Energy Systems and Adaptation to Climate Change

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Introduction

Climate change is upon us. Scientists, of course, have been studying trends in global temperatures for many years, and report with increasing confidence that changes are occurring. This consensus, along with increasingly more visible and compelling signs of change, have moved this issue on to the front pages on a more routine basis. One only need look at the spate of "green" issues of popular periodicals to see the growing interest of the public in understanding climate change and its implications.

In non-scientific circles, the discussions and analyses have focused on several things, including: gaining better understanding of what the science is – and isn't – saying about the changes that are occurring and can be expected to occur in the future; identifying the various human activities that are contributing to warming, along with ways to mitigate the impacts from a technological, policy, behavioral, and political point of view; and estimating the costs of taking actions to lessen climate-change impacts.[2]

It is well understand that combustion of fossil fuels contributes significantly, if not primarily, to climate change. Roughly 75%-85% of human CO_2 emissions come from combustion of fossil fuels, with the remaining amounts from land-use changes.[3] Given the relatively high contribution of the energy-related activities to the emissions of

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[1] I am grateful for the capable research and drafting assistance provided by Rachel S. Wilson of Analysis Group (and Masters of Environmental Management (2007), Yale School of Forestry and Environmental Studies).

[2] Scientific Expert Group Report on Climate Change and Sustainable Development, *Confronting Climate Change: Avoiding the Unmanageable and Managing the Unavoidable*, United Nations Foundation and Sigma Xi ("UN Foundation/Sigma Xi"), 2007; S. Pacala and R. Socolow, "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies," *Science* 13 August 2004: Vol. 305. no. 5686, pp. 968 – 972; *The Stern Review of the Economics of Climate Change*; Massachusetts Institute of Technology ("MIT"), *The Future of Coal: Options for a Carbon-Constrained World*, March 2007; MIT, *The Future of Nuclear Power: An Interdisciplinary MIT Study*, 2003; P-A. Enkvist, T. Naucier, and J. Rosander, A Cost Curve for Greenhouse Gas Reduction, *The McKinsey Quarterly*, 2007; National Commission on Energy Policy ("NCEP"), 2004. *Ending the Energy Stalemate: A Bipartisan Strategy to Meet America's Energy Challenges,* Washington, DC; NCEP, *Energy Policy Recommendations to the President and the 110th Congress*, April 2007.

[3] J. Holdren, "Meeting the Intertwined Challenges of Energy and Climate Change Presidential Symposium on Energy," Presentation to Presidential Symposium, University of Rochester, 7 October 2006; J. Holdren, "The Most Important Energy Numbers," updated 3-07.

greenhouse gases, it is no wonder that so much effort has been aimed at reducing or avoiding CO_2 emissions from energy production and use on

Less work has focused on adaptation. That is where this paper begins – as a threshold for thoughtful discussions at the National Summit's sessions on energy. This papers tees up the dialogue on "coping with climate change's impacts" on the energy-producing and energy-using activities in the U.S.

This paper, like the Summit itself, takes as its premise that some amount of climate change is at this point unavoidable. While that is not meant in any way to relieve pressure on parties to look for ways to avoid even worse damage than now appears quite inevitable, it does look squarely at reality and ask, "what do we know about the impacts of climate change *on* the energy sector" – on sources of production of energy supplies, and factors affecting demand for energy?

Not long ago, the US Climate Change Science Program published a "public comment draft" version of its paper, *Effects of Climate Change on Energy Production and Use in the United States* (November 30, 2006 Public Comment Draft). While not yet in final form, the paper provides a useful summary of what is known about the effects of climate change on energy production and use, what areas of uncertainty or knowledge exist, and what research gaps could usefully be filled.

An extensive literature review of some 170 studies, the USCCSP Energy Paper provides a useful platform for the energy-related discussions at the National Summit. And in light of its relevance, this Energy Paper is summarized here as a guide for the participants. Perhaps most significantly for the purposes of the National Summit, the Energy Paper:

> focuses on three questions… [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 have other effects that indirectly shape energy production and consumption in the United States?] 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.[4]

The paper concludes overall that "based on what we know now, there are reasons to pay close attention to possible climate change impacts on energy

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[4] U.S. Climate Change Science Program, *Effect of Climate Change on Energy Production and Use in the United States: Synthesis and Assessment Product 4.5,* Public Comment Draft, November 30, 2006 ("USCCSP Energy"), page viii-ix

production and use and to consider ways to adapt to possible adverse impacts and take advantage of possible positive impacts."[5]

Known Effects on the Energy Sector and Systems: the State of our Knowledge About Impacts and Adaptations

What is known (and unknown) about the impacts of climate change on energy production and use starts with the obvious: changes in temperature and climatic conditions are occurring in various parts of the country, which in turn affect not only how much energy we use, but also when we use it and what forms of energy may more limited (or plentiful) than they now are. Many of the general effects of climate change in the U.S. are widely agreed upon by climate scientists, although the degree to which these changes occur is uncertain and will likely vary by region. A predicted increase in mean global temperature will cause cold days and nights to become warmer and fewer, with warm days and nights becoming hotter and more frequent. This temperature rise will lead to a greater number of heat waves and increase the total land area in specific regions that is affected by drought. Agriculture will be significantly affected, as certain crops may not be able to grow in regions where they are grown currently. Weather patterns are shifting, with predicted increases in heavy precipitation events, the intensity of tropical storms and hurricanes, and an eventual rise in sea levels.

Taken together, these conditions are expected to lead to a greater number of cooling degree days and fewer heating degree days – and in energy terms, increased demand for cooling and reduced demand for heating. Many studies predict increases in both electricity consumption and consumption of primary fuels used to generate it.[6] It is predicted that as summer temperatures and electric cooling uses increase, it will become more difficult during warmer periods to transmit electricity from existing generating resources to meet demand; this relates to the hotter temperatures creating sag on transmission lines and diminishing their ability to carry electricity to consumers. While in theory demand forecasting can capture such anticipated changes, the effects underway in localized settings (including shifting seasonal patterns and more erratic weather conditions) will make forecasting energy use by location more difficult. Changing conditions may transform the "balance of energy use among delivery forms and fuel types, as between electricity used for air conditioning and natural gas used for heating."[7] A recent study supports this prediction, having found that consumers in warmer locations rely more heavily on electricity rather than natural gas, oil, and other fuels as well as using more energy.[8]

According to the USCCSP report, the research results to date paint "a picture that is cautionary rather than alarming."[9] Overall, many of the impacts are likely to unfold over some number of years in the future, giving potential time for impacts to occur and

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[5] USCCSP Energy, page viii-ix.
[6] USCCSP Energy, page 10.
[7] USCCSP Energy, page 8.
[8] E. Mansur, R. Mendelsohn, and W. Morrison, *A Study of Fuel Choice and Consumption in the U.S. Energy Sector*, March 19, 2007.
[9] USCCSP Energy, page 105.

for system to adapt to them. Here are some of the known effects that come out of this scientific literature:

	Virtually certain	**Very likely**	**Likely**
Energy use	Climate change will mean reductions in total U.S. energy demand for space heating for buildings, with effects differing by region. Climate change will mean increases in total U.S. energy demand for space cooling, with effects differing by region. 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 – and investments in new building stock.	Temperature increases will be associated with increased peak demands for electricity. Other effects of climate change are less clear; some could be non-trivial: e.g., increased energy use for water pumping and/or desalination in areas that see reductions in water supply.	Lower winter energy demands in Canada could add to available electricity supplies for a few U.S. regions.
Energy production and supply	Changes in the distribution of water availability in the U.S. will affect power plants; in areas with decreased water availability, competition for water supplies will increase between energy production and other sectors. Temperature increases will decrease overall thermoelectric power generation efficiency. In some regions, energy resource production and delivery systems are vulnerable to effects of sea level rise and extreme weather events, especially the Gulf Coast and the East Coast.	Hydropower production is expected to be directly and significantly affected by climate change, especially in the West and Northwest.	In some areas, the siting of new energy facilities and systems could face increased restrictions, related partly to complex interactions among the wider range of water uses as well as sea-level rise and extreme event exposures. Incorporating possible climate change impacts into planning processes could strengthen energy production and distribution system infrastructures, especially regarding water resource management. Climate change is expected to mean greater variability in wind resources and direct solar radiation, substantially impacting the planning, siting, and financing of these technologies.
Conclusions	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.	Climate change concerns are very likely to affect perceptions and practices related to risk management behavior in investment by energy institutions. Climate change can be expected to affect other countries in ways that in turn affect US energy conditions.	
Other		Climate change may have some effects on energy prices in the U.S., especially associated with extreme weather events.	Climate change effects on energy production and use could in turn affect some regional economies, either positively or negatively. Climate change concerns are likely to interact with some driving forces behind policies focused on U.S. energy security, such as reduced reliance on conventional petroleum products.

Source: USCCSP Energy, page 105.

In the regions most affected by heat and drought-like conditions, the effects on availability of water appear to be two-fold, with less water available to cool nuclear and thermal power plants where changing temperatures have an effect on energy output, and to flow through dams for hydroelectric power generation. This is particularly problematic during hot periods when demand for cooling from electricity is at its peak, but reduced water flows could exacerbate competition for over-allocated water resources.[10]

While science tells us that temperatures are increasing, it is much more difficult to predict changes in weather patterns, especially in particular geographic locations. We do know that tropical storms and hurricanes will grow in intensity, thus exposing energy production and delivery systems in off-shore, coastal areas and other low-land areas to more severe weather conditions. During Hurricanes Katrina and Rita, 109 of the 4,000 offshore oil and gas drilling platforms in the Gulf of Mexico were destroyed and 31 were damaged. Approximately 91% of oil production and 72% of gas production capacity was out of service, and energy companies were forced to shut down more than 25% of the refining capacity in the US.[11] The impacts on world oil and gas markets were substantial, with high prices affecting consumers' pocket books for months after the storms. And it is hard to know where or when such types of impacts might occur.

Other effects of erratic weather conditions are less certain. Changing wind patterns, for example, could affect wind production either positively or negatively, depending on the location. Wind power is already intermittent, and changing wind patterns may change energy production at various locations. In addition, climate changes may affect biomass production in different areas, in turn affecting power production output and fuel-delivery costs as distances change between sources of supply and power plant location. Such impacts may occur within the operating lives of individual power plants. Facilities that have long been sited in coastal areas (e.g., liquefied natural gas terminals, refineries, power production facilities, gas pipelines) may be more difficult to site, due to concerns about impacts resulting from climate change.

Areas of Uncertainty Surrounding the Effects of Climate Change on the Energy Systems

The USCCSP Energy report also discusses the many uncertainties about how adaptation may impact energy supply, delivery and use.

> 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

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[10] USCCSP Energy, page ix.
[11] H. Timmons and V. Bajaj, "BP Details its Damages from Hurricanes" *The New York Times,* October 4, 2005, page C1.

inform decisions about adaptive management, along with technological change in the longer term.

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. Needs 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.[12]

The USCCSP Energy Report also characterizes the knowledge base for indirect effects of climate change on energy systems. It described a greater degree of research and analysis conducted on the possible impacts on various energy-related activities that could result from climate change policy, as compared to indirect effects of those activities from actual climate change itself. This chart is shown below:

Overview of the Knowledge Base About Possible Indirect Effects of Climate Change and Climate Change Policy on Energy Systems in the U.S.		
Indirect Effect on Energy Systems	From Climate Change	From Climate Change Policy
On energy planning and investment	Very limited	Some literature
On technology R&D and preferences	Very limited	Considerable literature
On energy supply institutions	Very limited	Limited
On energy aspects of regional economies	Very limited	Limited
On energy prices	Almost none	Very limited
On energy security	Almost none	Almost none
On environmental emissions from energy production/use	Very limited	Considerable literature
On energy technology/service experts	Almost none	Very limited

Source: USCCSP Energy, page 85.

Perhaps this pattern of research results from past circumstances in which there has been considerable debate over whether climate change is occurring, and what might be the impacts of doing something about it. Research and analysis performed to date thus has focused more on understanding how policy – taking public action to mitigate human activities that contribute to climate change – might affect one set of interests over another. As the debate has rolled on, less time has been spent on presuming climate change *would* occur than on *whether* it might be occurring and, if so, whether it was worth doing something to mitigate it. By contrast, as science now more confidently

[12] USCCSP Energy, page x.

concludes that climate change is occurring, it is time to explore what research is needed to better understand its impacts. For energy systems, there is much that remains to be explored:

The state of today's science does not provide much confidence in predictions of *the degree* of the direct and indirect climate effects on various aspects of energy systems. Additional research is needed to identify and fill the knowledge gaps that still exist.

Expanding the knowledge base

There are both pragmatic and more-research-oriented ways to build our knowledge base. In the former approach, our energy institutions could ease their adaptation over time by determining where new data collection and analysis is needed. Having robust capabilities to detect climate-related changes in systems that affect energy production and use may facilitate timely and appropriate responses. This might mean deliberate identification of important climate-change-related factors (e.g., temperature of cooling water for thermally cooled plants, or trends in changing wind patterns in previously inventoried areas), along with efforts to collect and analyze different data than in the past. Analyzing changes in heating and cooling degree days by region will be important for assuring that demand and load forecasts remain reasonable for future conditions as they change. Computing changes in river temperature where water is used to cool nuclear or thermal power plants might provide lead-times for alternative strategies that prevent outright halting of production at affected plants.[13]

Institutions might need to ask themselves what new patterns, trends, phenomena should be on their 'radar screens,' in light of climate change impacts. This could include a variety of institutions involved in energy planning, energy forecasting, energy reliability, and so forth. Entities involved in forecasting (such system operators, utilities, state planning agencies, and the forecasting organizations) may need to more directly consider how their models may need to be modified in light of climate impacts. An example is the extent to which the customer load shapes are changing – with more on-peak use or longer summer seasons driven by different temperature patterns and different air-conditioning loads that respond to them. In 2005, the state of Massachusetts analyzed regional energy demand response to climate change, and that found "notable changes with respect to overall energy consumption by, and energy mix of the residential an commercial sectors in the region" as a result of changing degree-day variables.[14] Studies of this size and scope must be reproduced in other states and regions.

Organizations involved in system operations (including power plant owners/ operators, regional reliability organizations) may need to consider new operating standards as equipment needs to perform reliably under changing load and temperature conditions than have typically occurred in the past. Utilities and emergency management

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[13] USCCSP Energy, page 51.
[14] A. Amato, M. Ruth, P. Kirshen, and J. Horwitz. "Regional Energy Demand Responses to Climate Change: Methodology and Applications to the Commonwealth of Massachusetts," *Climatic Change*, 2005, 71: 175-201.

agencies may need to be prepared for more frequent and intense hits on critical energy infrastructure than were expected when facilities were built to withstand certain, say, hundred-year events. Energy facility permitting and siting agencies may need to look at new criteria in determining the appropriateness of allowing certain types of infrastructure in locales subject to new, uncertain and potentially more risky conditions as a result of climate change. Finally, more research must be conducted on risk management, new actuarial studies and preparedness to evaluate the impacts on energy facilities of more frequent and/or severe weather events and the ways in which the system could be made to be more resilient.

Examples of the types of organizations that may need to take up questions such as these are: regional reliability councils and the North American Electric Reliability Corporation; federal and state regulators and energy departments, like the Federal Energy Regulatory Commission, the U.S. Department of Energy, state public utilities commissions, state air and water regulators, and coastal zone management agencies; regional transmission operators; utilities and other energy companies; Energy Information Administration; and state and federal emergency management agencies.

Many of these institutions will need to be increasingly mindful of the potential for climate-related impacts if adaptation in the energy sector is to succeed. Organizations must have the ability to incorporate assumptions about changing weather patterns and possibilities, and consumer behavior in response to them, in order to create forecasts of long-range energy capability and demand. Additionally, they will need to have information with which to plan for the ability of energy facilities to supply and distribute energy under changing, and often extreme, weather conditions. The siting and permitting processes for energy facilities will need to examine questions relating to the long-term availability and use of cooling water for nuclear or thermal generating units and the location of facilities and their ability to withstand storms and other severe weather. Standard-setting processes and information sharing for systems operation, for equipment and material strengths, for emergency preparedness, for research needs, and other technological issues will become increasingly important.

As described previously, new attention to old – and in some cases new – metrics may be called for, with information tracked and analyzed. Information about changing climate conditions needs to be incorporated into analytic and planning tools. How, for example, will changing assumptions about the length of seasons? What is the new "normal" set of temperature conditions for which it is appropriate to forecast and plan? Do the extreme high and extreme low condition used for many years in forecasting peak loads need to be updated to reflect changing expectations? Are new reserve levels needed in a particular region, given its particular constellation of generating resources and its projected load conditions?

In additions to these more practical efforts, research is also needed to fill gaps in knowledge. The USCCSP Energy report provides a listing of additional research likely to be relevant to the process of better understanding what is needed in our energy systems to adapt well to climate change impacts:

Research needed to fill knowledge gaps – USCCSP Energy Report Suggestions	
General needs	**Needs Related To Major Technology Areas**
• 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 and assessments of implications of extreme weather events for energy system resiliency, including strategies for both reducing and recovering from impacts. • Research on and assessments of potentials, costs, and limits of adaptation to risks of adverse effects, for both supply and use infrastructures. • Research on efficiency of energy use in the context of climate warming, with an emphasis on technologies and practices that save cooling energy and reduce electrical peak load. • Research on and assessments of 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 applications of existing technologies and the 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.	• 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 potential climate change and localized variability on energy production from wind and solar technologies. • Developing strategies to increase the resilience of coastal and offshore oil and gas production and distribution systems to extreme weather events. • 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. • Improving understandings of potentials to improve resilience in electricity supply systems through regional intertie capacities and distributed generation. • Research on and assessments of the impacts of severe weather events on sub-sea pipeline systems, especially in the Gulf of Mexico, and strategies for reducing such impacts.

Source: USCCSP Energy, pages 108-110.

Additional research could be usefully carried out on energy technologies – e.g., their performance capabilities under new types of temperature conditions and weather-related stresses; any hardening of systems needed to satisfy new extremes; new fuel-supply risks to which the technology may be affected. For example, such research could include an evaluation of decentralized renewable energy technologies versus traditional central station technologies in order to meet demand.[15] Decentralizing energy supply was a solution proposed after the August 14, 2003 Northeast/MidWest blackout,[16] and might be an effective adaptation strategy. Similarly, what role might new investments in energy

[15] H. Venema and M. Cisse, *Seeing the Light: Adapting to climate change with decentralized renewable energy in developing countries*, International Institute for Sustainable Development, 2004.
[16] T. Eisenmann and R. Willis, *Blackout: August 14, 2003*, Harvard Business School Case Study, June 28, 2004.

efficiency play in improving the overall resiliency of energy systems? What changes in building design, materials and equipment components contribute to this resiliency? And how might investments in efficiency and other decentralized systems change, in terms of payback and cost-effectiveness, if climate change impacts are assumed into analyses, as compared to ignored?

Technological developments offer the prospect to aid research, planning, and adaptive capabilities in the energy sector. For example, currently there is no good way in which to store energy; batteries lack capacity and efficiency and it takes more energy to utilize pump storage methods than is produced to the consumer. Development of energy storage technology might aid in both planning and in managing for risk.

Studies that examine the effects of climate change and increased warming on peak electricity demand "emphasize that increases in peak demand would cause disproportionate increases in energy infrastructure investment."[17] Technological updates of aging infrastructure – generating units, transmission lines, and refining capacity – and improvements in energy efficiency can reduce losses of energy and help meet increased demand during peak times.[18] Technology may help us overcome energy sector effects brought about by climate-change-related water shortages, through better ways to supply and conserve water, such as linking reservoirs and building new holding capacity in reservoirs,[19] and through developments in the reuse of wastewater. Investment in wind generation can "offer communities in water-stressed areas the option of economically meeting increasing energy needs without increasing demands on valuable water resources" as wind energy does not use or consume water to generate electricity.[20]

Conclusion

The response of policymakers and other non-scientific stakeholders in the U.S. to the issue of climate change has focused primarily on mitigation strategies, yet the IPCC states that "[t]here are some impacts for which adaptation is the only available and appropriate response."[21] Importantly, the energy sector is not only a driver of climate change, but also subject to the effects of climate change.[22] It is now time for a wide array of public and private organizations that make up this sector to take up the adaptation question more directly – evaluating both the known and unknown effects of climate change, establishing metrics to measure these effects, creating plans for adaptation, and implementing these plans with the necessary scope and speed in order to avoid significant damage and costs. The discussions at the National Summit on Coping with Climate Change are a useful stimulus for greater effort in the energy area.

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[17] USCCSP Energy, page 11.
[18] USCCSP Energy, page 13.
[19] UN Foundation/Sigma Xi, pages 22, 111.
[20] USCCSP Energy, page 73.
[21] IPCC, *Climate Change 2007: Impacts, Adaptation and Vulnerability. A Summary for Policymakers – A Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report*, April 13, 2007, page 17. http://www.ipcc.ch/
[22] USCCSP Energy, page 1.