effects of the market penetration of space cooling into the energy market. They also speculate that warmer climates are more likely to feature all-electric heating and cooling systems, which are a natural market for heat pumps. In general, however, the effects of adaptive response in energy demand have not been studied in the United States.

High atmospheric humidity is known to have an adverse effect on the efficiency of cooling systems in buildings in the context of climate change because of the energy penalty associated with condensing water. This was demonstrated for a small commercial building modeled with the DOE-2 building energy simulation model in Scott et al. (1994), where the impact of an identical temperature increase created a much greater energy challenge for two relatively humid locations (Minneapolis and Shreveport), compared with two drier locations (Seattle and Phoenix). Mansur et al. (2005) modeled the effect of high humidity by introducing a rainfall variable into their cross-sectional equations. In their residential sector, a one-inch increase in monthly precipitation resulted in more consumption by gas users of both electricity (7%) and of gas (2%). In their commercial sector, a one-inch increase in January and July precipitation resulted in more consumption of gas (6%) and of oil (40%).

2.5 OVERALL EFFECTS OF CLIMATE CHANGE ON ENERGY USE IN BUILDINGS

2.5.1 Annual Consumption

Many of the U.S. studies of the impact of climate change on energy use in buildings deal with both heating and cooling and attempt to come to a “bottom line” net result for either total energy consumed or total primary energy consumed (that is, the amount of natural gas and fuel oil consumed directly in buildings and the amount of natural gas, fuel oil, and coal consumed to produce the electricity consumed in buildings.) All recent studies show similar net effects. Both net delivered and net primary energy consumption increase or decrease only a few percent; however, there is a robust result that, in the absence of conservation policy directed at space cooling, climate change would cause a significant increase in the demand for electricity in the United States, which would require the building of additional electric generation (and probably transmission facilities) worth many billions of dollars.

In much of the United States, annual energy used for space heating dominates energy use for space cooling, so net energy consumption would be reduced by global warming. Table 2.1 summarizes the results from a number of U.S. studies of the effects of climate change on energy demand in U.S. residential and commercial buildings.

Table 2.1. Global Warming and Estimated Changes in Energy Demand in U.S. Residential and Commercial Buildings

Study: Author(s) and Date	**Temperature Change (˚C) and Date for Change**	**Change in Energy Consumption (%)**	**Type of Buildings and Fuel Experiencing Change**	**Cost (Savings) of Energy Consumption ($Billion)**	**Improved Energy Efficiency Offset Evaluated?**	**Change in Energy Consumption from Efficiency Offset (%)**
Linder and Inglis (1989)	0.6°C to 1.6ºC (2010) 3.4ºC to 5.3°C (2055)	+8,8% to 19.6% +13.5% to 22.9% (capacity)	Electricity Electricity	$3.2 to $6.1 $33 to $73	No No	--
Loveland and Brown (1990)	3.2ºC to 4.0ºC ($2xCO_2$, no date)	+10.2% to +35.0% -22.0% to +48.1%	General office (space heating and cooling load) Single family (space heating and cooling load)	--	Yes, -50% lighting, +50% insulation, +75% window shade	-34.4% to -50.2% -31.5% to -44.4%
Scott, Hadley, and Wrench (1994)	3.9ºC (7.0ºF) (no date)	-8.0% to +6.3%, depending on location	Space heating and air conditioning (small office building in 4 cities)	--	Yes, state of technology building envelope, reduced internal loads	-51.8% to -63.8%
Rosenthal, et al. (1995)	1.8ºC (2010)	-11%	Space heating and air conditioning	-$5.5 (1991$)	No	--
Scott, Belzer, and Sands (1996)	4ºC (2030)	-13.1%	Site energy (commercial buildings only)	Not calculated	Yes, advanced building envelope	-4.5%
Sailor (2001)	3º C (sensitivity analysis: no year given)	-10.1 to +18.8% (R) +0.1% to +8.0% (C)	Per capita residential and commercial electricity (8 states)	--	No	--
Ruth and Amato (2002)	2020 2050	-6.6% -13.9%	Heating Fuel Heating Fuel (Massachusetts)	--	No	--
Sailor and Pavlova (2003)	+20% in heating degree days (about 1ºC to 2ºC)	+1% to +9%	Total residential electricity with increased air conditioning market	--	No	--

Scott et al., (2005) projected that overall energy consumption in U.S. residential and commercial buildings is likely to decrease by about 5% in 2020 (0°C to 2.5°C warming) and as much as 20% in 2080 (for 3.5°C to 10°C warming) (11 GCMs, 8 scenarios), but would be accompanied by an increase of up to 25% in temperature-sensitive electricity consumption by 2080. This amounts to about 2% per 1ºC warming. This is a "pure climate effect," not allowing for changes in the building stock or increased market penetration of air conditioning that specifically result from climate change. Sailor also conducted this type of analysis for several categories of buildings and equipment (Sailor and Muñoz 1997, Sailor 2001, Sailor and Pavlova 2003). An overall per capita increase in residential and commercial electricity consumption of 5-15% for a 3°C average temperature increase summarizes individual state and regional results that are variable and sensitive to the specific climate scenario (Sailor, 2001), or about a 1.5% to 5% increase per 1ºC warming. He found a temperature increase of 2°C is associated with an 11.6% increase in residential per capita electricity used in Florida (a summer-peaking state dominated by air conditioning demand), 5% increase per 1ºC warming, but a 7.2% decrease in Washington (which uses electricity extensively for heating and is a winter-peaking system), about a 3% decrease per 1ºC warming.

There are also a number of specific state-level studies with similar outcomes. For Massachusetts in 2020, Ruth and Amato (Ruth and Amato, 2002) projected a 6.6 % decline in annual heating fuel consumption (8.7% decrease in heating degree days—overall temperature change not given) and a 1.9% increase in summer electricity consumption (12% in annual cooling degree-days). Continuing their research (Amato et al. 2005), the team noted that per capita residential and commercial energy demand in Massachusetts are sensitive to temperature and that a range of scenarios of climate change may noticeably decrease winter heating fuel and electricity demands and increase summer electricity demands. For 2030, the estimated residential summer monthly electricity demand increases that averaged about 20% in the Canadian Climate Model climate scenarios and up to 40% in the Hadley Center model. Wintertime monthly natural gas demand declined by 10% to 20% in the Canadian Model scenarios and 10% to 15% in the Hadley model scenarios. Fuel oil demand was down about 20% to

30% in the Canadian Model scenarios and 15% to 20% in the Hadley model scenarios. For the commercial sector, electricity consumption rose about 6% in the Canadian Climate Model scenarios and up to 10% in the Hadley Center model scenarios. Winter natural gas demand declined by 7% to 14% and 6% to 8% in the respective scenarios.

One study that takes a somewhat different approach is Hadley et al. 2004, which translates temperatures from a single climate scenario of the Parallel Climate Model into changes in heating degree days (HDD) and cooling degree-days (CDD) population-averaged in each of the nine U.S. Census divisions (on a 65° F base –against the findings of Rosenthal et al., Belzer et al., and Mansur et al. 2005, all of which projected a lower balance point temperature for cooling and a variation in the balance point across the country). They then compared these values with 1971-2000 normal HDDs and CDDs from the National Climate Data Center for the same regions. The changes in HDD and CDD were then used to drive changes in a special version (DD-NEMS) of the National Energy Modeling System (NEMS) of the U.S. Energy Information Administration, generally used to provide official energy consumption forecasts for the *Annual Energy Outlook* (EIA 2006). Two advantages of this approach are that it provides a direct comparison at the regional level to official forecasts and that it provides a fairly complete picture of energy supply, demand, and endogenous price response in a market model. One disadvantage is that the DD-NEMS model only forecasted out to 2025 in their work (now, 2030), which is only on the earliest part of the period where climate change is expected to substantially affect energy demand. In this study, the regional results were broadly similar to those in Scott, *et al.* For example, they showed decreases in energy demand for heating, more than offsetting the increased demand for cooling in the north (New England, Mid-Atlantic, West North Central and especially East North Central Census Division). In the rest of the country, the increase in cooling was projected to dominate. Nationally, the *delivered* energy savings were shown to be greater than the delivered energy increases, but because of energy losses in electricity generation, primary energy consumption increased by about 3% by 2025, driving up the demand for coal and driving down the demand for natural gas. Also, because electricity costs more than gas per delivered Btu, the increase in total energy cost per year was found to be about $15 billion (2001 dollars).

2.5.2 Peak Consumption

Studies published to date agree that temperature increases with global warming would increase peak demand for electricity in most regions of the country, but the amount of the increase varies with the region or regions covered and the study methodology–in particular, whether the study allows for changes in the building stock and increased market penetration of air conditioning in response to warmer conditions. One of the few early studies of the effects of climate change on regional electricity was conducted by Baxter and Calandri (1992), using very detailed data and electricity demand forecasting models of the California Energy Commission. Under their worst case in 1990 to 2010, a 1.9ºC (3.4ºF) increase in mean statewide temperature, the state would have required an additional peak capacity of 2,400 megawatts (MW), representing an increase of 3.7% in peak generation capacity from their 2010 base case. Uncertainties in the state's economic growth rate would have had comparable or larger impacts on electricity demand over this 20-year projected estimation.

Much more recently, using IPCC scenarios of climate change from the Hadley3, PCM, and GFDL climate models downscaled for California, Franco and Sanstad (2006) found high correlation between the simple average daily temperature and daily peak electricity demand in the California Independent System Operator region, which comprises most of California. They evaluated three different periods: 2005-2034, 2035-2064, and 2070-2099. In the first period, depending on the scenario and model, peak summer demand was projected to increase 1.0%-4.8%; in the second, 2.2%-10.9%; in the third, 5.6%-19.5%.

Some U.S. regions could benefit from lower winter demand for energy in Canada. In Québec, the Ouranos organization (Ouranos 2004) estimated that net energy demand for heating and air conditioning across all sectors could fall by 32 PJ, or 9.4 % of 2001 levels by 2100 (CGCM IS92a). Seasonality of demand also would change markedly. Residential heating in Québec would fall by 15% and air conditioning would increase nearly four-fold. Commercial-institutional heating demand falls by 13% and air conditioning demand doubles. Peak (winter) electricity demand in Québec would decline. Since much of the space heating in Québec is provided by hydro-generated electricity, the decline in energy demand in the province could free up a certain amount of capacity for bordering U.S. regions in the winter. Unfortunately, Québec's summer increase in air conditioning demand would coincide with an increase of about 7% to 17% in the New York metropolitan region (Ouranos 2004), so winter savings might be only of limited assistance in the summer cooling season, unless the water not used for hydroelectric production in the winter could be stored until summer and the transmission capacity existed to move the power south (Québec's hydroelectric generating capacity is sized for the winter peak and should not be a constraint).

Scott et al. (2005) did not directly estimate effects of climate change on peak electricity demand; however, using nuclear power's 90% average capacity factor for 2004 as an upper bound estimate of baseload power plant availability, they projected that national climate sensitive demand consumption (1.4 exajoules per year by 2080) would be equivalent of roughly 48 GW, or 48 baseload power plants of 1,000 MW each. At the much lower 2003 average U.S. generation/capacity ratio of 47%, 93 GW of additional generation capacity would be required. This component of demand would be a factor in addition to any increases due to additional climate-related market penetration of air conditioning and any other causes of increased demand for electricity the national electrical system will be dealing with for the rest of the century.

2.6 ADAPTATION: INCREASED EFFICIENCY AND URBAN FORM

Although improving building energy efficiency should help the nation cope with impacts of climate change, there is relatively little specific empirical information available on the potential impacts of such improvements. Partly this is because it has been thought that warming would already be reducing energy consumption, so that the additional effects of energy efficiency have not been of much interest. Scott et al. (1994) and Belzer et al. (1996) concluded that in the commercial sector, very advanced building designs could increase the savings in heating energy due to climate warming alone. Loveland and Brown (1990), Scott, et al. (1994), and Belzer, et al. (1996) all estimated the effects of energy-efficient buildings on energy consumption in the context of climate change and also concluded that much of the increase in energy consumption due to warming could be offset by increased energy efficiency. Loveland and Brown (1990) projected that changes leading to -50% lighting, +50% insulation, +75% window shading would reduce total energy use in residential buildings by 31.5% to -44.4% in the context of a 3.2° to 4°C warming. Scott et al. (1994) examined the impact of "advanced" building designs for a 48,000 square foot office building in the context of climate change in the DOE-2 building energy simulation model. The building envelope was assumed to reduce heat transfer by about 70% compared to the ASHRAE 90.1 standard. It included extra insulation in the walls and ceiling, reduction in window conductivity by a factor of 6, and window shading devices. The result was that at a 3.9°C increase in annual average temperature, an advanced design building, instead of experiencing between an 8% savings in energy use (Minneapolis) and a 6.3% increase in overall energy use (Phoenix), would experience a 57.2% to 59.8% decrease in energy used. In addition, the cooling energy impact was reversed in sign–a 47% to 60% decrease instead of a 35% to 93% increase. Belzer et al. (1996) projected that with a 3.9°C increase in annual average temperature, the use of advanced buildings would increase the overall energy savings in EIA's year 2030 projected commercial building stock from 0.47 QBtu (20.4%) to 0.63 QBtu (27%). Use of advanced building designs in the 2030 commercial building stock would increase the overall energy savings by 1.15 QBtu (40.6%) relative to a 2030 building stock frozen at 1990 efficiency. The cooling component of building energy consumption was only reduced rather than reversed by advanced designs in this study. Finally, Scott et al. (2005) explicitly considered the savings that might be achieved under the Department of Energy's energy efficiency programs as projected in August 2004 for the EIA building stock in the year 2020 (temperature changes of about 0.4°C at the low end to about 2.8°C at the high end). This is the only study to have estimated the national effects of actual energy efficiency programs in the context of global warming. (The analysis did not count any potential increase in energy demand due to additional climate change-induced market penetration of air conditioning). The efficiency programs were less effective if the climate did not change; however, buildings still saved between 2.0 and 2.2 QBtu. This was a savings of about 4.5%, which would more than offset the growth in temperature-sensitive energy consumption due to increases in cooling and growth in building between 2005 and 2020.

Except for Scott et al. (2005), even where studies purport to address adaptive response (e.g., Loveland and Brown 1990; Belzer et al. 1996; Mendelsohn 2001), they generally do not involve particular combinations of technologies to offset the effects of future climate warming. Regionally, Franco and Sanstad (2006) did note that the very aggressive energy efficiency and demand response targets for California's investor-owned utilities such as those recently enacted by the California Public Utilities Commission could, if extended beyond the current 2013 horizon, provide substantial "cushioning" of the electric power system against the effects of higher temperatures.

2.7 OTHER POSSIBLE EFFECTS, INCLUDING ENERGY USE IN KEY SECTORS

With a few exceptions, it is not thought that industrial energy demand is particularly sensitive to climate change. For example, Amato et al. (2005) stated that "industrial energy demand is not estimated since previous investigations (Elkhafif, 1996; Sailor and Munoz, 1997) and our own findings indicate that it is non-temperature-sensitive." A small number of studies have focused on other climate-sensitive industrial uses of energy such as agricultural crop drying and irrigation pumping (e.g., Darmstadter 1993; Scott et al. 1993). While it seems logical that warmer weather or extended warm seasons should result in warmer water inlet temperatures for industrial processes and higher rates of evaporation, possibly requiring additional industrial diversions, as well as additional municipal uses for lawns and gardens, the literature review conducted for this chapter did not locate any literature either laying out that logic or calculating any associated increases in energy consumption for water pumping. Such increases are likely to be small relative to those in agriculture, which consumes the lion's share (40%) of fresh water withdrawals in the United States (USGS, 2004). Some observations on energy use in climate-sensitive economic sectors follow.

2.7.1 Transportation

Running the air conditioning in a car reduces its fuel efficiency by approximately 12% at highway speeds (Parker 2005). A more extended hot season likely would both increase the percentage of vehicles sold with air conditioning and would increase their use. No data appear to be available on the total impact of climate change on energy consumption in automotive air conditioners, however.

Much of the food consumed in the United States moves by refrigerated truck or rail. One of the most common methods is via a refrigerated truck-trailer combination. As of the year 2000, there were approximately 225,000 refrigerated trailers registered in the United States, and their Trailer Refrigeration Units (TRUs) used on average 0.7 to 0.9 gallons of fuel per hour to maintain 0°F. On a typical use cycle of 7200 hours per year (6 days per week, 50 weeks per year), the typical TRU would use 5,000 to 6,000 gallons of diesel per year (Shurepower, LLC 2005), or between 26 and 32 million barrels for the national fleet. Even though diesel electric hybrid and other methods are making market inroads and over time could replace a substantial amount of this diesel use with electricity from the grid when the units are parked, climate warming would add to the energy use in these systems. No data appear to be available on the total impact of climate change on energy consumption, however

2.7.2 Construction

Warming the climate should result in more days when outdoor construction activities are possible. In many parts of the northern states, the construction industry takes advantage of the best construction weather to conduct activities such as some excavation, pouring concrete, framing buildings, roofing, and painting, while sometimes enclosing buildings, partially heating them with portable space heaters, and conducting inside finishing work during "bad" weather. The literature survey conducted for this chapter was not able to locate any studies in the United States that have investigated either the lengthening of the construction season in response to global warming or any resulting impacts on energy consumption.

2.7.3 Agriculture

Agricultural energy use generally falls into five main categories: equipment operations, irrigation pumping, embodied energy in fertilizers and chemicals, product transport, and drying and processing. A warmer climate implies increases in the demand for water in irrigated agriculture and use of energy (either natural gas or electricity) for pumping. Though not a factor in many parts of the country, irrigation energy is a significant source of energy demand west of the 100th meridian, especially in the Pacific Southwest and Pacific Northwest. For example, irrigation load in one early climate change impact assessment increased from about 8.7% to about 9.8% of all Pacific Northwest electricity load in July (Scott et al. 1993), even with no change in acreage irrigated.

In some parts of the country, the current practice is to keep livestock and poultry inside for parts of the year, either because it is too cold or too hot outside. Often these facilities are space-conditioned. In Georgia, for example, there are 11,000 poultry houses, and many of the existing houses are air-conditioned due to the hot summer climate (and all new ones are) (University of Georgia and Fort Valley State University 2005). Poultry producers throughout the South also depend on natural gas and propane as sources of heat to keep their birds warm during the winter (Subcommittee on Conservation, Credit, Rural

Development, and Research 2001). The demand for cooling livestock and poultry would be expected to increase in a warmer climate, while that for heating should fall.

Food processing needs extensive refrigerated storage, which may take more energy in a warmer climate. However, there seem to be no U.S. studies on this subject.

2.8 CONCLUSIONS AND ISSUES FOR RESEARCH

Generally speaking, the net effects of climate change in the United States on total energy demand are projected to be modest, amounting to between perhaps a 5% increase and decrease in demand per 1°C in warming in buildings, about 1.1 Quads in 2020 based on EIA 2006 projections (EIA, 2006). Existing studies do not agree on whether there would be an increase or decrease in energy consumption with changed climate because a variety of methodologies have been used, which has taken into account all of the potential effects of warming. There are differences in climate sensitivities, differences in methodological emphasis (econometric models have incorporated some market response to warming and fuel costs but not differences in building size and technology over time and space, while the opposite is true of building simulation approaches), as well as differences in climate and market scenarios. Studies of the effects of climate change on energy use outside of buildings are so rare that there is almost no set of studies to reconcile. It appears likely that some of the largest effects of climate change on energy use are in buildings, however, with other sensitivities being of secondary or tertiary importance.

- Can differences between studies be reconciled? To some extent, it is possible to control for differences in climate scenarios by comparing percentage changes in energy use per a standardized amount of temperature change, as has been done in this chapter. It is also possible to search for a set of robust results and to compare impacts, for example, that come from models that have fixed technologies and no market responses with those that allow technology to evolve and businesses and individuals to respond to higher or lower energy bills.

- If effects cannot be reconciled, which results are more likely to be correct? Because of compensating market and technological responses, impacts of climate change should be less with models that allow technology to evolve and businesses and individuals to respond to higher or lower energy bills. Because they also assess more realistically the factors actually likely to be in play, they are likelier to be closer to correct. None of the models actually does all of this, but Mansur et al. (2005) probably comes the closest on the market side and Scott et al. (2005) on the technology side. Using the results from these two approaches, together with Sailor and Pavlova (2003) to inform and modify the Hadley et al. (2004) special version of NEMS probably has the best chance of being correct for buildings.

- What are the impacts of climate and other major market drivers such as demographic shifts when taken together? One implication of the geographic shift of population in the United States from the north and east to the south and west is that air conditioning (space cooling) in residential and commercial buildings becomes a larger overall fraction of total national energy demand. Second, increased wealth of the population has caused increased market penetration of air conditioning and increased summer electrical demand everywhere in the nation. Recent literature has identified a strong relationship between cooling degree days and market saturation of air conditioning using an exponential saturation function (Sailor and Pavlova 2003), but the effect of increasing wealth has not been investigated, and has not been combined with demographic shifts. These factors are expected to substantially shift demand for building energy from winter heating load, provided primarily by natural gas, to summer electrical load provided by coal, nuclear, and natural gas resources. This shift from winter to summer places additional strain on regional electrical generation, transmission, and distribution systems, produces an unknown effect on the volatility of natural gas demand (possibly a reduction in season-to season variation, since winter heating demand currently dominates and would decline), and decreases the overall efficiency with which natural gas is consumed.

- What surprises might we expect from entirely missing effects and sectors? Agriculture is probably the sector most likely to supply surprises. Large amounts of energy are currently expended in agriculture to provide water for irrigation and for tilling, planting and pest control (e.g. aerial spraying of crops). There is major uncertainty concerning the future locations, timing, and amounts of precipitation that can be expected. Unexpectedly high demand for irrigation or pest control in currently rain-fed crop growing regions could greatly stress both water and energy supplies.

CHAPTER 3. EFFECTS OF CLIMATE CHANGE ON ENERGY PRODUCTION AND DISTRIBUTION IN THE UNITED STATES

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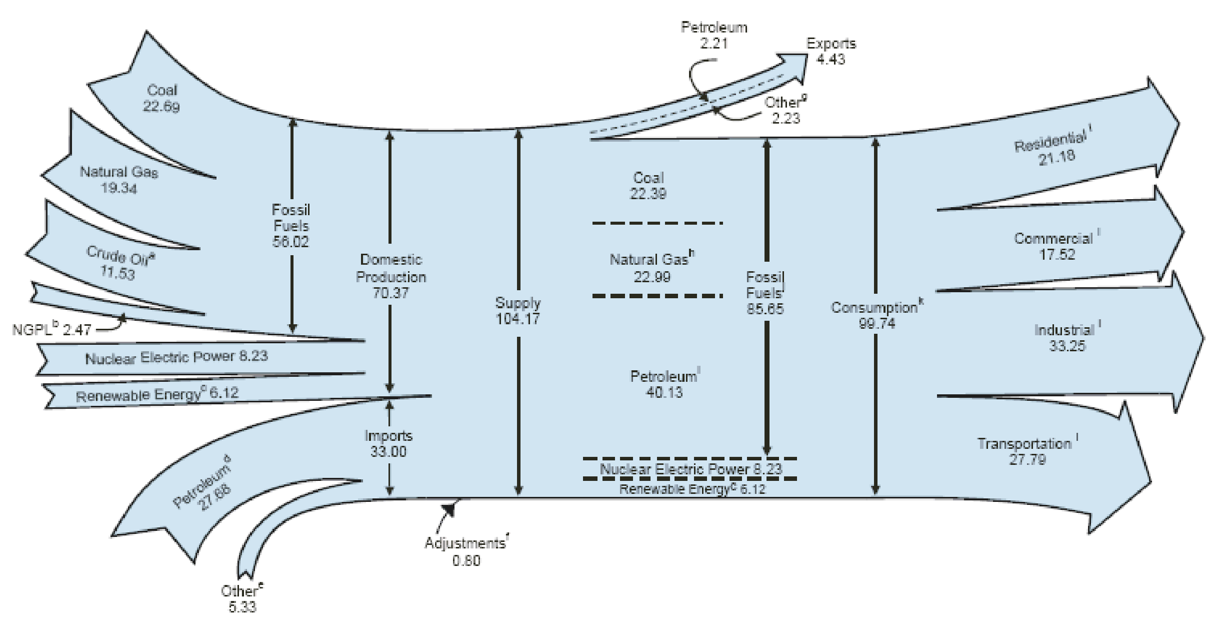
Energy production in the U.S. is dominated by fossil fuels: coal, natural gas, and petroleum (Fig. 3.1). Every existing source of energy has some vulnerability to climate variability (Table 3-1). Renewable energy sources tend to be more sensitive to climate variables; but fossil energy production can also be adversely effected by air and water temperatures and the thermoelectric cooling process that is critical to maintaining high energy efficiencies and nuclear energy requires cooling as well. In addition, extreme weather events have adverse effects on energy production, distribution, and fuel transportation as well.

This section discusses the specific impacts on energy production and distribution associated with projected changes in temperature, precipitation, water resources, severe weather events, and sea level rise. Overall, the effects on the existing infrastructure might be categorized as modest; however, local and industry-specific impacts could be large, especially in areas that may be prone to disproportional warming (Alaska) or weather disruptions (Gulf Coast). The existing assemblage of power plants and distribution systems is likely to be more affected by ongoing unidirectional changes, compared with future systems, if future systems can be designed with the upfront flexibility to accommodate the span of potential impacts. Possible adaptation measures include technologies that minimize the impact of increases in ambient temperatures on power plant equipment, technologies that conserve water use for power plant cooling processes, planning at the local and regional level to anticipate storm and drought impacts and establish action plans, and policies that conserve both energy and water.

Diagram 1. Energy Flow, 2004
(Quadrillion Btu)



[a] Includes lease condensate.

[b] Natural gas plant liquids.

[c] Conventional hydroelectric power, wood, waste, ethanol blended into motor gasoline, geothermal, solar, and wind.

[d] Crude oil and petroleum products. Includes imports into the Strategic Petroleum Reserve.

[e] Natural gas, coal, coal coke, and electricity.

[f] Stock changes, losses, gains, miscellaneous blending components, and unaccounted-for supply.

[g] Coal, natural gas, coal coke, and electricity.

[h] Includes supplemental gaseous fuels.

[i] Petroleum products, including natural gas plant liquids.

[j] Includes 0.14 quadrillion Btu of coal coke net imports.

[k] Includes, in quadrillion Btu, 0.30 ethanol blended into motor gasoline, which is accounted for in both fossil fuels and renewable energy but counted only once in total consumption; and 0.04 electricity net imports.

[l] Primary consumption, electricity retail sales, and electrical system energy losses, which are allocated to the end-use sectors in proportion to each sector's share of total electricity retail sales. See Note, "Electrical Systems Energy Losses," at end of Section 2.

Notes: • Data are preliminary. • Totals may not equal sum of components due to independent rounding.

Sources: Tables 1.1, 1.2, 1.3, 1.4, 2.1a, and 10.1.

Energy Information Administration / Annual Energy Review 2004 3

Figure 3.1. Energy Flow in the U.S. (EIA, Annual Energy Review 2004)

3.1 EFFECTS ON FOSSIL AND NUCLEAR ENERGY

Climate change can affect fossil and nuclear energy production, conversion, and end-user delivery in a myriad of ways. Average ambient temperatures impact heating and cooling demand, generation cycle efficiency, and cooling water requirements in the electrical sector, water requirements for energy production and refining, and Gulf of Mexico (GOM) produced water discharge requirements. Often these impacts appear "small" based on the change in system efficiency or the potential reduction in reliability but the scale of the energy industry is vast: fossil fuel-based net electricity generation exceeded 2,500 billion kWh in 2004 (EIA, 2006). A net reduction in generation of 1% due to

Table 3.1. Mechanisms of climate impacts on various energy supplies in the U.S. (percentages shown are of total domestic consumption; T=water/air temperature, W=wind, H=humidity, P=precipitation, and E=extreme weather events)

Energy Impact Supplies		*Climate Impact Mechanisms*
Fossil Fuels (86%)	**Coal (22%)**	Cooling water quantity and quality (T), cooling efficiency (T, W, H), erosion in surface mining
	Natural Gas (23%)	Cooling water quantity and quality (T), cooling efficiency (T, W, H), disruptions of off-shore extraction (E)
	Petroleum (40%)	Cooling water quantity and quality, cooling efficiency (T, W, H), disruptions of off-shore extraction and transport (E)
	Liquified Natural Gas (1%)	Disruptions of import operations (E)
Nuclear (8%)		Cooling water quantity and quality (T), cooling efficiency (T, W, H)
Renewables (6%)	**Hydropower**	Water availability and quality, temperature-related stresses, operation modification from extreme weather (floods/droughts), T&E
	Biomass	
	• Wood and forest products	Possible short-term impacts from timber kills or long-term impacts from timber kills and changes in tree growth rates (T, P)
	• Waste (municipal solid waste, landfill gas, etc.)	n/a
	• Biofuels	Changes in food crop residue and dedicated energy crop growth rates (T, P, E, carbon dioxide levels)
	Wind	Wind resource changes (intensity and duration), damage from extreme weather
	Solar	Insolation changes (clouds), damage from extreme weather
	Geothermal	n/a

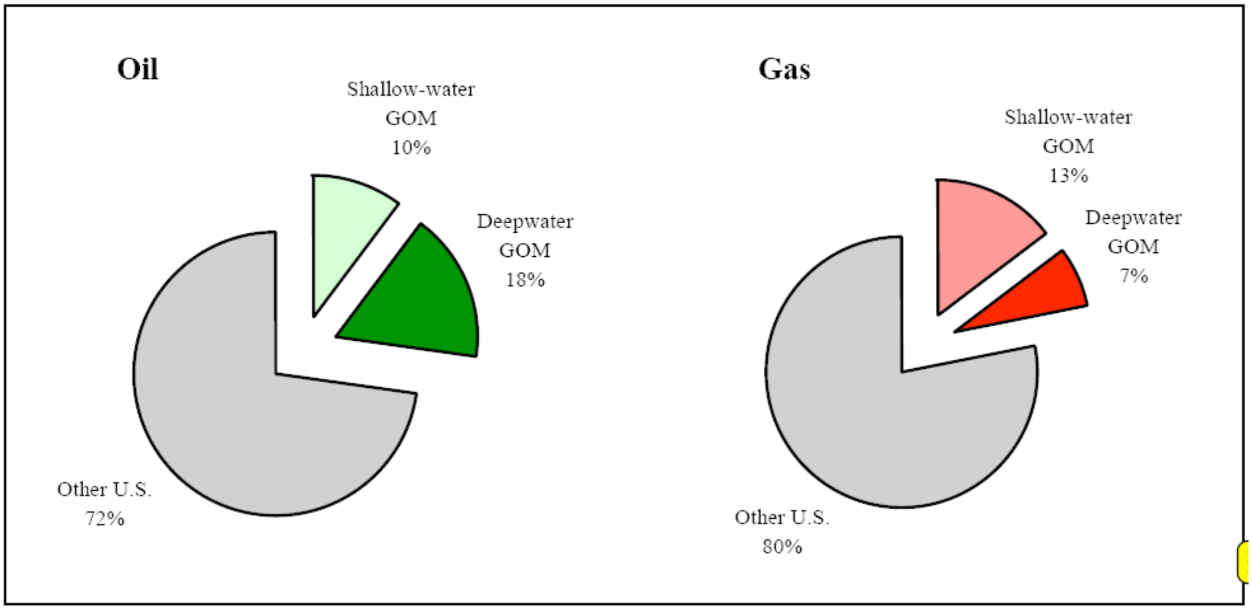
(Source: EIA 2004).

increased ambient temperature (Maulbetsch and DiFilippo, 2006) represents a drop in supply of 25 billion kWh that might need to be replaced somehow. The GOM temperature-related issue is a result of the formation of water temperature-related anoxic zones and is important because that region accounts for 20 to 30 percent of the total domestic oil and gas production in the U.S. (Figure 3.2). Constraints on produced water discharges can increase costs and reduce production, both in the GOM region and elsewhere. Impacts of extreme weather events could range from localized railroad track distortions due to temperature extremes, to regional-scale coastal flooding from hurricanes, and to watershed-scale river flow excursions from weather variations superimposed upon, or possibly augmented by, climate change. Spatial scale can range from kilometers to continent-scale; temporal scale can range from hours to multi-year. Energy impacts of episodic events can linger for months or years as illustrated by the continuing loss of oil and gas production in the GOM (MMS, 2006a, 2006b, and 2006c) eight months after the 2005 hurricanes.

3.1.1 Thermoelectric Power Generation

Climate change impacts on electricity generation at fossil and nuclear power plants are likely to be similar. The most direct climate impacts are related to power plant cooling and water availability.

Predicted changes in water availability throughout the world would directly affect the availability of water to existing power plants. While there is uncertainty in the nature and amount of the change in water availability in specific locations, there is agreement among climate models that there will be a redistribution of water, as well as changes in the availability by season. As currently designed, power plants require significant amounts of water and they will be vulnerable to fluctuations in water supply. Regional-scale changes would likely mean that some areas could see significant increases in water availability while other regions could see significant decreases. In those areas seeing a decline, the impact on power plant availability or even siting of new capacity could be



(Source: Deepwater Gulf of Mexico 2006: America's Expanding Frontier OCS Report MMS 2006-022).

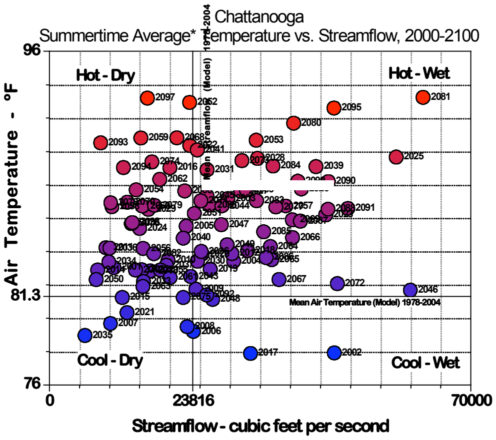
Figure 3.2. Distribution of off-shore oil and gas wells in the Gulf of Mexico (GOM) and elsewhere in the U.S.

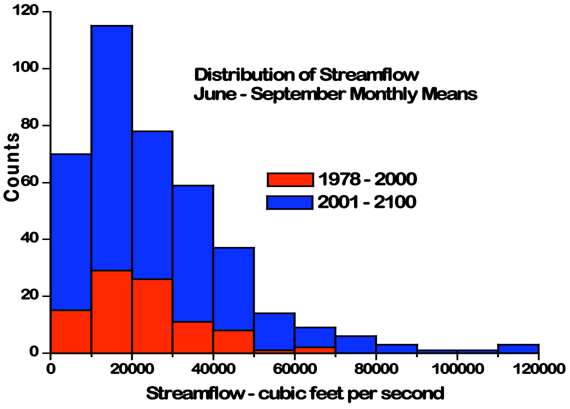
significant. Plant designs are flexible and new technologies for water reuse, heat rejection, and use of alternative water sources are being developed but at present, some impact—significant on a local level—can be foreseen. An example of such a potential local effect is provided in Box 3.1—Chattanooga: A Case Study, which shows how cooling conditions might evolve over the 21st century for generation in one locality. Situations where the development of new power plants is being slowed down or halted due inadequate cooling water are becoming more frequent throughout the U.S. (SNL, 2006).

In those areas seeing an increase in stream flows and rainfall, impacts on groundwater levels and on seasonal flooding could have a different set of impacts. For existing plants, these impacts could include increased costs to manage on-site drainage and run-off, changes in coal handling due to increased moisture content or additional energy

BOX 3.1. CHATTANOOGA: A CASE STUDY OF COOLING EFFECTS

A preliminary analysis of one IPCC climate change scenario (A1B) indicates one example of how cooling conditions might evolve over the 21st century for generation in the Chattanooga vicinity (ORNL work in progress). In this example, a slight upward trend in stream flow would provide a marginal benefit for once-through cooling, but would be offset by increasing summertime air temperatures that trigger limits on cooling water intake and downstream mixed temperatures. Closed-cycle cooling would also become less effective as ambient temperature and humidity increased. Utilities would need to maintain generation capacity by upgrading existing cooling systems or shifting generation to newer facilities with more cooling capacity. Without technology-based improvements in cooling system energy efficiency or steam-cycle efficiency, overall thermoelectric generation efficiency would decrease





requirements for coal drying, etc. The following excerpt details the magnitude of the intersection between energy production and water use.

An October 2005 report produced by the National Energy Technology Laboratory stated, in part, that the production of energy from fossil fuels (coal, oil, and natural gas) is inextricably linked to the availability of adequate and sustainable supplies of water. While providing the United States with a majority of its annual energy needs, fossil fuels also place a high demand on the Nation’s water resources in terms of both use and quality impacts (EIA, 2005d). Thermoelectric generation is water intensive – on average each kWh of electricity generated via the steam cycle requires approximately 25 gallons of water (This number is a weighted average that captures total thermoelectric water withdrawals and generation for both once-through and recirculating cooling systems) to produce. According to the United States Geological Survey (USGS), power plants rank only slightly behind irrigation in terms of freshwater withdrawals in the United States (USGS, 2004), although irrigation withdrawals tend to be m ore consumptive). Water is also required in the mining, processing, and transportation of coal to generate electricity all of which can have direct impacts on water quality. Surface and underground coal mining can result in acidic, metal-laden water that must be treated before it can be discharged to nearby rivers and streams. In addition, the USGS estimates that in 2000 the mining industry withdrew approximately 2 billion gallons per day of freshwater. Although not directly related to water quality, about 10% of total U.S. coal shipments were delivered by barge in 2003 (USGS, 2004). Consequently, low river flows can create shortfalls in coal inventories at power plants.

Freshwater availability is also a critical limiting factor in economic development and sustainability and directly impacts electric-power supply. A 2003 study conducted by the Government Accountability Office indicates that 36 states anticipate water shortages in the next ten years under normal water conditions, and 46 states expect water shortages under drought conditions (GAO, 2003). Water supply and demand estimates by the Electric Power Research Institute (EPRI) for the years 1995 and 2025 also indicate a high likelihood of local and regional water shortages in the United States (EPRI 2003). The area that is expected to face the most serious water constraints is the arid southwestern United States.

In any event, the demand for water for thermoelectric generation will increasingly compete with demands from other sectors of the economy such as agriculture, domestic, commercial, industrial, mining, and in-stream use. EPRI projects the potential for future constraints on thermoelectric power in 2025 for Arizona, Utah, Texas, Louisiana, Georgia, Alabama, Florida, and all of the Pacific Coast states. Competition over water in the western United States, including water needed for power plants, led to a 2003

Department of Interior initiative to predict, prevent, and alleviate water-supply conflicts (DOI, 2003). Other areas of the United States are also susceptible to freshwater shortages as a result of drought conditions, growing populations, and increasing demand.

Concern about water supply expressed by state regulators, local decision-makers, and the general public is already impacting power projects across the United States. For example, Arizona recently rejected permitting for a proposed power plant because of concerns about how much water it would withdraw from a local aquifer (Land Letter, 2004). An existing Entergy plant located in New York is being required to install a closed-cycle cooling water system to prevent fish deaths resulting from operation of its once-through cooling water system (Greenwire, 2003). Water availability has also been identified by several Southern States Energy Board member states as a key factor in the permitting process for new merchant power plants (Clean Air Task Force, 2004). In early 2005, Governor Mike Rounds of South Dakota called for a summit to discuss drought-induced low flows on the Missouri River and the impacts on irrigation, drinking-water systems, and power plants (Billingsgazette.com 2005). Residents of Washoe County, Nevada expressed opposition to a proposed coal-fired power plant in light of concerns about how much water the plant would use (Reno-Gazette Journal 2005). Another coal-fired power plant to be built in Wisconsin on Lake Michigan has been under attack from environmental groups because of potential effects of the facility's cooling-water-intake structures on the Lake's aquatic life (Milwaukee Journal Sentinel, 2005).

Such events point towards a likely future of increased conflicts and competition for the water the power industry will need to operate their thermoelectric generation capacity. These conflicts will be national in scope, but regionally driven. It is likely that power plants in the west will be confronted with issues related to water rights, that is, who owns the water and the impacts of chronic and sporadic drought. In the east, current and future environmental requirements, such as the Clean Water Act's intake structure regulation, could be the most significant impediment to securing sufficient water, although local drought conditions can also impact water availability. If changing climatic conditions affect historical patterns of precipitation, this may further complicate operations of existing plants, and the design and site selection of new units.

EIA reports (EIA, 2004) net summer and winter capacity for existing generating capacity by fuel source. Coal-fired and nuclear have summer/winter ratios of 0.99 and 0.98 and average plant sizes of 220 MW and 1015 MW respectively. Petroleum, natural gas and dual fuel-fired plants show summer/winter net capacity ratios of 0.90 to 0.93, indicating higher sensitivity to ambient temperature while average plant sizes range from 12 MW to 84 MW. Although large coal and nuclear generating plants report little degradation of net generating capacity from winter to summer conditions, there are reports (University of Missouri-Columbia, 2004) of plant derating and shutdowns caused by temperature-related river water level changes and thermal limits on water discharges. Actual generation in 2004 (EIA, 2004) show coal-fired units with 32% of installed capacity provided 49.8% of generation and nuclear units with 10% of installed capacity provided 17.8% of power generated, indicating that these sources are much more heavily dispatched than are petroleum, natural gas and dual-fired sources. To date, this difference has been generally attributed to the lower variable costs of coal and nuclear generation, driven by fuel costs rather than temperature-related capacity constraints.

Gas turbines, in their varied configurations, provide about 20 % of the electric power produce in the U.S. (EIA, 2006). Gas turbines in natural gas simple cycle, combined cycle (gas and steam turbine) and coal based integrated gasification combined cycle applications are effected by local ambient conditions. These conditions include for the most part local ambient temperature and pressure. Ambient temperature and pressure conditions have an immediate impact on gas turbine performance. Turbine performance is measured in terms of heat rate (efficiency) and power output. A 60 - 120ºF change (60 ºF) in ambient temperature would have a 1-2 percentage point reduction in efficiency and a 20-25% reduction in power output (Davcock, DesJardins, and Fennell, 2004). This impact is nearly linear, so a 10 degree Fahrenheit change would produce as much as a 0.5 percentage point reduction in efficiency and a 3-4% reduction in power output. Therefore, the impact of potential climate change on the fleet of existing turbines would be driven by the impact that small changes in overall performance would have on both the total capacity available at any time and the actual cost of electricity.

Turbines for NGCC and IGCC facilities are designed to run 24 hours, seven days a week but simple cycle turbines used in topping and intermediate service are designed for frequent startups and rapid ramp rates to accommodate grid dispatch requirements. Local ambient temperature conditions will normally vary by 10 – 20 °F on a 24 hour cycle and many temperate-zone areas have winter-summer swings in average ambient temperature of 25 – 35 F. Consequently, any long term climate change that would impact ambient temperature is believed to be on a scale within the design envelope of currently deployed turbines. As noted earlier, both turbine power output and efficiency vary with ambient temperature deviation from the design point. The primary impacts of longer periods of off-design operation will be modestly reduced capacity and reduced efficiency. Currently turbine-based power plants are deployed around the world in a wide variety of ambient conditions and applications, indicating that new installations can be designed to address long-term changes in operating conditions. In response to the range of operating temperatures and pressures to which gas turbines are being subjected, turbine designers have developed a host of tools for dealing with daily and local ambient conditions. These tools include inlet guide vanes, inlet air fogging (essentially cooling and mass flow addition), inlet air filters and compressor blade washing techniques (to deal with salt and dust deposited on compressor blades). These tools could also be deployed to address changes in ambient conditions brought about by long term climate change.

3.1.2 Energy Resource Production And Delivery

Other than for renewable energy sources, energy resource production and delivery systems are mainly vulnerable to effects of sea level rise and extreme weather events.

The IPCC (IPCC, 2001a) estimated a 50 cm. (20 inch) rise in sea level around North America in the next century from climate change alone. This is well within the normal tidal range and would not have any significant effect on off-shore oil and gas activities.

On-shore oil and gas activities could be much more impacted which could create derivative impacts on off-shore activities.

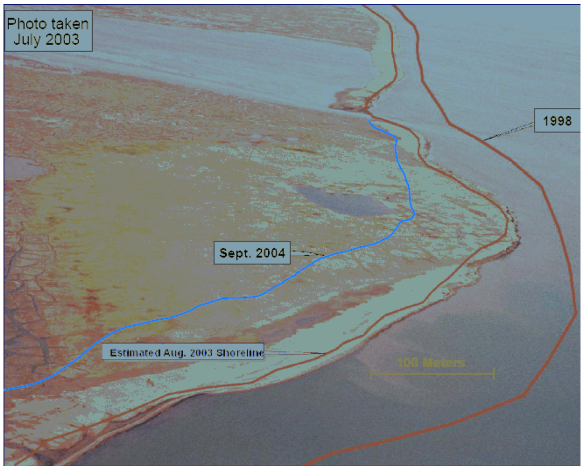
A number of operational power plants are sited at elevations of 3 feet or less, making them vulnerable to these rising sea levels. In addition, low lying coastal regions are being considered for the siting of new plants due to the obvious advantages in delivering fuel and other necessary feedstocks. Significant percentages of other energy infrastructure assets are located in these same areas including a number of the nation's oil refineries as well as most coal import/export facilities and liquefied natural gas terminals. Given that a large percentage of the Nation’s energy infrastructure lies along the coast, rising sea levels could lead to direct losses such as equipment damage from flooding or erosion, or indirect effects such as the costs of raising vulnerable assets to higher levels or building future energy projects further inland, thus increasing transportation costs.

IPCC (2001a) and USGS (2000) have identified substantial areas of the US East Coast and Gulf Coast as being vulnerable to sea-level rise. Roughly one-third of US refining and gas processing physical plant lies on coastal plains adjacent to the GOM, hence is vulnerable to inundation, shoreline erosion, and storm surges. On-shore, but non-coastal oil and gas production and processing activities may be impacted by climate change primarily as it impacts extreme weather events, phenomena not presently well understood.

Florida’s energy infrastructure may be particularly susceptible to sea-level rise impacts. Most of the petroleum products consumed in Florida are delivered by barge to three ports (NASEO, 2005) two on the East Coast of Florida and one on the West Coast. The interdependencies of natural gas distribution, transportation fuel distribution and delivery, and electrical generation and distribution were found to be major issues in Florida’s recovery from multiple hurricanes in 2004. Alaska represents a special case for climate adaptation because of the scale of the predicted impacts are expected to be greater in higher latitudes (See Box 3.2. Alaska: A Case Study).

BOX 3.2. ALASKA: A CASE STUDY

Alaska represents a special case for climate adaptation because of the scale of the predicted impacts are expected to be greater in higher latitudes—some models predict an arctic temperature increase to be double the global average (ref…). In areas of the north slope, change is already being observed, as illustrated below by the changes in shoreline along the Teshekpuk Lake Special Area and the inundation of the pilings protecting the J.W. Dalton well heads and pilings (photos taken September 2004 and 2005 (ref….).



Energy impacts specific to Alaska include:

- Warming and ensuing ice melts may provide alternative opportunities for marine transportation of fossil fuels. For example, oil from northern Russia might be delivered to New York terminals via a route over the top of the North American continent if the sea ice thins sufficiently.
- Areas of the National Petroleum Reserve -Alaska have already lost significant amounts of shore ice, in areas that are of interest to the oil industry.
- When thermokarsting (melting permafrost) occurs beneath a road, house, pipeline, etc, then the structural integrity of the facility is threatened. Technologies already exist to protect the permafrost, but may not be sufficient given predicted temperature increases.
- Negative economic and operational impacts may result from an increasingly shorter winter work season, which has shortened over the past 30 years, dropping from over 200 days in 1970 to about 100 days in 2003. A season of only 100 days translates into a minimum of two years to complete an exploration program.

Regarding extreme weather events, which could represent more significant effects, see 3.1.4. Coal production is susceptible to extreme weather events which can directly impact open-cast mining operations and coal cleaning operations of underground mines.

Potential impacts on novel resources are speculative at present. Oil shale resource development, which is considered to be water intensive, could be made more difficult if climate change further reduces annual precipitation in an already arid region that is home to the major oil shale deposits. Water availability (Struck, 2006) is beginning to be seen as a potential constraint on synthetic petroleum production from the Canadian oil sands. Coal-to-Liquids operations also require significant quantities of water.

3.1.3 Transportation of Fuels

Roughly 65% of petroleum products supplied in the Petroleum Administration for Defense (PAD) East Coast District (Figure 3.3) arrive there via pipeline, barge, or ocean vessel (EIA, 2004). Approximately 80% of the domestic-origin product is transported by pipeline. Certain areas, e.g., Florida, are nearly totally dependent on maritime (barge) transport. About 97% of the crude oil charged to PAD I refineries is imported, arriving primarily by ocean vessels. PAD II receives the bulk of its crude oil via pipeline, roughly two-thirds from PAD III and one-third from Canada. Both pipeline and barge transport has been susceptible to extreme weather events with pipeline outages mostly driven by interdependencies with the electrical grid. In addition (see 3.3.2), increased ambient temperatures can degrade pipeline system performance, particularly when tied to enhanced oil recovery and, if practiced in the future, carbon sequestration. Moreover, (see 3.3.2), increased ambient temperatures can degrade pipeline system performance, particularly when tied to enhanced oil recovery and, if practiced in the future, carbon sequestration. The transportation of coal to end users, primarily electrical generation facilities, is dependent on rail and barge transportation modes (EIA, 2004). Barge transport is susceptible to both short term, transient weather events and to longer-term shifts in regional precipitation and snow melt patterns which may reduce the extent of

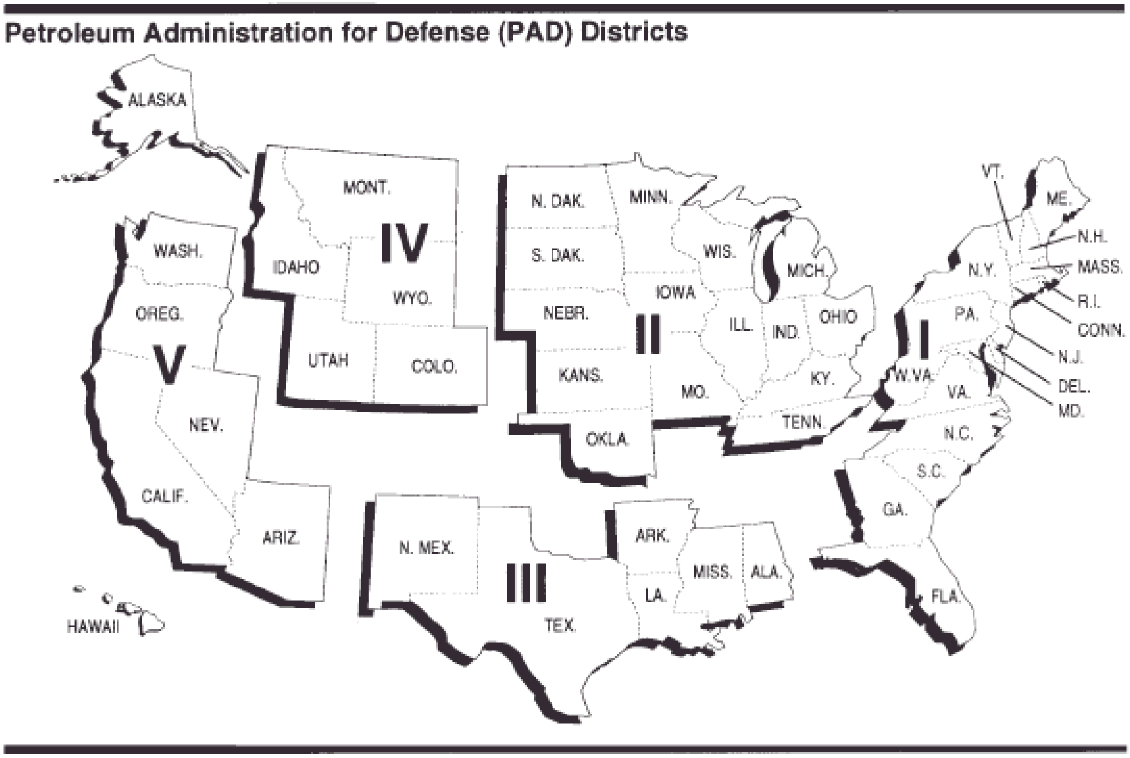


Figure 3.3. Petroleum Administration for Defense (PAD) Districts

navigability of rivers and reduce or expand the annual navigable periods. In addition, offshore pipelines were impacted by Hurricane Ivan even before the arrival of Hurricane Katrina (see 3.1.4).

3.1.4 Extreme Events

Climate change may cause significant shifts in current weather patterns and increase the severity and frequency of major storms (NRC, 2002). As witnessed in 2005, hurricanes can have a debilitating impact on energy infrastructure. Direct losses to the energy industry are estimated at $15 billion dollars (Marketwatch.com, 2006), with millions more in restoration and recovery costs. Future energy projects located in storm prone areas will face increased capital costs of hardening their assets due to both legislative and insurance pressures. For example, the Yscloskey Gas Processing Plant was forced to close for six months following Hurricane Katrina, resulting in both lost revenues to the plant's owners and higher prices to consumers as alternative gas sources had to be procured. In general, the incapacitation of energy infrastructure – especially of refineries, gas processing plants and petroleum product terminals – is widely credited with driving a price spike in fuel prices across the country, which then in turn has national consequences. The potential impacts of more severe weather are not limited to hurricane-prone areas. Rail transportation lines, which transport approximately 2/3 of the coal to the nation's power plants (EIA, 2002), often closely follow riverbeds, especially in the Appalachian region. More severe rain storms can lead to flooding of rivers which then can wash out or degrade the nearby roadbeds. Flooding may also disrupt the operation of inland waterways, the second-most important method of transporting coal. With utilities carrying smaller stockpiles and projections showing a growing reliance on coal for a majority of the nation's electricity production, any significant disruption to the transportation network has serious implications for the overall reliability of the grid as a whole.

Off-shore production is susceptible to extreme weather events. Hurricane Ivan (2004) destroyed seven GOM platforms, significantly damaged 24 platforms, and damaged 102 pipelines (MMS, 2006). Hurricanes Katrina and Rita in 2005 destroyed more than 100 platforms and damaged 558 pipelines (MMS, 2006). Figures 3.4a, b, c, and d show the typhoon and Mars deepwater platforms before and after the 2005 hurricanes. The $250 million Typhoon platform was so severely damaged that Chevron is working with the MMS to sink it as part of he artificial reef program in the GOM; the billion dollar plus Mars platform has been repaired, and returned to production about eight months post-hurricane.

Figures 3.4a and 3.4b. Hurricane damage at the Mars drilling platform in the Gulf of Mexico – Typhoon platform

Figures 3.4 c and 3.4d. Hurricane damage at the Mars drilling platform in the Gulf of Mexico – Mars platform

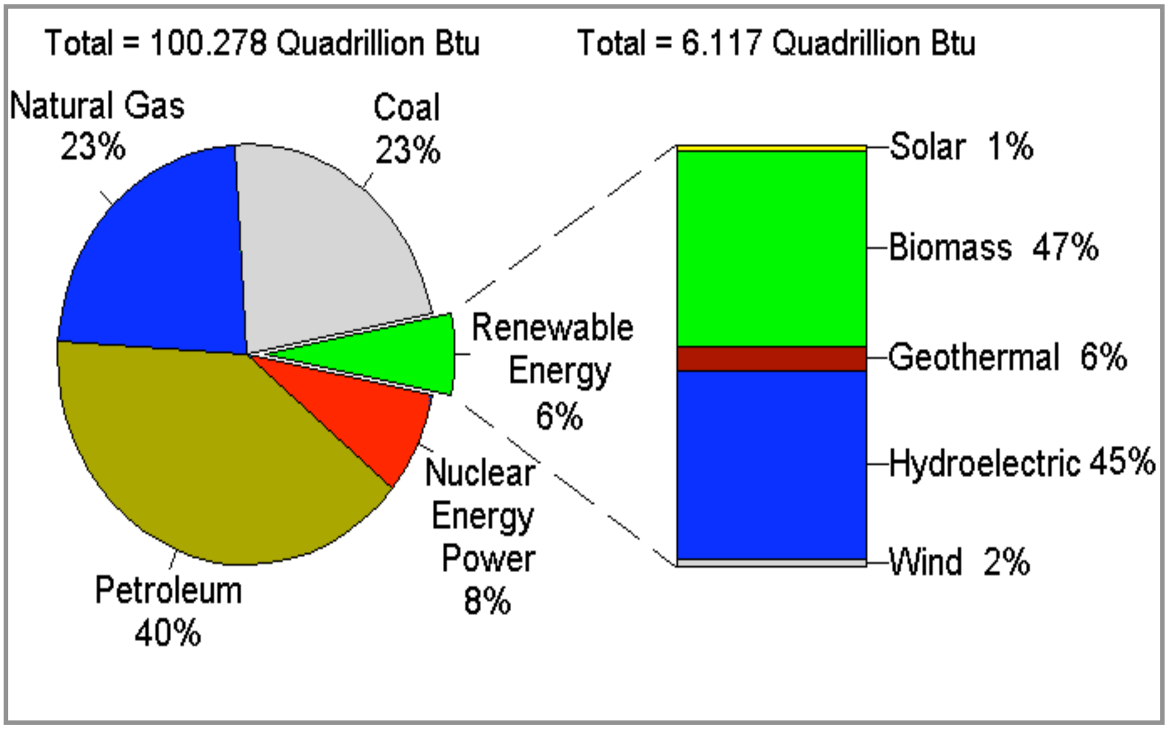
3.1.5 Adaptation to Extreme Events

Energy assets can be protected from these impacts both by protecting the facility or relocating it to safer areas. Hardening could include reinforcements to walls and roofs, the building of dikes to contain flooding or structural improvements to transmission assets. However, the high costs of relocating or protecting energy infrastructure drives many companies to hedge these costs against potential repair costs if a disaster does strike. For example, it is currently estimated to cost up to $10 billion to build a new refinery from the ground up (Petroleum Institute for Continuing Education, undated) and significant additional costs to fully harden a typical at-risk facility against a hurricane, compared to only a few million dollars in repairs that may or may not be required if a hurricane does strike. Relocation of rail lines also faces a similar dilemma. BNSF's capacity additions in the Powder River Basin are expected to cost over $200 million dollars to add new track in a relatively flat region with low land prices – changes to rail lines in the Appalachian region would be many times more due to the difficult topography and higher land acquisition costs.

Industry, government agencies, and the American Petroleum Institute met jointly in March 2006 (API, 2006) to plan for future extreme weather events. Interim guidelines for jackup (shallow water) rigs (API, 2006) and for floating rigs (API, 2006) have been developed. MMS, DOT, and several industry participants have formed a Joint Industry Program (JIP) (Stress Subsea, Inc., 2005) to develop advanced capabilities to repair damaged undersea pipelines.

3.2 EFFECTS ON RENEWABLE ENERGY PRODUCTION

Renewable energy production accounts for about 6% of the total energy production in the U.S. (Figure 3.5); biomass and hydropower are the most significant contributors (EIA, 2005d). Biomass energy is primarily used for industrial process heating, with substantially increasing use for transportation fuels and additional use for electricity



(Source: EIA, 2005d).

Figure 3.5. Renewable energy's share in U.S. energy supply
(http://www.eia.doe.gov/cneaf/solar.renewables/page/trens/highlight1.html)

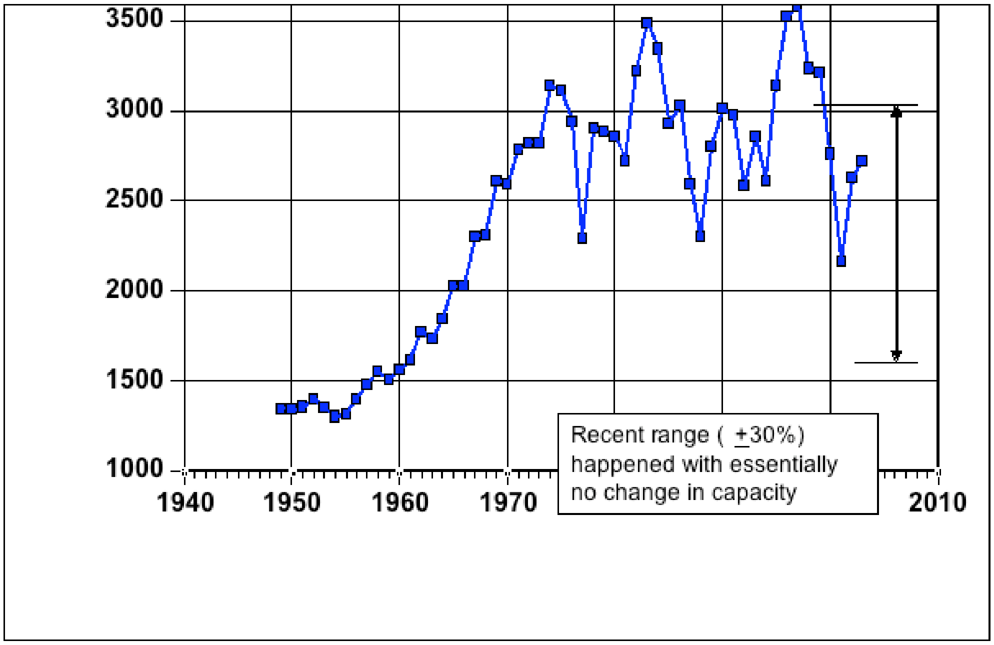
generation. Hydropower is primarily used for generating electricity, providing 270 billion kWh in 2005 (EIA, 2006d). Wind power is the fastest growing renewable energy technology, with total generation increasing to 14 billion kWh in 2004. Because renewable energy depends directly on ambient natural resources such as water, wind patterns and intensity, and solar radiation, it is likely to be more sensitive to climate variability than fossil or nuclear energy systems that rely on geological stores. At the same time, increasing renewable energy production is a primary means for reducing greenhouse gas emissions and thereby mitigating the impacts of potential climate change. Renewable energy sources are therefore connected with climate change in very complex ways: their use can affect the magnitude of climate change, while the magnitude of climate change can affect their prospects for use.

3.2.1 Hydroelectric Power

Hydropower is the largest renewable source of electricity in the U.S. In the period 2000-2004, hydropower produced approximately 75% of the electricity from all renewable sources (EIA, 2006d). In addition to being a major source of base-load electricity in some regions of the U.S. (e.g., Pacific Northwest states), hydropower plays an important role in stabilizing electrical transmission grids, meeting peak loads and regional reserve requirements for generation, and providing other ancillary electrical energy benefits that are not available from other renewables. Hydropower project design and operation is very diverse; projects vary from storage projects with large, multi-purpose reservoirs to small run-of-river projects that have little or no active water storage. Approximately half of the U.S. hydropower capacity is federally owned and operated (e.g., Corps of Engineers, Bureau of Reclamation, and the Tennessee Valley Authority); the other half is at nonfederal projects that are regulated by the Federal Energy Regulatory Commission. Nonfederal hydropower projects outnumber federal projects by more than 10:1.

The interannual variability of hydropower generation in the U.S. is very high, especially relative to other energy sources (Figure 3.6) – the difference be the most recent high (2003) and low (2001) generation years is 59 billion kWh, approximately equal to the total electricity from biomass sources and much more than the generation from all other non-hydropower renewables (EIA, 2006). The amount of water available for hydroelectric power varies greatly from year to year, depending upon weather patterns and local hydrology, as well as on competing water uses, such as flood control, water supply, recreation, and instream flow requirements (e.g., conveyance to downstream water rights, navigation, and protection of fish and wildlife). The annual variability in hydropower is usually attributed to climate variability, but there are also important impacts from multiple use operational policies and regulatory compliance.

There have been a large number of published studies of climate impacts on water resource management and hydropower production (e.g., Miller and Brock 1988; Lettenmaier et al. 1999; Barnett et al. 2004). Significant changes are being detected now in the flow regimes of many western rivers (Dettinger, 2005), consistent with the predicted effects of global warming. The sensitivity of hydroelectric generation to both changes in precipitation and river discharge is high, in the range 1.0 and greater (e.g., sensitivity of 1.0 means 1% change in precipitation results in 1% change in generation). For example, Nash and Gleick (1993) estimated sensitivities up to 3.0 between hydropower generation and stream flow in the Colorado Basin (i.e., change in generation three times the change in stream flow). Such magnifying sensitivities, greater than 1.0, occur because water flows through multiple power plants in a river basin. Climate impacts on hydropower occur when the either the total amount or the timing of runoff is altered, for example when natural water storage in snow pack and glaciers is reduced under hotter climates (e.g., melting of glaciers in Alaska and the Rocky Mountains of the U.S.).



Recent range (±30%) happened with essentially no change in capacity

Figure 3.6. Historical variability of total annual production of hydroelectricity from conventional projects in the U.S.

Hydropower operations are also affected indirectly when air temperatures, humidity, or wind patterns are affected by changes in climate, and these driving variables cause changes in water quality and reservoir dynamics. For example, warmer air temperatures and a more stagnant atmosphere cause more intense stratification of reservoirs behinddams and a depletion of dissolved oxygen in hypolimnetic waters (Meyer et al., 1999). Where hydropower dams have tailwaters supporting cold-water fisheries for trout or salmon, warming of reservoir releases may have unacceptable consequences and require changes in project operation that reduce power production.

Competition for available water resources is another mechanism for indirect impacts of climate change on hydropower. These impacts can have far-reaching consequences through the energy and economic sectors, as happened in the 2000-2001 energy crises in California (Sweeney, 2002).

Recent studies in California and elsewhere are showing how hydropower systems can adapt to climate variability by reexamining management policies (Vicuña et al., 2006). The ability of river basins to adapt is proportional to the total active storage in surface water reservoirs (e.g., Aspen Environmental Group and M-Cubed, 2005). Many water management institutions, however, are slow to take action on such adaptations.

3.2.2 Biomass Power And Fuels

Total biomass energy production has surpassed hydroelectric energy for most years since 2000 as the largest U.S. source of renewable energy, providing 46% of renewable or 4% of total U.S. energy in 2005 (EIA 2006). The largest source of that biomass energy (29%) was black liquor from the pulp and paper industry, combusted as part of a process to recover pulping chemicals which provides process heat for the mills as well as generating electricity. Wood and wood waste from sources such as lumber mills provide more than 19% (industrial sector alone) and combusted municipal solid waste and recovered landfill gas about 16%, respectively, of current U.S. biomass energy (EIA, 2005d). Because energy resource generation is a byproduct of other activities in all these cases, there is little reason to expect climate change to directly impact any of these or most other sources of biomass power production derived from a waste stream. There are few examples of literature addressing this area, though Edwards notes that climatechange-induced events such as timber die-offs could present short-term opportunity or long-term loss for California (Edwards, 1991).

Liquid fuel production from biomass is highly visible as a key renewable alternative to imported oil. Current U.S. production is based largely on corn for ethanol and, to a lesser extent, soybeans for biodiesel. Because both crops are used primarily for animal feed, with only small portions going to fuel production, and because both are currently price supported, changes in crop growth rates might again not immediately affect their use for fuel. In the longer term, cellulosic feedstocks should supplant grain and oilseed crops for transportation fuel production from biomass. Cellulosic crop residues such as corn stover and wheat straw would likely be affected by climate change the same way as the crops themselves due to a rise in average temperatures, more extreme heat days, and changes in precipitation patterns and timing, with greater impact on fuel production because that would be their primary use. Potential dedicated cellulosic energy crops for biomass fuel, such as grasses and fast-growing trees, would also be directly affected by climate change. As discussed below, limited literature suggests that for at least one region, one primary energy crop candidate—switchgrass-- may benefit from climate change, both from increased temperature and increased atmospheric carbon dioxide levels.

More specifically, about 10% of U.S. biomass energy production (EIA 2005d), enough to provide about 2% of U.S. transportation motor fuel (Federal Highway Administration, 2003), currently comes from ethanol made predominantly from corn grown in the Midwest (Iowa, Illinois, Nebraska, Minnesota, and South Dakota are the largest ethanol producers). Climate change sufficient to substantially affect corn production would likely impact the resource base, but corn is price supported and currently only uses about 13% of the U.S. corn crop (livestock feed is the predominant use) (RFA, 2006). Although ethanol production did drop in 1996 following a poor corn crop and associated high prices, the combined influence of various agricultural and fuel incentive and regulatory policies probably overshadow any near-term impacts of climate change on ethanol production. Production of biodiesel from soybeans—growing rapidly, but still very small—is likely a similar situation. In the long term, however, significant crop changes—

and trade-offs between them, as they are generally rotated with each other—would likely have an impact in the future. Looking at Missouri, Iowa, Nebraska, and Kansas, with an eye toward energy production, Brown, et al. (2000) used a combination of the NCAR climate change scenario, regional climate, and crop productivity models to predict how corn, sorghum, and winter wheat (potential ethanol crops) and soybeans (biodiesel crop) would do under anticipated climate change. Negative impact from increased temperature, positive impact from increased precipitation, and positive impact from increased atmospheric carbon dioxide combined to yield minimal negative change under modest carbon dioxide level increase, but 5% to 12% yield increases with high carbon dioxide level increases.

Although ethanol production from corn can still increase substantially (mandated to double under the recently enacted renewable fuel standard), it can still only meet a small portion of the need for renewable liquid transportation fuels to displace gasoline if dependence on petroleum imports is to be reduced. Processing the entire projected 2015 corn crop to ethanol (highly unrealistic, of course) would only yield about 35 billion gallons of ethanol, less than 14% of the gasoline energy demand projected for that year. Biomass fuel experts are counting on cellulosic biomass as the feedstock to make larger renewable fuel production possible. A recent joint study of the U.S. Departments of Agriculture and Energy (USDA and DOE), *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply,* projected that by 2030 enough biomass could be made available to meet 40% of 2004 gasoline demand via cellulosic ethanol production and other technologies. The two largest feedstocks identified are annual crop residues and perennial dedicated energy crops (NREL 2006).

The primary potential annual crop residues are corn stover—the leaves, stalks, and husks generally now left in the field—and wheat straw. Corn stover is the current DOE research focus in part because it is a residue with no incremental cost to grow and modest cost to harvest, but also particularly because of its potential large volume. Stover volume is roughly equivalent to grain volume and corn is the largest U.S. agricultural crop. As such it would be affected by climate change in much the same way as the corn crop itself, described above.

Frequently discussed potential dedicated perennial energy crops include fast-growing trees such as hybrid poplars and willows and grasses such as switchgrass (ORNL Bioenergy Feedstock Information Network, Agricultural Research Service Bioenergy and Energy Alternatives Program). Switchgrass is particularly attractive because of its large regional adaptability, fast growth rate, and minimal adverse environmental impact. The primary objective of the Brown, *et. al.* (2000) study referenced above for Missouri, Iowa, Nebraska, and Kansas was to see how climate change would affect growth of switchgrass. The study projected that switchgrass would do very well benefiting from both higher temperatures (unlike the grain crops) and higher atmospheric carbon dioxide levels, with yield increasing 74% with the modest CO_2 increase and nearly doubling with the higher CO_2 increase. One may not expect projected impact to be as beneficial for Southern regions already warm enough for rapid switchgrass growth or more Northern areas still colder than optimal even with climate change, but the models would need to be run.

Because most current U.S. electric power production from biomass is tied to particular opportunities presented by other industries, changes such as timber growth rates would have less direct impact, at least for the near term.

3.2.3 Wind Energy

Wind energy currently accounts for about 2.5% of U.S. renewable energy generation' but its use is growing rapidly, and it has tremendous potential due to its close cost competitiveness with fossil fuel plants for utility-scale generation. Although policy incentives and the ability to integrate a variable resource with utility systems are also important, that near-competitiveness is a key factor. Any projected impact of climate change such as changes in seasonal wind patterns or strength would likely be significant positively or negatively since wind energy generation is a function of the cube of the wind speed. Increased variability in wind patterns could also create additional challenges for accurate wind forecasting for generation and dispatch planning.

California is currently the largest wind-power-producing state, followed by Texas, Iowa, Minnesota, Washington, and Oregon (EIA, 2005d). Development in these states is a function of policy incentives as well as available resource, but these regions would certainly be expected to continue among the main wind-power areas. North Dakota and South Dakota, while modest in wind development so far, have tremendous wind potential, particularly as technology and economics allow development of lower wind-speed regimes further from major load centers.

One study modeled wind speed change for the United States divided into northern and southern regions under two climate-change circulation models. Overall, the Hadley Center model suggested minimal decrease in average wind speed, but the Canadian model predicted very significant decreases of 10%-15% (30%-40% decrease in power generation) by 2095. Decreases were most pronounced after 2050, in the fall for both regions, and in the summer for the northern region (Breslow and Sailor, 2002).

Another study mapped wind power changes in 2050 based on the Hadley Center General Circulation Model—the one suggesting more modest change of the two used by Breslow and Sailor above. For most of the United States, they predicted decreased wind resources to as much as 10% on an annual basis and 30% on a seasonal basis. Wind power increased for the important Texas-Oklahoma region and for the Northern California-Oregon-Washington region, although the latter had decreased power in the summer. For the key Northern Great Plains and for the mountainous West, however, they predict decreased wind power (Segal et al., 2001). Edwards suggests that warming-induced offshore current changes could intensify summer winds for California and thus increase its wind energy potential (Edwards, 1991).

3.2.4 Solar Energy

Photovoltaic (PV) electrical generation and solar water heating are suitable for much of the United States, with current deployment primarily in off-grid locations or rooftop systems where state or local tax incentives are present. For utility-scale generation, the technologies are most attractive in the Southwest with its high direct-radiation resource, where concentrating or high-efficiency PV and solar thermal generation systems can be used. California and Arizona have the only existing utility-scale systems (EIA 2005d) with additional projects being developed in Nevada and Arizona.

Pan et al. (2004) modeled changes to global solar radiation to the 2040s based on the Hadley Center circulation model. This study projects a solar resource reduced to as much as 20% seasonally, presumably from increased cloud cover, throughout the country, but particularly in the West with its greater present resource. Increased temperature can also reduce the effectiveness of PV electrical generation and solar thermal energy collecion. One international study predicts that a 2% decrease in global solar radiation will decrease solar cell output by 6% overall (Fidge and Martinsen, 2006).

3.2.5 Other Renewable Energy Sources

Climate change could affect geothermal energy production (6% of current U.S. renewable energy: (EIA 2005c) in the same way that higher temperatures reduce the efficiency of fossil-fuel-boiler electric turbines, but otherwise should not cause any impact. The United States currently makes no significant use of wave, tidal, or ocean thermal energy, but any of these could be affected by climate change. Harrison observes that wave heights in the North Atlantic have been increasing and discusses how wave energy is affected by changes in wind speed (Harrison and Wallace, 2005).

3.2.6 Summary

Of the two largest U.S. renewable energy sources, hydroelectric power generation can be expected to be directly and significantly affected by climate change, but biomass power and fuel production are likely to be only modestly impacted in the short term. The impact on hydroelectric production will vary by region, but production will likely decrease in key areas such as the Columbia River Basin and Northern California. Current U.S. electricity production from wind and solar energy is modest but anticipated to play a significant role in the future as these technologies become more cost competitive and accepted by electric utilities. As such, even modest impacts from climate change on cost effectiveness in key resource areas could substantially affect the ability of the technologies to gain broader market penetration, which is more significant than overall changes in the resource availability. At a minimum, both wind and direct-solar-radiation will likely be marked by greater variability as a result of climate change.

3.3 EFFECTS ON ENERGY TRANSMISSION, DISTRIBUTION, AND SYSTEM INFRASTRUCTURE

In addition to the direct effects on operating facilities themselves, networks for transport, electric transmission, and delivery would be susceptible to changes in stream flow, annual precipitation and seasonal patterns, storm severity, and even temperature increases, (e.g., pipelines handling supercritical fluids may be impacted by greater heat loads if temperatures increase and/or cloud cover diminishes).

3.3.1 Electricity Transmission and Distribution

Severe weather events and associated flooding cause direct disruptions in energy services. With more intense events, increased disruptions might be expected. Electricity reliability might also be affected as a result of increased demand combined with high soil temperatures and soil dryness (IPCC, 2001a).

Grid technologies in use today are at least 50 years old and although “smart grid” technologies exist, they are not often employed. Two such technologies that may be employed to help offset climate impacts include upgrading the grid by employing advanced conductors that are capable withstanding greater temperature extremes and automation of electric distribution (Gellings and Yeager, 2004).

3.3.2 Energy Resource Infrastructure

A substantial part of the oil imported into the United States is transported over long distances from the Middle East and Africa in supertankers. While these supertankers are able to offload within the ports of other countries, they are too deeply drafted to enter the shallow U.S. ports and waters. This occurs because, unlike most other countries, the continental shelf area of the United States extends many miles beyond its shores and territorial waters. This leads to a number of problems related to operation of existing ports, and to programs (such as NOAA's P.O.R.T.S. Program) to improve efficiency at these ports. In addition, the Deepwater Ports Act (1975) has lead to plans to develop a number of deepwater ports for either for petroleum or LNG import. These planned facilities are concentrated in relatively few locations, in particular with a concentration along the Gulf Coast (Figure 3.7). Changes in weather patterns, leading to changes in stream flows and wind speed and direction can impact operability of existing harbors. Severe weather events can impact access to deepwater facilities or might disrupt well-established navigation channels in ports where keel clearance is a concern (DOC/DOE, 2001).

Climate change may also affect the performance of the extensive pipeline system in the United States. For example, for CO_2-enhanced oil recovery, experience has shown that summer injectivity of CO_2 is about 15% less than winter injectivity into the same reservoir. The CO_2 gas temperature in Kinder Morgan pipelines during the winter are

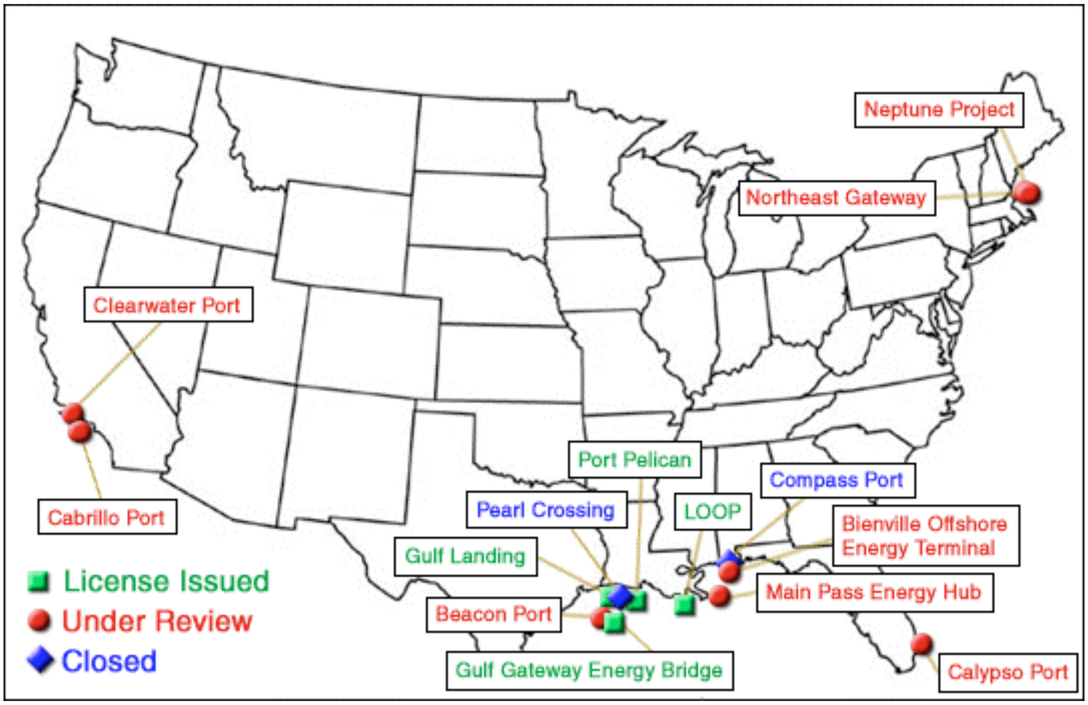


Figure 3.7. Proposed deepwater ports for petroleum and LNG

about 60F and in late summer about 74F. At higher temperatures, compressors and fan coolers are less efficient and are processing a warmer gas. Operators just cannot pull as much gas off the supply line with the given horsepower when the CO_2 gas is warm. (source: personal communication from Ken Havens of Kinder Morgan CO_2)

Efficiencies of most gas injection is similar and thus major gas injection projects like produced gas injection on the North Slope of Alaska have much higher gas injection and oil production during cold winter months. Persistently higher temperatures will have an impact on deliverability and injectivity for applications where the pipeline is exposed to ambient temperatures.

3.3.3 Storage And Landing Facilities

The Strategic Petroleum Reserve storage locations (EIA,2004b) that are all along the Gulf Coast, were selected because they provide the most flexible means for connecting to the commercial oil transport network. Figure 3.8 illustrates their locations along the Gulf Coast in areas USGS (2000) sees as being susceptible to sea-level rise. Similarly located on the Sabine Pass is the Henry Hub, the largest gas transmission interconnection site in the U.S., connecting 14 interstate and intrastate gas transmission pipelines. Henry Hub was out of service briefly from Hurricane Katrina and for some weeks from Hurricane Rita, which made landfall at Sabine Pass.

3.3.4 Infrastructure Planning And Considerations For New Power Plant Siting

Water availability and access to coal delivery are currently critical issues in the siting of new coal-fired generation capacity. New capacity, except on coasts and large estuaries, will generally require cooling towers rather than once-through cooling water usage based on current and expected regulations (EPA, 2000) independent of climate change issues. New turbine capacity will also need to be designed to respond to the new ambient conditions.

Siting of new nuclear units will face the same water availability issues as large new coal-fired units; they will not need to deal with coal deliverability but may depend on barge transport to allow factory fabrication rather than site fabrication of large, heavy wall vessels, as well as for transportation of any wastes that need to be stored off-site.

Capacity additions and system reliability have recently become important areas for discussion. A number of approaches are being considered to run auctions (or other approaches) to stimulate interest in adding new capacity without sending signals that would result in over-building (as has happened in the past). Planning to ensure that both predictions of needed capacity and mechanisms for stimulating companies to build such capacity (while working through the process required to announce, design, permit, and build it) will become more important as future demand is affected by climatic shifts. Similarly, site selection may need to factor in longer-term climatic changes for technologies as long-lived as coal-fired power plants (which may last for 50 - 75 years) (NARUC, 2006).

3.4 EFFECTS ON ENERGY INSTITUTIONS

(To be added)

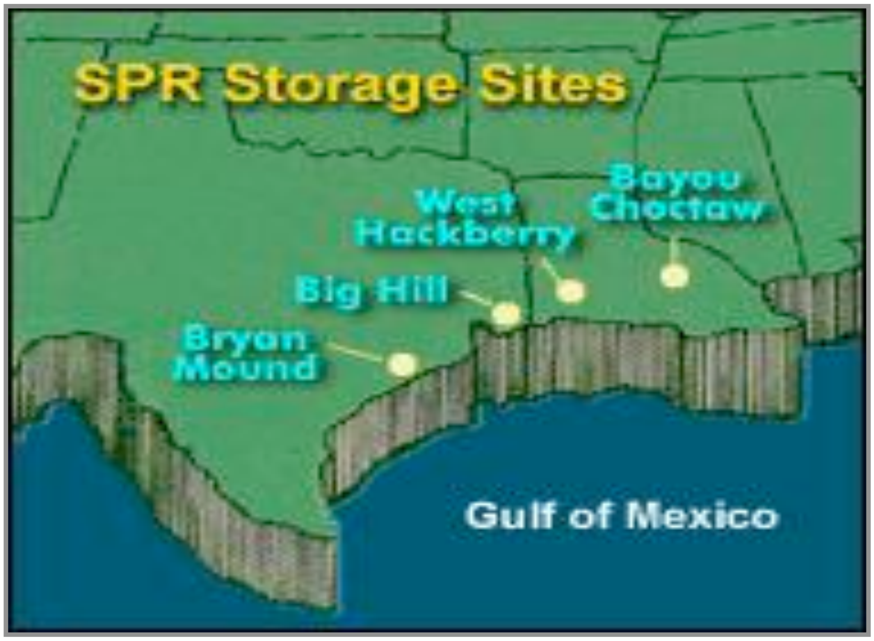


Figure 3.8. Strategic Petroleum Reserve storage sites

3.5 SUMMARY OF KNOWLEDGE ABOUT POSSIBLE EFFECTS

Significant uncertainty exists about the potential impacts of climate change on energy production and distribution, in part because the timing and magnitude of climate impacts are uncertain. This report summarizes many of the key issues and provides information available on possible impacts; however this topic represents a key area for future analysis.

Many of the technologies needed for existing energy facilities to adapt to increased temperatures and decreased water availability are available for deployment; and, although decreased efficiencies and lower output can be expected, significant disruptions seem unlikely. Incorporating potential climate impacts into the planning process for new facilities will strengthen the infrastructure. This is especially important for water resources, as electricity generation is one of many competing applications for what may be a (more) limited resource.

There are regionally important differences in adaptation needs. This is true for the spectrum of climate impacts from water availability to increased temperatures and changing patterns of severe weather events. The most salient example is for oil and gas exploration and production in Alaska, where projected temperature increases may be double the global average and melting permafrost and changing shorelines could significantly alter the landscape and available opportunities for oil and gas production

Increased temperatures will also increase demand-side use, and the potential system-wide impacts on electricity transmission and distribution and other energy system needs are not well understood. Future planning for energy production and distribution may therefore need to accommodate possible impacts of climate change.

CHAPTER 4. POSSIBLE INDIRECT EFFECTS OF CLIMATE CHANGE ON ENERGY PRODUCTION AND USE IN THE UNITED STATES

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4.1 INTRODUCTION

Changes in temperature, precipitation, storms, and/or sea level are likely to have direct effects on energy production and use, as summarized above; but they may also have a number of indirect effects – as climate change affects other sectors and if it shapes energy and environmental policy-making and regulatory actions (Fig. 4.1). In some cases, it is possible that indirect effects could have a greater impact, positive or negative, on certain institutions and localities than direct effects.

In order to provide a basis for such a discussion, this chapter of SAP 4.5 offers a preliminary taxonomy of categories of indirect effects that may be of interest, along with a summary of existing knowledge bases about such indirect effects. Some of these effects are from climate change itself, e.g., effects on electricity prices of changing conditions for hydropower production. Other effects could come from climate change related policies,(e.g., effects of stabilization-related emission ceilings on energy prices, energy technology choices, or energy sector emissions) (Table 4.1).

Most of the existing literature is concerned with implications of climate change mitigation policies on energy technologies, prices, and emissions in the U.S. Because this literature is abundant, relatively well-known, and in some cases covered by other SAPs (such as SAP 2.2), it will be only briefly summarized here, offering links to more

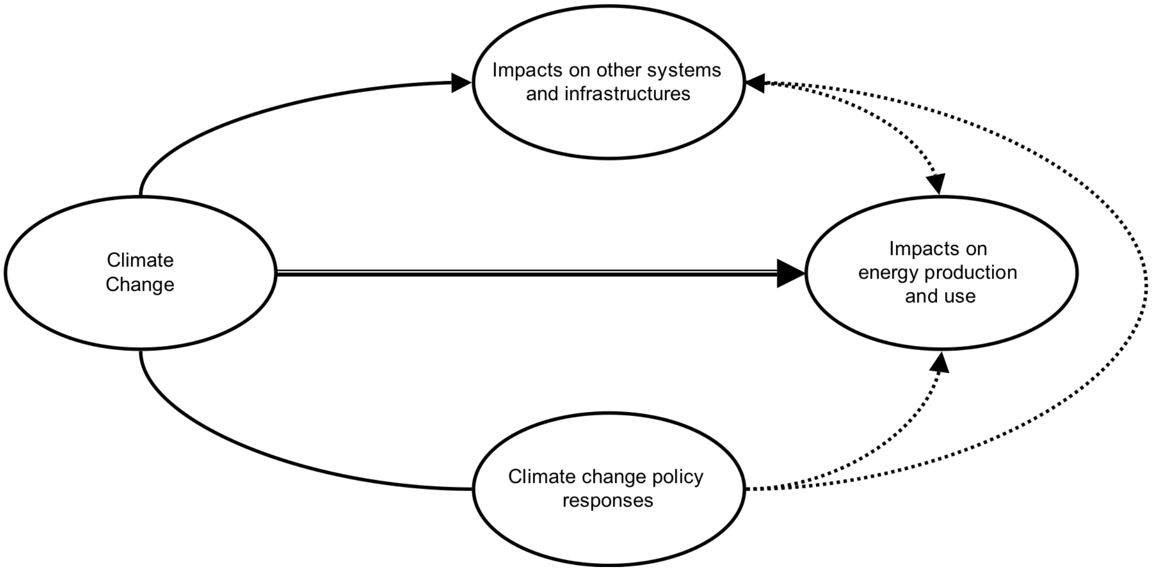

Figure 4.1 This chapter is concerned with the dashed lines in this flow diagram of connections between climate change and energy production and use.

detailed discussions. Of greater interest to some readers may be the characterization of other possible indirect effects besides these.

4.2 CURRENT KNOWLEDGE ABOUT INDIRECT EFFECTS

4.2.1 Possible Effects On Energy Planning

Climate change is likely to affect energy planning, nationally and regionally, because it is likely to introduce new considerations and uncertainties to institutional (and individual) risk management. Such effects can arise either through anticipated changes in climate-related environmental conditions, such as hydropower potentials, possible exposure to storm damages (see Chapter 3), or changed patterns of energy demand (see Chapter 2), or through possible changes in policies and regulations.

Indirect Effect On Energy Systems	**From Climate Change**	**From Climate Change Policy**
On energy planning and investment	X	XX
On technology R&D and preferences	X	XX
On energy supply institutions	X	X
On energy aspects of regional economies	X	X
On energy prices	?	X
On energy security	?	?
On environmental emissions from energy production/use	X	XX
On energy technology/service exports	?	X

Table 4.1. Overview of possible indirect effects of climate change and climate change policy on energy systems in the U.S.
(Double X indicates well-established by research literature;
X indicates some basis for anticipating an effect;
? indicates that effects are uncertain*)*

For instance, a pathbreaking study supported by EPRI and the Japanese Central Research Institute of Electric Power Industry (CRIEPI) assessed possible impacts of global climate change on six utilities, five of them in the United States (ICF, 1995). The study considered a variety of scenarios depicting a range of underlying climate, industry, and policy conditions. It found that GHG emission reduction policies could cause large increases in electricity prices, major changes in a utility's resource mix related to requirements for emission controls, and significant expansions in demand-side management programs. Major impacts are likely to be on Integrated Resource Planning regarding resource and capacity additions and/or plant retirements, along with broader implications of increased costs and prices. In another example, Burtraw et al., 2005 analyzed a nine-state northeastern regional greenhouse gas initiative (RGGI), an allowance-based regional GHG cap-and-trade program for power sector. They found that how allowances are allocated has an effect on electricity price, consumption, and the mix of technologies used to generate electricity. Electricity price increases in most of the cases. They also note that any policy that increases energy costs in the region is likely to cause some emission leakage to other areas outside the region as electricity generation or economic activity moves to avoid regulation and associated costs.

Electric utilities in particular are already sensitive to weather as a factor in earnings performance, and they utilize weather risk management tools to hedge against risks associated with weather-related uncertainties. Issues of interest include plans for capacity additions, system reliability assurance, and site selection for long-lived capital facilities (O'Neill, 2006). Even relatively small changes in temperature/demand can affect total capacity needs across the U.S. power sector, especially in peak periods.

Many energy-related investments are made without a clear financial understanding of values, risks, and volatilities (Mills, et al., 2006; also see Vine, et al., 2000 and Crichton, 2005), especially where newly emerging forces surrounded by uncertainties are concerned. Faced with uncertainties, many energy decision-makers on both the production and use sides choose to focus on options, such as energy efficiency improvement investments, with a high level of confidence of payoff regardless of future developments. Meanwhile, many sophisticated investors overlook energy investments that would contribute to adapting to likely climate change because risk and volatility information is limited. Given an improved risk management analysis framework, incorporating current information about exposures to climate change impacts, it is likely that investments in climate change adaptation for the energy sector would expand and new market-based opportunities for risk management would appear (also see 4.2.3 below).

Current policy initiatives hint at what the future might be like, in terms of their possible effects on energy planning. U.S. national and state climate policy actions include a variety of traditional approaches such as funding mechanisms (incentives and disincentives); regulation (caps, codes and standards); technical assistance (direct or in kind); research and development; information and education; and monitoring and reporting (including impact disclosure) (Rose and Shang, 2004). Covered sectors include power generation, oil and gas, residential, commercial, industry, transportation, waste management, agriculture and forestry. These sectors cut across private and public sector facilities and programs, as well as producers and consumers of energy (Peterson and Rose, 2006).

One key issue involves the provision of financial incentives that create, encourage or force markets to reward GHG mitigation, such as preferential qualifying credit for transportation projects or energy production facilities. At the national level**,** clean and renewable energy technology deployment is promoted primarily through a federal production tax credit (PTC) and investment tax credit (ITC). Such incentives have been offered in the Energy Policy Act (EPAct 2005) for electricity production from advanced nuclear, clean coal, biomass, municipal solid waste and other renewable energy technologies. For instance, installation of IGCC electric generation units with carbon capture and sequestration to save carbon may cost up to 20% more than traditional pulverized coal-fired units for electric power generation. Many recent studies have suggested public-private partnerships for financial and risk alleviation incentives that could help make early nuclear plants more competitive (DOE-Industry Report, 2004; the University of Chicago, 2004; MIT, 2003; Dominion and Other Industries, 2004; and Scully Capital, 2002). The EPAct (2005) provides PTC, loan guarantees and federal risk insurance known as Standby Support for advanced nuclear power facilities. Since it was introduced in 1992, the PTC – which was designed to spur the deployment of technologies that are near economic competitiveness – has encouraged domestic renewable technologies, such as wind, solar and biomass (NCEP, 2004). The EPAct (2005) extended most of these PTCs to 2007, except to solar technologies that ended in

2005. Rabe, 2006 suggests that repeated fluctuation in the federal production tax credit for renewable energy has fostered a boom-and-bust cycle for renewable development in a number of states, leaving significant lags in the development of renewables during those periods in which the credit has been terminated or its status has remained uncertain.

Other incentive mechanisms are potentially important for GHG mitigation. According to Peterson & Rose (2006), cost sharing of fixed or variable mitigation program costs is common, such as payments to farmers for installation of best management practices or waste recovery facilities. These programs support measures that serve as alternatives to more costly energy reduction measures. Extra credit in applications for financing is common, where as preferential treatment in siting decisions can also reduce the time and risk associated with recovery of costs. By providing faster approval of the project than normal, or a higher guarantee of rate recovery, the financing costs to these projects can be substantially reduced due to the time value of money and reduction of risk premiums in financial markets. Policy makers may choose to endorse this sort of market intervention due to superior environmental performance, and a host of related co-benefits, including air quality, energy and water savings. This may be a critical issue in the future as decisions are made on the degree and type of market interventions to support emissions reduction from power generation.

Some of the policy alternatives facilitate differentiating policies to meet special geographic needs, a critical issue given the substantial differences between state renewable portfolio standards (RPS) which force a percentage of sold (or consumed) electricity to be supplied by low emission renewable sources, and currently 22 states operate RPSs in the U.S. Economic development opportunities are paramount in all cases and environmental factors, including reduction of conventional air emissions as well as greenhouse gases, figure differently in various cases but are clearly seen as a secondary driver in many states (Rabe, 2006). To date, 39 states have developed greenhouse gas inventories and 30 states have developed some form of greenhouse gas action plan (EPA, 2003). Many initial versions of these plans were developed in anticipation of a treaty that would lead to national legislation and coordination with sub-federal governments. At the time, US states were not expected to lead national policy, but the emphasis has since shifted in this direction, along with significant local government actions. Kousky and Schneider (2003) note that by mid-2003, 140 cities in the U.S. had established GHG reduction targets and had begun mitigation action planning.

In California, the Governor's Executive Order #S-3-05, calls for an 80% reduction in climate change emissions, relative to 1990 levels, by 2050 (CEPA, 2006). As a result, the state has resolved to a series of extensive market based and policy driven demand and supply side management initiatives (Luers and Moser, 2006). According to Peterson & Rose (2006), a number of sub-federal jurisdictions have developed (or are developing) comprehensive plans that are expected to include numerical goals and timetables and a portfolio of actions across all economic sectors. Coordination with regional agreements in New England (The New England Governors/Eastern Canadian Premiere's Agreement or NEG/ECP), the Northeast (the Regional Greenhouse Gas Initiative, or RGGI), the West Coast (the West Coast Climate Initiative), and the northern Midwest (the Powering the Plains initiative) are significant steps in this direction. Such regional initiatives, as explained by Kelly et al. (2005) for TX, OK and the Northeast states, promote energy market transformation with the help of public-private partnerships and create implementation projects to reduce GHG footprints. However, Peterson and Rose, (2006) indicate that many energy industries and some states have opposed the establishment of binding caps on emissions that could constrain market growth and product output. Recently, a number of design alternatives in the U.S. have been explored that modify the way standards are set for electric power generation caps to allow growth (such an output based allocation system) or provide compensation for affected parties by sharing or recycling of revenues from auction of permits. Rose et al., (2006) note that the composition and scope of RGGI participating states are changing. This refers to the considerations for expanding beyond just the electricity sector to include natural gas efficiency and soil sequestration, expanding beyond carbon dioxide to include landfill gas, SF6, HFC-23 and coal mine methane and expanding participation in the Clean Development Mechanism (CDM) and including the European Union (EU).

Energy efficiency can contribute significantly in reducing market distortions while a cap-and-trade framework like RGGI is in place. Prindle et al., (2006) concluded that doubling the current level of energy efficiency spending in the RGGI region would have several very favorable effects on the carbon cap-and-trade system. It would reduce electricity load growth, future electricity prices, carbon emissions, carbon emission prices, and total energy bills for electricity customers of all types. Similarly, in a case-study of New York City, Kelly et al., (2005) show that energy efficiency and urban heat island mitigation strategies can significantly reduce electricity peak load, GHG emissions and energy system cost.

4.2.2 Possible Effects On Energy Production And Use *Technologies*

Perhaps the best-documented case of indirect effects of climate change on energy production and use in the United States is effects of climate change policy on technology research and development and on technology preferences and choices.

For instance, if the world moves toward concerted action to stabilize concentrations of greenhouse gases (GHG) in the earth's atmosphere, the profile of energy resources and technologies being used in the U.S. – on both the production and use sides – would have to change significantly (CCTP, 2005). Developing innovative energy technologies and approaches through science and technology research and development is widely seen as a key to reducing the role of the energy sector as a driver of climate change. Considering various climate change scenarios, researchers have modeled a number of different pathways in order to inform discussions about technology options that might contribute to energy system strategies (e.g., Edmonds et al, 1996; Akimoto et al., 2004; Hoffert et al., 2002; van Vuuren et al, 2004; Kainuma et al, 2004; IPCC 2005a; Kurosawa, 2004; and Pacala and Socolow, 2004). In addition, there have been important recent developments in scenario work in the areas of non-CO2 GHGs, land use and forestry emission and sinks, emissions of radiatively important non-GHGs such as black and organic carbon, and analyses of uncertainties, among many issues in increasing mitigation options and reducing costs (Nakicenovic and Riahi, 2003; IPCC 2005b; van Vuuren et al, 2006; and Placet et al, 2004.

These references indicate that a high degree of emissions reductions could be achieved through combinations of many different technologies. A large number of scenario-based analyses conducted by different research groups show the importance of technology advancement, especially if R&D support is diversified. Although the full range of effects in the future is necessarily speculative, it is possible that successful development of advanced technologies could result in potentially large economic benefits. When the costs of achieving different levels of emission reductions have been compared for cases with and without advanced technologies, many of the advanced technology scenarios projected that the cost savings from advancement would be significant. Note, however, that there is considerable "inertia" in the nation's energy supply capital stock because institutions that have invested in expensive facilities prefer not to have them converted into "stranded assets." Note also that any kind of rapid technological transformation would be likely to have cross-commodity cost/price effects, e.g., on costs of specialized components in critical materials that are in greater demand.

4.2.3 Possible Effects On Energy Production And Use *Institutions*

Climate change could affect the institutional structure of energy production and use in the United States, although relatively little research has been done on such issues. Institutions include energy corporations, electric utilities, governmental organizations at all scales, and non-governmental organizations. Their niches, size and structure, and operation tend to be sensitive to changes in "market" conditions from any of a variety of driving forces, these days including such forces as globalization, technological change, and social/cultural change (e.g., changes in consumer preferences). Climate change is likely to interact with other driving forces in ways that could affect institutions concerned with energy production and use.

Most of the very limited research attention to this type of effect has been focused on effects of climate change policy (e.g., policy actions to reduce greenhouse gas emissions) on U.S. energy institutions: such as on the financial viability of U.S. electric utilities (see, for instance, WWF, 2003). Other effects could emerge from changes in energy resource/technology mixes due to climate change: e.g., changes in renewable energy resources and costs or changes in energy R&D investment patterns.

Most of these issues are speculative at this time, but identifying them is useful as a basis for further discussion. Issues would appear to include (see effects on planning, above).

4.2.3.1 <u>Effects on the institutional structure of the energy industry</u>

Depending on its impacts, climate change could encourage large energy firms to move into renewable energy areas that have been largely the province of smaller firms, as was the case in some instances in the wake of the energy "shocks" of the 1970s (e.g., Flavin and Lenssen, 1994). This kind of diversification into other "clean energy" fields could be reflected in horizontal and/or vertical integration, but possible effects of climate change on such issues as organizational consolidation vs. fragmentation are unknown.

4.2.3.2 <u>Effects on electric utility restructuring</u>

Recent trends in electric utility restructuring have included increasing competition in an open electricity supply marketplace, which has sharpened attention to keeping supply costs as low as possible. A corollary has been a reduction in the importance of state and other regulatory bodies. Some research literature suggests that one side-effect of restructuring has been a reduced willingness on the part of some utilities to invest in environmental protection beyond what is absolutely required by law and regulation (Parker, 1999; Senate of Texas, 1999). If climate change introduces new risks for utility investment planning and reliability, it is possible that policies and practices could encourage greater cooperation and collaboration rather than further increases in competition.

4.2.3.3 Effects on the health of fossil fuel-related industries

If climate change is associated with policy and associated market signals that decarbonization of energy systems, industries focused on the production of fossil fuels, converting them into useful energy forms, transporting them to demand centers, and providing them to users could face shrinking markets and profits. The coal industry seems especially endangered in such an eventuality. In the longer run, this type of effect depends considerably on technological change: e.g., affordable carbon capture and sequestration, fuel cells, and efficiency improvement. It is possible that industries (and regions) concentrated on fossil fuel extraction, processing, and use will seek to diversify as a hedge against risks of economic threats from climate change policy.

4.2.3.4 Effects on other supporting institutions such as financial and insurance industries

Many major financial and insurance institutions are gearing up to underwrite emission trading contracts, derivatives and hedging products, wind and biofuel crop guarantee covers for renewable energy, and other new financial products to support carbon emission trading and CDM, while they are concerned about exposure to financial risks associated with climate change impacts. In recent years, various organizations have tried to engage the global insurance industry in the climate change debate. Casualty insurers are concerned about possible litigation against companies responsible for excessive GHG emissions, and property insurers are concerned about future uncertainties in weather damage losses. However, it is in the field of adaptation where insurers are most active, and have most to contribute. 200 major companies in the financial sector around the world have signed up to the UN Environment Program's - Finance Initiative, and 95 institutional investment companies have so far signed up to the Carbon Disclosure Project. They ask businesses to disclose investment-relevant information concerning their GHGs. Their website provides a comprehensive registry of GHGs from public corporations. Over 300 of the 500 largest companies in the world now report their emissions on this website, recognizing that institutional investors regard this information as important for shareholders (Crichton, 2005).

4.3 POSSIBLE EFFECTS ON ENERGY-RELATED DIMENSIONS OF *REGIONAL AND NATIONAL ECONOMIES*

It is at least possible that climate change could have an effect on regional economies by impacting regional comparative advantages related to energy availability and cost. Examples could include regional economies closely associated with fossil fuel production and use (especially coal) if climate change policies encourage decarbonization, regional economies dependent on affordable electricity from hydropower if water supplies decrease or increase, regional economies closely tied to coastal energy facilities that could be threatened by more intense coastal storms, and regional economies dependent on abundant electricity supplies if demands on current capacities increase or decrease due to climate change.

Hurricanes Katrina and Rita were particularly damaging to the energy availability to the U.S. from the Gulf Coast region, which amounts to about 30 percent and 21 percent, respectively of a normal year's crude oil and natural gas production from U.S. offshore fields (MMS, 2006). EIA (2006a) estimates that at the height of the refinery outages (September 22-25, 2005), as much as 29 percent of U.S. refining capacity and over 60 percent of refining capacity in the Gulf Coast region were shut down, affecting jobs, incomes, and tax revenues in the region as well as economies in other regions. Another EIA Report published in December 2005 indicated that energy prices increased significantly compared to the same time previous year due to these hurricanes (EIA, 2005c).

Attempts to estimate the economic impacts that could occur 50–100 years in the future have been made using various climate scenarios, but the interaction of climate and the nation's economy remains very difficult to define. Significant uncertainties therefore surround projections of climate change induced energy sector impacts on the U.S.or regional economies. Changnon estimated that annual national economic losses from energy sector will outweigh the gains in years with major weather and climate extremes (Changnon, 2005). Jorgenson et. al. (2004) study impacts of climate change on various sectors of the U.S. economy from 2000 – 2100. In three optimistic scenarios, they conclude that increased energy availability and cost savings from reduced natural gas-based space heating more than compensate for increased expenditures on electricity-based space cooling. These unit cost reductions appear as productivity increases and, thus, improve the economy, whereas other three pessimistic scenarios show that electricity-based space conditioning experiences relatively larger productivity losses than does space conditioning from coal, wood, petroleum or natural gas; accordingly its (direct) unit cost rises faster and thus produces no benefits to the economy. Additionally, higher domestic prices discourage exports and promote imports leading to a worsening real trade balance. According to Mendelsohn et al., (2000), the U.S. economy will benefit from the climate change induced energy sector changes. However, Mendelsohn and Williams (2004) suggest that climate change will cause economic damages in the energy sector in every scenario. They suggest that temperature changes cause most of the energy impacts. Larger temperature increases generate significantly larger economic damages. The damages are from increased cooling expenditures required to maintain desired indoor temperatures. In the empirical studies, these cost increases outweighed benefits of the reduced heating expenditures unless starting climates are very cool (Mendelsohn and Neumann, 1999; Mendelsohn, 2001) (also see Chapter 2).

In California, a preliminary assessment of the macroeconomic impacts associated with the climate change emission reduction strategies shows that the overall impacts of the climate change emission reduction strategies on the state’s economy could be positive. Resulting impacts on the economy could translate into job and income gains for Californians. Such favorable impacts on the economy are possible because of the reduced costs associated with many of the strategies (CEPA, 2006). On the other hand, the study emphasizes that even relatively small changes in in-state hydropower generation result in substantial extra expenditure burdens on an economy for energy generation, because losses in this “free” generation must be purchased from other sources; a ten percent decrease in hydroelectric supply would impose a cost of approximately $350 million in additional electricity expenditures annually (Franco and Sanstad, 2006). Whereas electricity demand is projected to rise in California between 3 to 20 percent by the end of this century, peak electricity demand would increase at a faster rate. Since annual expenditures of electricity demand in California represent about $28 billion, even such a relatively small increases in energy demand would result in substantial extra energy expenditures for energy services in the state; a three percent increase in electricity demand by 2020 would translate into about $930 million (in 2000 dollars) in additional electricity expenditures (Franco and Sanstad, 2006). Particular concerns are likely to exist in areas where summer electricity loads already strain supply capacities (e.g., Hill and Goldberg, 2001; Kelly et al., 2005; Rosenzweig and Solecki, 2001) and where transmission and distribution networks have limited capacities to adapt to changes in regional demands, especially seasonally (e.g., London Climate Change Partnership, 2002).

Rose and others have examined effects of a number of climate change mitigation policies on U.S. regions in general and the Susquehanna River basin in particular (Rose and Oladosu, 2002; Rose and Zhang, 2004; Rose et al., 1999; Rose et al., forthcoming). In general, they find that such policy options as emission permits tradable among U.S. regions might have less than expected effects, with burdens impacting at least one Southern region which needs maximum permits but whose economy is not among the nation's strongest. Additionally, they discuss Pennsylvania's heavy reliance on coal production and use infrastructure that increases the price of internal CO2 mitigation. They suggest that the anomalies stem from the fact that new entrants, like Pennsylvania, into regional coalitions for cap-and-trade configuration may raise the permit price, may undercut existing states' permit sales, and may be able to exercise market power. Particularly, they raise an issue of the "responsibility" for emissions. Should fossil fuel producing regions take the full blame for emissions or are the using regions also responsible? They find that aggregate impacts of a carbon tax on the Susquehanna River Basin would be negative but quite modest. While Prindle et. al., (2006) suggest that adding energy efficiency savings to such a cap-and-trade scheme will considerably lower the consumer energy bills, increase the economic output and personal income with a positive private-sector job growth by 2021.

Concerns remain, however, that aggressive climate policy interventions to reduce GHG emissions could negatively affect regional economies linked to coal and other fossil energy production. Concerns also exist that climate change itself could affect the economies of areas exposed to severe weather events (positively or negatively) and areas whose economies are closely linked to hydropower and other aspects of the "energy-water nexus."

4.4 POSSIBLE RELATIONSHIPS WITH *OTHER ENERGY-RELATED ISSUES*

Many other types of indirect effects are possible, although relatively few have received research attention. Without asserting that this listing is comprehensive, such effects might include:

4.4.1 Effects Of Climate Change In Other Countries On US Energy Production And Use

We know from recent experience that climate variability outside the U.S. can affect energy conditions in the U.S.; an example is an unusually dry year in Spain in 2005 which led that country to enter the international LNG market to compensate for scarce hydropower, which in turn raised LNG prices for U.S. consumption (Sen, 2005; Alexander's Gas & Oil Connections, 2005). It is important, therefore, to consider possible effects of climate change not only on international energy product suppliers and international energy technology buyers but also on other countries whose participation in international markets could affect U.S. energy availability and prices from international sources, which could have implications for energy security (see below). Climate change-related energy supply and price effects could be coupled with other price effects of international trends on U.S. energy, infrastructures, such as effects of aggressive programs of infrastructure development on China and India.

A particularly important case is U.S. energy inputs from Canada. Canada is the largest single source of petroleum imports by the US (about 2.2 million barrels per day) and exports more than 15% of the natural gas consumed in the U.S. (EIA, 2005a, 2006). In 2004, it exported to the U.S. 33 MWh of electricity, compared with imports of 22.5 MWh (EIA, 2005b). Climate change could affect electricity exports and imports, for instance if electricity demands for space cooling increase in Canada or if climate change affects hydropower production in that country.

4.4.2 Effects Of Climate Change On Energy Prices

Climate change could affect energy prices in the U.S., more likely by adding to pressures for energy price increases than to decreases. Hurricane Katrina is a recent example of how increased exposure to severe storms due to climate change could raise energy prices, at least in the relatively short term, by disrupting energy production, storage, and transmission. This is one of several reasons why climate change might be associated with greater volatility in energy prices (Abbasi, 2005). Another possible example would be reduced production of relatively inexpensive hydropower in areas dependent on winter snowfall for production potential, where warming reduces annual snowfall. On the other hand, it can be argued that energy technology responses to climate change and related policies would reduce energy price volatility by diversifying sources, which means that overall effects of climate change on energy prices are unclear.

4.4.3 Effects Of Climate Change On Environmental Emissions

Climate change is very likely to lead to reductions in environmental emissions from energy production and use in the U.S. One possibility is that climate change will enhance the competitiveness of renewable energy alternatives as technological change reduces their costs, and their growing share in total U.S. energy production would reduce net emissions. Another possibility, perhaps a higher probability, is that climate change policy will affect choices of energy resources and technologies in ways that result in reduced greenhouse gas and other environmental emissions (see indirect impacts on technologies above), including but not limited to renewable energy sources.

4.4.4 Effects Of Climate Change On Energy Security

Climate change relates to energy security because different drivers of energy policy interact. As one example, some strategies to reduce oil import dependence, such as increased use of renewable energy sources in the U.S., are similar to strategies to reduce GHG emissions as a climate change response (e.g., IEA, 2004; O'Keefe, 2005). As another example, energy security relates not only to import dependence but also to energy system reliability, which can be threatened by possible increases in the intensity of severe weather events. A different kind of issue is potential impacts of abrupt climate change in the longer run. One study has suggested that abrupt climate change could lead to very serious international security threats, including threats of global energy crises, as countries act to defend and secure supplies of essential commodities (Schwarz and Randall, 2003).

4.4.5 Effects Of Climate Change On Energy Technology And Service Exports

Finally, climate change could affect U.S. energy technology and service exports. It is very likely that climate change will have some impacts on global energy technology, institutional, and policy choices. Effects of these changes on U.S. exports would probably be determined by whether the US is a leader or a follower in energy technology and policy responses to concerns about climate change. More broadly, carbon emission abatement actions by various countries are likely to affect international energy flows and trade flows in energy technology and services (e.g., Rutherford, 2001). In particular, one might expect flows of carbon-intensive energy forms and energy technologies and energy-intensive products to be affected.

4.5 SUMMARY OF KNOWLEDGE ABOUT INDIRECT EFFECTS

From the available research literature, it appears that the most salient indirect effects of climate change on energy production and use in the United States are likely to be changes in energy resource/technology preferences and investments, along with associated reductions in GHG emissions. Less-studied but also potentially important are possible impacts on the institutional structure of energy supply in the United States, responding to changes in perceived investment risks and emerging market and policy realities. Perhaps the most important insight from the limited current research literature is that climate change will affect energy production and use not only as a driving force in its own right but in its interactions with other driving forces such as energy security. Where climate change response strategies correspond with other issue response strategies, they can add force to actions such as reduced dependence on imported oil and gas and increased reliance on domestic non-carbon energy supply sources. Where climate change impacts contradict other driving forces for energy decisions, they are much less likely to have an effect on energy production and use.

CHAPTER 5: CONCLUSIONS AND RESEARCH PRIORITIES

5.1 INTRODUCTION

The previous chapters have summarized a variety of currently available information about effects of climate change on energy production and use in the United States. For two reasons, it is important to be careful about drawing firm conclusions about effects at this time. One reason is that the research literatures on many of the key issues are limited, supporting an identification of issues but not a resolution of most uncertainties. A second reason is that, as with many other categories of climate change effects in the U.S., the effects depend on a wide range of factors beyond climate change alone, such as patterns of economic growth and land use, patterns of population growth and distribution, technological change, and social and cultural trends that could shape policies and actions, individually and institutionally.

Accordingly, this final chapter of SAP 4.5 will sketch out what appear, based on the current knowledge base, to be the most likely types of effects on the energy sector. These should be considered along with effects on other sectors that should be considered in risk management discussions in the near term. As indicated in Chapter 1, conclusions are related to degrees of likelihood: likely (2 chances out of 3), very likely (9 chances out of 10), or virtually certain (99 chances out of 100). The chapter will then discuss issues related to prospects for energy systems in the U.S. to adapt to such effects, although literatures on adaptation are very limited. Finally, it will suggest a limited number of especially high priorities in expanding the knowledge base so that, when further assessments on this topic are carried out, conclusions about effects can be offered with a higher level of confidence.

5.2 CONCLUSIONS ABOUT EFFECTS

If one assumes that widely accepted scenarios for climate change can be accepted with relatively high levels of confidence, a number of conclusions are possible about likely effects on energy ***use*** in the U.S:

- Climate change will mean significant reductions in heating requirements for buildings, with different effects on energy sources for heating (e.g., electricity, natural gas, fuel oil) and by regions (virtually certain)

- Climate change will mean significant increases in cooling requirements for buildings, mainly affecting electricity supply, with different impacts by region (virtually certain)

- Net effects on energy use will differ by region, with net lower total energy requirements for buildings in net heating load areas and net higher energy requirements in net cooling load areas, with overall impacts affected by patterns of interregional migration – which are likely to be in the direction of net cooling load regions (virtually certain)

- Climate change will have particular implications for peak demands for energy, positive or negative (virtually certain)

- Other effects of climate change are less clear, but some could be non-trivial: e.g., increased energy use for water pumping and/or desalination in areas that see reductions in water supply (very likely)

A number of conclusions can be offered with relatively high levels of confidence about effects of climate change on energy ***production and supply*** in the U.S., but generally the research evidence is not as strong as for effects on energy use:

- Higher temperatures are likely to affect process efficiencies and water needs for thermal facilities (very likely)

- Regions facing reductions in water supplies, from either reduced precipitation or reduced snowpack, are likely to experience impacts on energy systems and facilities that are sensitive to water availability, such as hydropower and thermal power plants requiring water-based cooling (very likely)

- In general, the siting of new energy facilities and systems are likely to fact increased restrictions, related partly to complex interactions among the wider range of water uses (likely)

- More intensive extreme weather events are likely to affect energy systems in vulnerable areas, including coastal and offshore oil/gas facilities and electricity transmission lines (likely)

- Sea-level rise and possible risks of increased flooding could affect energy facility siting and the operation of existing facilities, such as in coastal areas (likely)

- Effects on biomass for biofuels are likely to be considerable, positively or negatively depending on crop and region, with positive impacts more likely on adaptable dedicated energy crops such as switchgrass (likely)

- Overall, the current energy supply infrastructure is often located in areas where significant climate change might occur, but large-scale disruptions are not likely except during extreme weather events. Most effects on fossil and nuclear electricity components are likely to be modest decreases in cycle efficiency due to rises in air and water temperatures and/or reduced availability of cooling water.

California is one U.S. state where impacts on both energy use and energy production have been studied with some care (See Box 5.1 California: A Case Study).

BOX 5.1 CALIFORNIA: A CASE STUDY

California is unique in the United States as a state that has examined possible effects of climate change on its energy production and use in some detail. Led by the California Energy Commission and supported by such nearby partners as the Electric Power Research Institute, the University of California–Berkeley, and the Scripps Institution of Oceanography, the state is developing a knowledge base on this subject that could be a model for other states and regions (as well as the nation as a whole).

Generally, the analyses to date (many of which are referenced in Chapters 2 and 3) indicate that electricity demand will grow due to climate change, with an especially close relationship between peak electricity demand and temperature increases (Franco and Sanstad, 2006), and water supply – as an element of the "energy-water nexus" – will be affected by a reduction in the Sierra snowpack (by as much as 70-90 % over the coming century: Vicuña et al., 2006). Patterns of urbanization could add to pressures for further energy supplies. Adaptations to these and other climate change impacts appear possible, but they could be costly (Franco, 2005). Overall economic impacts will depend considerably on the effectiveness of response measures, which tend currently to emphasize emission reduction but also consider impact scenarios and potential adaptation measures (CEPA, 2006).

Other relevant studies of the California context for climate change effects reinforce an impression that effects of warming and snowpack reduction could be serious (Hayhoe et al., 2004) and that other ecosystems related to renewable energy potentials could be affected as well (Union of Concerned Scientists, 1999).

About ***indirect effects of climate change on energy production and use*** in the U.S., conclusions are notably mixed. Conclusions related to possible impacts of climate change policy interventions on technology choice and emissions can be offered with relatively high confidence based on published research. Other types of possible indirect effects can be suggested as a basis for discussion, but conclusions must await further research

Conclusions

- Climate change concerns are very likely to affect perceptions and practices related to risk management in investment behavior by energy institutions (very likely)

- Climate change concerns, especially if they are expressed through policy interventions, are almost certain to affect public and private sector energy technology R&D investments and energy resource/technology choices by energy institutions, along with associated emissions (virtually certain)

- Climate change can be expected to affect other countries in ways that in turn affect US energy conditions (very likely)

Other Types Of Possible Effects

- Climate change could affect the structure and health of some energy institutions in the U.S. (likely)

- Climate change effects on energy production and use could in turn affect some regional economies, either positively or negatively (likely)

- Climate change is likely to have some effects on energy prices in the U.S., especially associated with extreme weather events (likely)

- Climate change concerns are likely to reinforce some driving forces behind policies focused on U.S. energy security, such as reduced reliance on oil products (likely)

These conclusions add up to a picture that is cautionary rather than alarming. Since in many cases effects that could be a concern to U.S. citizens and U.S. energy institutions are some decades in the future, there is time to consider strategies for adaptation to reduce possible negative impacts and take advantage of possible positive impacts.

5.3 CONSIDERING PROSPECTS FOR ADAPTATION

The existing research literature tends to treat the U.S. energy sector mainly as a driving force for climate change rather than a sector subject to impacts from climate change. As a result, there is very little literature on adaptation of the energy sector to effects of climate change, and the following discussion is therefore largely speculative.

Generally, both energy users and providers in the U.S. are accustomed to changes in conditions that affect their decisions. Users see energy prices fluctuate with international oil market conditions and with Gulf Coast storm behavior, and they see energy availability subject to short-term shortages for a variety of reasons (e.g., the California energy shortage of 2000 or electricity blackouts in some Northeastern cities in 2003). Energy providers cope with shifting global market conditions, policy changes, financial variables such as interest rates for capital infrastructure lending, and climate variability. In many ways, the energy sector is among the most resilient of all U.S. economic sectors, at least in terms of responding to changes within the range of historical experience.

For instance, electric utilities consider such planning strategies as weather-adjusted load growth forecasting, incorporating load uncertainty in both strategic and operational planning, and separating climate change signals from the noise of historic variability (Niemeyer, 2005). These are sophisticated, risk-averse institutions that care a great deal about avoiding mistakes that affect the reliability of service and/or the assurance of continued financial viability. One important guide to adaptation to climate *change* is what makes sense in adapting to climate *variability* (Franco, 2005).

On the other hand, such recent events as Hurricane Katrina (Box 5.2: Hurricane Katrina and the Gulf Coast: A Case Study) suggest that the U.S. energy sector is better at

BOX 5.2 HURRICANE KATRINA AND THE GULF COAST: A CASE STUDY

It is not possible to attribute the occurrence of Hurricane Katrina, August 29, 2005, to climate change; but projections of climate change say that extreme weather events are very likely to become more intense. If so (e.g., more of the annual hurricanes at higher levels of wind speed and potential damages), then the impacts of Katrina are an indicator of possible impacts of one manifestation of climate change.

Impacts of Katrina on energy systems in the region and the nation were dramatic at the time, and some impacts remained many months later. The hurricane itself impacted coastal and offshore oil and gas production, offshore oil port operation (stopping imports of more than one million bbl/d of crude oil), and crude oil refining along the Louisiana Gulf Coast. Within only a few days, oil product and natural gas prices had risen significantly across the U.S. As of mid-December 2005, substantial oil and gas production was still shut-in, and refinery shutdowns still totaled 367, 000 bbl/d (EIA, 2005) (see Chapter 3).

Possibilities for adaptation to reduce risks of damages from future Katrinas are unclear. They might include such alternatives as hardening offshore platforms and coastal facilities to be more resilient to high winds, wave action, and flooding (potentially expensive) and shifting the locations of some coastal refining and distribution facilities to less vulnerable sites, reducing their concentration in the Gulf Coast (potentially very expensive).

responding to relatively short-term variations and uncertainties than to changes that reach beyond the range of familiar short-term variabilities (Niemeyer, 2005). In fact, the expertise of U.S. energy institutions in reducing exposure to risks from short-term variations might tend to reduce their resilience to larger long-term changes, unless an awareness of risks from such long-term changes is heightened.

Adaptations to effects of climate change on energy ***use*** may focus on increased demands for space cooling in areas affected by warming. Alternatives could include reducing costs of cooling for users through energy efficiency improvement in cooling equipment and building envelopes; responding to likely increases in demands for electricity for cooling through expanded generation capacities, expanded interties, and possibly increased capacities for storage; and responding to concerns about increased peakiness in electricity loads, especially seasonally, through contingency planning for load-leveling.

Adaptations to effects on energy ***production and supply*** are less straightforward to evaluate, not only because such activities are so diverse but also because they are enmeshed in so many uncertainties about climate change mitigation policymaking. The most likely effect is an increase in perceptions of uncertainty and risk in longer-term strategic planning and investment, which could seek to reduce risks through such approaches as diversifying supply sources and technologies and risk-sharing arrangements.

Adaptation to ***indirect effects*** of climate change on the energy sector is likely to be bundled with adaptation to other issues for energy policy and decision-making in the U.S., such as energy security: for instance, in the development of lower carbon-emitting fossil fuel use technology ensembles and the development of alternatives to fossil fuels and effects on energy institutional structures. Issues related to effects of climate change on other countries linked with U.S. energy conditions are likely to be addressed through attention by both the public and private sectors to related information systems and market signals.

It seems possible that adaptation challenges would be greatest in connection with possible increases in the intensity of extreme weather events and possible significant changes in regional water supply regimes. More generally, adaptation prospects appear to related to the magnitude and rate of climate change, with adaptation more likely to be able to cope with effects of lesser amounts and slower rates of change (Wilbanks et al., 2006).

Generally, prospects for these types of adaptations depend considerably on the level of awareness of possible climate changes at a relatively localized scale and possible implications for energy production and use – the topic of this study. When the current knowledge base to support such awareness is so limited, this suggests that expanding the knowledge base is important to the energy sector in the United States.

5.4 PRIORITIES FOR EXPANDING THE KNOWLEDGE BASE

Expanding the knowledge base about effects of climate change on energy production and use in the United States is not just a responsibility of the federal government. As the work of such institutions as the Electric Power Research Institute and the California Energy Commission demonstrates, a wide variety of parts of U.S. society have knowledge, expertise, and data to contribute to what should be a broad-based multi-institutional collaboration.

Recognizing that roles in these regards will differ among federal and state governments, industry, non-governmental institutions, and academia and that all parties should be involved in discussions about how to proceed, this study suggests the following priorities for expanding the knowledge base on its topic.

5.4.1 General Priorities

- Improved projections of climate change and its effects on a relatively fine-grained geographic scale, especially of precipitation changes and severe weather events: e.g., in order to support evaluations of impacts at local and small-regional scales, not only in terms of gradual changes but also in terms of extremes, since many energy facility decisions are made at a relatively localized scale

- Research on implications of extreme weather events for energy system resiliency

- Research on potentials, costs, and limits of adaptation to risks of adverse effects, for both supply and use infrastructures

- Research on implications of changing regional patterns of energy use for regional energy supply institutions and consumers

- Improvements in the understanding of effects of changing conditions for renewable energy and fossil energy development and market penetration on regional energy balances and their relationships with regional economies

- In particular, improvements in understanding likely effects of climate change in Arctic regions and on storm intensity to guide development and deployment of new technologies and other adaptations for energy infrastructure and energy exploration and production in these relatively vulnerable regions

- Attention to linkages and feedbacks among climate change effects, adaptation, and mitigation; to linkages between effects at different geographic scales; and relationships between possible energy effects and other possible economic, environmental, and institutional changes (Parson et al., 2003; Wilbanks, 2005).

5.4.2 Priorities Related To Major Technology Areas

- Improving the understanding of potentials to increase efficiency improvements in space cooling

- Improving information about interactions among water demands and uses where the quantity and timing of surface water discharge is affected by climate change

- Improving the understanding of potentials to increase thermal power plant cooling in ways that reduce water usage (consumptive or otherwise)

- Developing strategies to increase the resilience of coastal and offshore oil and gas production and distribution systems to extreme weather events

- Improving information about possible climate change effects on biofuels production and market competitiveness

- Pursuing strategies and improved technology potentials for adding resilience to energy supply systems that may be subject to stress under possible scenarios for climate change: e.g., energy storage approaches

- Improving understandings of potentials to improve resilience in electricity supply systems through regional inertie capacities and distributed generation

Other needs for research exist as well, and the process of learning more about this topic in coming yeas may change perceptions of needs and priorities; but based on current knowledge, these appear to be high priorities in the next several years.

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